✓
Prepared for the U. S. Department of Energy
Assistant Secretary for Resource Applications
Grand Junction Office, Colorado

GJBX-138 '81

DPST-79-146-18

MASTER

MARBLE CANYON 1° x 2° NTMS AREA ARIZONA

DATA REPORT

NATIONAL URANIUM RESOURCE
EVALUATION PROGRAM

HYDROGEOCHEMICAL AND STREAM
SEDIMENT RECONNAISSANCE

J. D. HEFFNER

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, South Carolina 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

FOREWORD

This report is released without standard editorial and technical review in order to make the information available as soon as possible to interested organizations and to assist the search for uranium resources.

Note: Because this report contains data from samples collected on portions of Navajo Tribal Lands, distribution of this report is subject to approval of the Navajo Tribal Council or its legal representative.

DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MARBLE CANYON 1° x 2° NTMS AREA ARIZONA

DATA REPORT

NATIONAL URANIUM RESOURCE EVALUATION PROGRAM

HYDROGEOCHEMICAL AND STREAM SEDIMENT RECONNAISSANCE

by

J. D. HEFFNER

Approved by

M. L. Hyder
Analytical Chemistry Division

Publication Date: July 1980

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

E. I. du Pont de Nemours & Co.
Savannah River Laboratory
Aiken, South Carolina 29808

PREPARED FOR THE U. S. DEPARTMENT OF ENERGY UNDER CONTRACT DE-AC09-76SR00001

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
yp

ABSTRACT

This data report presents results of ground water and stream/surface sediment reconnaissance (HSSR) in the National Topographic Map Series (NTMS) Marble Canyon 1° x 2° quadrangle. The target sampling density for all media collected was one site per 12 square kilometers. This resulted in 884 sediment samples being collected; however, dry conditions and sparse population resulted in the collection of only 2 ground water samples. Grand Canyon National Park, Glen Canyon National Recreation Area, and much Indian tribal land in the southern half of the quadrangle were not sampled. Neutron activation analysis (NAA) results are given for uranium and 16 other elements in sediments, and for uranium and 9 other elements in ground water. Mass spectrometry results are given for helium in ground water. Field measurements for sediment samples are presented in tables and maps. Statistical summaries of data and a brief description of results are given. A generalized geologic map and a summary of the geology of the area are included.

Data from ground water (on microfiche in pocket) include: water chemistry measurements (pH, conductivity, and alkalinity); physical measurements (water temperature, and scintillometer readings); and elemental analyses (U, Al, Br, Cl, Dy, F, He, Mg, Mn, Na, and V).

Data from sediment sites (also on microfiche in pocket) include: water chemistry measurements (where available) for pH, conductivity, and alkalinity; and elemental analyses (U, Th, Hf, Al, Ce, Dy, Eu, Fe, La, Lu, Mn, Sc, Sm, Na, Ti, V, and Yb). Sample site descriptors (stream characteristics, vegetation, etc.) are also tabulated. Histograms, cumulative frequency, and areal distribution plots for most elements; Log U/Th, Log U/Hf, and Log U/(Th + Hf) ratios; and scintillometer readings are included on the microfiche.

CONTENTS

Introduction	7
Geologic Summary and Mineral Occurrences	10
Hydrology	18
Factors Affecting the Data	20
Quality Assurance	20
Description of Data Tables	22
Results and Discussion of the Data	28
Acknowledgments	29
Cited References	31
Related Geologic Bibliography	36

LIST OF FIGURES

- 1 Location Map for the Marble Canyon 1° x 2°
NTMS Quadrangle 9
- 2 Location of the Marble Canyon Quadrangle on a
Physiographic Province Map 11
- 3 Index Map of the Tectonic Divisions of the
Marble Canyon 1° x 2° NTMS Quadrangle 14
- 4 SRL Field Data Form for Western Quadrangles 21

LIST OF TABLES

- 1 Accuracy and Precision of Analyses of
SRL Sediment Standards 23
- 2 Statistical Summary of Field Measurements and Elemental
Analyses - Sediment; Marble Canyon 30

MAPS

(In Pocket)

A. Full Size (in pocket)

PLATE 1A Geologic Map of the Marble Canyon Quadrangle
(U.S. Geological Survey publication; Map I-1003,
Sheet 1 of 2)*

PLATE 1B Geologic Structure and Uranium Occurrences in the
Marble Canyon Quadrangle (U.S. Geological Survey
Publication; Map I-1003, Sheet 2 of 2)*

B. Reduced (on film in pocket)

PLATE 2 Ground Water Sample Site Locations in the Marble
Canyon Quadrangle

PLATE 3 Surface Sample Site Locations in the Marble Canyon
Quadrangle

PLATE 4 Uranium Distribution in Surface Sediments of the
Marble Canyon Quadrangle

PLATE 5 Thorium Distribution in Surface Sediments of the
Marble Canyon Quadrangle

* Haynes and Hackman (1978).

MARBLE CANYON TABLES

Tabulated reconnaissance data and elemental concentrations in sediment samples and ground water samples.

MARBLE CANYON SED PLOTS

Areal distribution maps, histograms, and frequency distribution plots for elemental U, Th, Hf, La, Ce, Sm, Eu, Dy, Yb, Lu, Al, V, Ti, Mn, Fe, Sc, and Na; for Log U/Hf, Log U/Th, Log U/La, Log U/(Th + Hf) in sediment samples; and scintillometer readings at sediment sites.

USER'S GUIDE

DATA REPORT: MARBLE CANYON 1° x 2° NTMS QUADRANGLE:
ARIZONA

INTRODUCTION

The National Uranium Resource Evaluation (NURE) program was established to evaluate domestic uranium resources in the continental United States and to identify areas favorable for uranium exploration. The Grand Junction Office (GJO) of the Department of Energy (DOE) is responsible for administering and coordinating NURE program efforts. The Savannah River Laboratory (SRL) has responsibility for hydrogeochemical and stream/surface sediment reconnaissance (HSSR) of 3.9 million square kilometers (1,500,000 square miles) in 37 eastern and western states. Other DOE laboratories are responsible for similar reconnaissance in the rest of the continental United States, including Alaska. The significance of the distribution of uranium in natural waters and sediments will be assessed as an indicator of areas favorable for the location of uranium deposits.

The principal objectives of the NURE program are:

- Increase geologic knowledge of U.S. uranium resources in regions where uranium ore bodies are known to exist and are candidate supplies under present and near-term market conditions.
- Complete assessment of lower cost potential uranium resources in the conterminous U.S. and Alaska.
- Improve reliability and validate resource estimates and increase confidence levels.
- Expand scope of uranium assessment to include higher cost and relatively unknown domestic resources that may be feasible uranium supply alternatives.
- Apply advanced technologies for detection and assessment of uranium resources.

DOE-GJO is responsible for administering and coordinating efforts to meet these objectives, including distribution of reports. Inputs to the NURE program come from DOE prime contractors, DOE-sponsored research and development, the uranium industry, U.S. Geologic Survey, U.S. Bureau of Mines, other federal and state government agencies, and independent sources.

The NURE program consists of six parts:

1. Hydrogeochemical and Stream Sediment Reconnaissance Survey
2. Aerial Radiometric Survey
3. Intermediate Grade Resource Studies
4. World Class Geologic Studies
5. Subsurface Geologic Investigation
6. Technology Application

The data presented here are reconnaissance data intended for use in identifying broad areas for further study. While care has been taken to provide reliable sampling and analyses, verification of individual analyses is beyond the scope of this report. The data should be viewed statistically because "one-point anomalies" may be misleading. Regional trends, however, should be reliable. With careful consideration of regional geology, these data should provide reliable guides to areas warranting further study.

This report is one of a series presenting basic data obtained by SRL reconnaissance. In the interest of disseminating available data as soon as possible, only neutron activation analyses are reported here. Supplementary reports will be issued later. All data will be available on magnetic tape from:

GJOIS Project
UCC-ND Computer Applications Department
4500 North Building
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830

A brief description of sampling and analytical procedures and a detailed description of the maps, tables, and figures contained in this report are presented in the SRL document **USER'S GUIDE** included on microfiche in the pocket on the inside back cover of this report. A summary of the SRL development program in support of the reconnaissance is available in SRL-NURE progress reports (SRL-138). SRL data reports (SRL-146) have been open-filed for other western quadrangles (Figure 1).

FIGURE 1. Location Map for the Marble Canyon 1° x 2° NTMS Quadrangle

GEOLOGIC SUMMARY AND MINERAL OCCURRENCES

Location and Physical Geography

The Marble Canyon 1° x 2° NTMS quadrangle lies entirely within the Colorado Plateau physiographic province and spans part or all of several structural-physiographic features including the Kaibab Plateau, Paria Plateau, Kaibito Plateau, Monument Uplift, and Black Mesa Basin (Figure 2). Elevations range from over 2700 m (8800 ft) on the North Rim of the Grand Canyon to about 800 m (2500 ft) at the Colorado River, but most of the area lies between 1500 and 2100 m (5000 to 7000 ft). Soil and vegetation cover are sparse. Abundant exposures of bedrock facilitate mapping.

Geologic History

The oldest rocks in the region are Precambrian metamorphic and igneous rocks, exposed only in the Grand Canyon (southwestern corner of map) where the Colorado River has removed the cover of younger Precambrian, Paleozoic, and Mesozoic rocks. The Precambrian rocks are not exposed anywhere else in the region, but they lie at various depths below sedimentary rocks of Paleozoic and Mesozoic age.

The older Precambrian rocks include the Vishnu Group and the Zoroaster Plutonic Complex. The Vishnu Group is predominantly quartzofeldspathic and micaceous schist that was altered from an originally sedimentary state. The Zoroaster Plutonic Complex includes granitic plutons, dikes, and sills that have been interspersed with the Vishnu Group. The oldest radiometric dates on these rocks (1,695 to 1,725 Myr BP) indicate that a period of metamorphism occurred about 1.7 billion years ago. This period of metamorphism has been termed the Mazatzal Orogeny (Brown, Babcock, and Clark, 1974) or the Mazatzal Revolution.

The Mazatzal Orogeny resulted in the emplacement of large plutonic intrusions, accompanied by major folding and foliation having prevailing northeast trends. Minor folding, thrust-faults, and steep reverse-faults were developed with west and northwest trends. Shear faults were developed with west and northwest trends. Vertical displacements on many Precambrian faults amounted to several thousand meters.

The Mazatzal Revolution must have produced high mountain ranges that were eroded down to a plain. The Mazatzal structural pattern influenced subsequent tectonic events throughout the area as faults were commonly rejuvenated during later periods of deformation (Wilson, 1962).

FIGURE 2. Location of the Marble Canyon Quadrangle
on a Physiographic Province Map

Following the peneplanation of the Mazatzal Mountains, the younger Precambrian Grand Canyon Series of sedimentary and volcanic rocks accumulated to a thickness of 5,000 meters (~16,000 ft). The Grand Canyon series has been divided into the Unkar and Chuar Groups. A Rb-Sr date of 1090 ± 70 Myr BP was determined for the Cardenas Lavas interbedded with the sediments (McKee and Noble, 1974).

A subsequent, less severe, period of structural deformation occurred at the end of Precambrian time and resulted in folding and faulting of younger Precambrian sedimentary and volcanic rocks. The result of this deformation, called the Grand Canyon Disturbance, was a series of fault-block mountains (similar to the Basin and Range structures) along structural trends similar to those of the Mazatzal Revolution. These mountains were eroded away prior to the deposition of Cambrian sediments over much of the area (Wilson, 1962).

From the beginning of Paleozoic time, the Colorado Plateau has been relatively stable. The Plateau was periodically inundated by shallow epicontinental seas along the eastern margin of the Cordilleran Geosyncline. Beginning in Permian time, however, the area was predominantly emergent and blanketed by thick sequences of deltaic, fluvial, and aeolian sediments. Infrequent inundations occurred during the Triassic and Jurassic Periods when the uranium host rocks for the region were deposited as fluvial, lacustrine, or deltaic sediments. These rocks, mostly redbeds, were eroded from the Kaibab Plateau and the Monument Uplift, but are present to varying degrees throughout the rest of the region.

Igneous Activity

Igneous activity within the Marble Canyon $1^\circ \times 2^\circ$ NTMS quadrangle has been sparse and infrequent. Late Precambrian basaltic rocks were formed as dikes, sills, and flows in the Unkar Group of the Grand Canyon Series. Extrusive rocks, called the Cardenas Lavas, rest conformably on the Dox Sandstone, and the dikes and sills intrude all sedimentary formations beneath the flows. The basalt to basaltic andesite flows are about 300 meters thick and show evidence of deposition in a low-energy shallow sea. The sills are composed chiefly of medium-grained diabase consisting of plagioclase, olivine, and magnetite with minor augite and biotite (Hendricks and Lucchitta, 1974).

No evidence of Paleozoic volcanic activity has been reported in the area, but considerable bentonitic clay in the Triassic Chinle Formation is believed to have been derived from tuffaceous volcanic ash. Similar bentonitic clays are present in the Jurassic

Morrison Formation. The uranium and associated metal deposits in the Chinle Formation are postulated to have been concentrated from trace amounts contained in the tuffaceous debris (Keith, 1970).

Tertiary (Pliocene) volcanic dikes and necks occur in scattered localities in the area, forming prominent landmarks such as Tuba Butte and Wildcat Peak (in the Tuba City, Arizona, area), Agathla Peak, and several others in the Monument Valley area that penetrated rocks as young as Triassic. Several dikes cut the Morrison Formation near Chilchinbito. These volcanic rocks are mapped as monchiquite and minette on Plate 1A. Pleistocene basalt flows and dikes occur about 27 km (17 miles) southwest of Tuba City in the southwestern corner of the area.

All the Cenozoic volcanic activity in the area postdates uranium mineralization; therefore, the two events have no evident genetic relationship (Keith, 1970).

Structure

The major structural features in the Marble Canyon 1° x 2° NTMS quadrangle are broad anticlinal uplifts, synclinal basins, and monoclines which are generally attributed to Late Cretaceous or Early Tertiary (Laramide) compressional events (Huntoon, 1974). These major structures include the Kaibab Uplift, East Kaibab Syncline, Echo Cliffs Uplift, Preston Bench, Kaibito Saddle, Piute Folds, Monument Upwarp, and Black Mesa Basin (Figure 3), and many subsidiary folds as shown on Plate 1B. The monoclines bounding major structures (e.g., the East Kaibab, Echo Cliffs, Organ Rock, and Comb Ridge Monoclines) are believed to be the result of reverse movement along Precambrian normal faults, produced by the Laramide compression (Huntoon, 1974). This relationship is clearly demonstrated in exposures of the East Kaibab Monocline and has been applied to other monoclines in the region (Huntoon, 1974).

A series of northeast-trending faults in the eastern Grand Canyon (e.g., the Eminence Break Fault) are clearly tensional features which probably were initiated during the Miocene or Pliocene epochs and have been active since then (Huntoon, 1974).

Mineral Occurrences

The mineral occurrences in the Marble Canyon 1° x 2° NTMS quadrangle are primarily uranium, vanadium, and molybdenum minerals in sedimentary host rocks. The locations and stratigraphic positions of mines and prospects are plotted on Plate 1B. The sparsity of igneous and metamorphic rocks precludes the presence of other minerals in this area.

FIGURE 3. Index Map of the Tectonic Divisions of the Marble Canyon 1° x 2° NTMS Quadrangle

Uranium

Uranium deposits in the area are of two general types: peneconcordant with sediments, and fracture fillings. The most abundant and generally most productive are the peneconcordant deposits that are found mostly in sandstone and conglomerate of continental origin. These deposits consist of masses of rocks impregnated with uranium oxides, commonly in association with vanadium and, sometimes, with iron, lead, and zinc. The uranium content of these deposits ranges from trace amounts to several percent, but the average grade of ore mined has been about 0.29 percent pitchblende (Butler and Byers, 1969).

The production of uranium from the Colorado Plateau in Arizona has come predominantly from two Mesozoic formations: the Triassic Chinle Formation (53%) and the Jurassic Morrison Formation (28%), with the remaining 19% from various other stratigraphic units and veins (Butler and Byers, 1969). The following brief discussion summarizes the occurrences and production of uranium in these Mesozoic formations.

Chinle Formation (Upper Triassic - Deposits in the Chinle Formation occur mostly in the basal (0 to 50 m thick) Shinarump Conglomerate member. This member is composed of sand and gravel that were spread by meandering streams over an extensive erosional surface that cut into the underlying Moenkopi Formation (Lower Triassic). Many small and medium-sized deposits are in similar lenticular channel-filling sandstones in the lower part of the Petrified Forest member (Butler and Byers, 1969). The uranium ore bodies are localized in conglomeratic sandstone that fills stream channels scoured from the Moenkopi Formation. Uranium probably was precipitated from ground water flowing through the permeable channels in sites formerly occupied by plant material (Birdseye, 1958). Deposits in the Chinle Formation are concentrated in two areas of major production; one in Monument Valley, and the other near Cameron in the valley of the Little Colorado River. Smaller deposits occur along the southern margin of the Paria Plateau (Butler and Byers, 1969; Keith, 1970).

The deposits in the Monument Valley area are vanadiferous; their ratio of V_2O_5 to U_3O_8 ranges up to 4.6 to 1 (Johnson and Thordarson, 1966). In the Cameron area, vanadium is distinctly subordinate to uranium (Austin, 1964). The minerals that have been reported in the Monument Valley Chinle Formation have been compiled by Keith (1970) as follows: Metahewettite, uraninite, torbernite, metatorbernite, zippeite, metazippeite, becquerelite, natroalunite, uranyl phosphate, ilsemanite (rhenium noted), tyuyamunite, metatyuyamunite, corvusite, hewettite, and volbrothite.

The minerals reported by Keith (1970) in mines and prospects of the Cameron District include uraninite, becquerelite, and tyuyamunite. Most localities have no mineralogical information listed.

Morrison Formation (Upper Jurassic) - Uranium ore deposits in the Morrison Formation in Arizona are virtually restricted to the Salt Wash Sandstone member, which crops out in the vicinity of the Carrizo and Lukachukai Mountains in the extreme northeastern corner of the state. This member consists of lenticular lenses of sandstone interbedded with mudstone. Eighty-five percent of the ore mined from the Morrison Formation in Arizona has come from the Lukachukai Mountains (Butler and Byers, 1969).

Only one prospect in the Morrison Formation has been reported in the Marble Canyon quadrangle. Carnotite is reported by Keith (1970) in the Blue Lake Mines area about 13 km east of Kayenta, Arizona.

Toreva Formation (Upper Cretaceous) - A few productive uranium deposits have been found in fluviatile sandstone interbedded with carbonaceous siltstone in the lower member of the Toreva Formation on the northeastern margin of Black Mesa (Butler and Byers, 1969).

About 30 noncommercial uranium deposits are reported by Clinton and Carithers (1956) in the Toreva Formation along the eastern edge of Black Mesa between Yale Point and Black Mountain Trading Post off the eastern edge of the map (Figure 3). The ore minerals are carnotite and tyuyamunite which have replaced the original calcite cement in the quartzose sandstone. Although only three of these occurrences are in the Marble Canyon quadrangle, the Toreva Formation underlies most of Black Mesa, and should be considered a potential host rock for uranium minerals in the area.

Diatremes and Breccia-Pipes - These masses of fractured rock contain one of the major types of uranium occurrence in Arizona; however, deposits in diatremes and collapse breccias are small and difficult to find. The main occurrences of diatremes are in the Hopi Buttes and Monument Valley areas. Many of the uranium deposits are associated with infilling lacustrine limestone, sandstone, and volcanic ash rather than breccia. Most deposits are low-grade and have produced only a few tens of tons.

The most productive deposit in breccia-type structures is the Orphan Mine on the south rim of the Grand Canyon, which has

produced about 500,000 tons of good-grade uranium ore. Typical of breccia pipes in the area, this deposit originated by the collapse of solution caverns in the Mississippian Redwall Limestone, with further collapse of the overlying strata as a breccia-filling. Several similar structures are exposed, and many others must occur on the Plateau. However, their small size and concealed locations make them difficult and expensive to find (Keith, 1970). The Orphan Mine is outside the Marble Canyon 1° x 2° NTMS quadrangle, but the Grandview Mine in the extreme southwestern corner of the Marble Canyon quadrangle does have some uranium mineralization in a similar geologic setting.

Vanadium

As summarized on previous pages, the Monument Valley uranium deposits have a high (4.6 to 1) ratio of V_2O_5 to U_3O_8 (Johnson and Thordarson, 1966). Elsewhere in the Marble Canyon quadrangle, vanadium is distinctly subordinate to uranium (Keith, 1969).

Molybdenum

Keith (1969) reported only two significant occurrences of molybdenum in the Marble Canyon quadrangle. These are 1) the Monument No. 1 Mine and the Mitchell Mesa Mine in Monument Valley, and 2) the Sun Valley Mine on the southern margin of the Paria Plateau. The minerals reported are ilsemanite and jordisite in association with uranium minerals.

Current Research

The most comprehensive research of the geology and mineral resources in the Marble Canyon 1° x 2° NTMS quadrangle has recently been completed and published as the U.S. Geological Survey (USGS) Miscellaneous Investigations Map I-1003 (Plates 1A and 1B).

Al Bush of the Central Mineral Resources Branch of the USGS office at Denver, Colorado, is doing geological geochemical mapping of Bureau of Land Management (BLM) land in House Rock Valley and the Paria Plateau. Thor Karlstrom of the USGS Environmental Branch at Flagstaff, Arizona, is nearing completion of a study of the Cenozoic history of Black Mesa, which will include a surficial geologic map.

HYDROLOGY

Climate

The climate in the Marble Canyon 1° x 2° NTMS quadrangle is variable with cold winters and fairly hot summers. The average July temperature is about 21°C, and the average January temperature is about -1°C. The average rainfall varies from about 300 mm in the higher areas to near zero in the desert areas (NOAA, 1977).

Geography

The western fifth of the quadrangle is the Grand Canyon Section of the Colorado Plateau Province; the eastern four-fifths of the quadrangle are in the Navajo Section of the Colorado Plateau.

The Colorado River flows southward near the western border of the study area. It has cut canyon walls in Marble Canyon for a distance of more than 90 km. Outward from the canyon walls of the river are plateaus of several levels; each level displays escarpments above which are nearly flat-lying resistant rocks. In the southwest corner of the quadrangle, the Kaibab Plateau reaches an altitude of 2700 m; farther north, the Paria Plateau rises above the spectacular Vermillion Cliffs to an altitude of 2150 m. The eastern border of the Grand Canyon Section is marked by Echo Cliffs, a long distinctive escarpment that faces westward on the lower Painted Desert. Above the Echo Cliffs eastward is the Kaibito Plateau; the plateau is on a gentle east-dipping monocline of Jurassic sandstone.

The southeast part of the study area is underlain by Cretaceous beds of the Black Mesa. The Black Mesa is bordered by outfacing cliffs on the north and west, and the plateau displays rugged topography characterized by many gullies and washes.

The quadrangle has many escarpments and structural benches carved by erosion on weak and strong rocks (Thornbury, 1965, p. 405). The arid climate and horizontality of rock units have resulted in a conspicuously angular topography.

There are a few irrigated farms in the area, and livestock grazing is practiced.

The population of the area is very sparse. A few people live in small towns, on ranches, and on reservations (U.S. Bureau of Census, 1970).

Drainage and Hydrology

The arid climate that characterizes most of the Marble Canyon quadrangle results in only two major perennial streams; the Colorado and the Little Colorado Rivers. The Colorado River has an average discharge of $360.2 \text{ m}^3/\text{s}$ ($12,720 \text{ ft}^3/\text{s}$) near Grand Canyon, and meanders southward near the west border of the study area. The Little Colorado River joins the Colorado River near the southwest corner of the quadrangle. Both rivers and many of their short tributaries are deeply entrenched in canyons. Many ephemeral streams and washes can be found on the plateaus east of the Colorado River.

Groundwater supplies lie at great depths below most of the plateau areas, and water supplies are at a premium, even for domestic and stock use (McGuinness, 1963, p. 145). The Coconino Sandstone of Permian age supplies some water in the western part of the quadrangle, but poor recharge conditions (because of the arid climate) and deep entrenchment of the formation by canyons have prevented good aquifers from developing.

The vast central and eastern areas contain scant water reserves. The Navajo Sandstone yields small to moderate supplies to wells in the southeast part of the quadrangle; this sandstone aquifer, generally artesian, yields from less than 40 to more than 1000 liters per minute.

The water-table aquifer in much of the southeastern part of the study area is the Toreva and Wepo Formations that crop out in this area (Levings and Farrar, 1977). This water is obtained from sandstone beds. The depth to the water table varies from about 15 m to more than 100 m, depending partly on the number of perched zones of water penetrated by wells in the intercalated siltstones and sandstones. Wells generally yield 35 to 45 liters per minute.

The nearly horizontal layering of moderately permeable and nearly impermeable beds throughout the study area leads to numerous springs in coves and valley heads. Water discharges in the coves where permeable beds overlie the nearly impermeable beds. Most of the springs are small and lead to ephemeral streams. However, perennial springs are the source of base flow of the major tributaries that contribute water to the Colorado River (Johnson and Sanderson, 1968, p. 8).

The chemical quality of the groundwater varies considerably, according to depth of occurrence and aquifer characteristics. Almost all of the water contains 300 mg/L or more of total solids.

The water in the Navajo Sandstone beneath the Black Mesa generally contains less than 500 mg/L of total solids, and the water is of a sodium bicarbonate composition. The water-table aquifer in the Toreva and Wepo Formations beneath the Black Mesa Formation is locally unacceptable because of high sulfate and fluoride contents (Levings and Farrar, 1977).

Most surface waters in the area have a fairly high dissolved solids content because of prior use from irrigation, municipal, and industrial purposes. These waters have dissolved solids as high as 1000 mg/L at times. The chief constituents are sodium bicarbonate, sulfate, and chloride.

FACTORS AFFECTING THE DATA

Samples and associated site data were collected in May and November 1979. All streams were dry at the time of sampling. Some parts of the Marble Canyon 1° x 2° NTMS quadrangle were sampled by teams in a helicopter. The use of a helicopter increased the samplers' access to remote sites, but also decreased the accuracy of locating the sites on maps. Sampling was not permitted on lands governed by the National Park Service or by the Hopi Indian tribe.

Too few ground water samples were taken to be useful in interpretation. Analyses of ground water samples are tabulated, but are not displayed graphically.

QUALITY ASSURANCE

Sample Collection

Sampling teams marked each sampling site on an SRL-approved map and completed a Field Data Form (Figure 4) for every sample. About eight percent of the sampled sites were checked by SRL or subcontractor personnel to ensure that the reported field locations were accurate. No evidence has been discovered of deliberate malfeasance by the sampling teams. Ninety-five percent of the positively identified sites checked were found to be located within 800 m (0.5 mi) of the locations plotted on sample maps. However, the locations of about one-third of the total sites were based on photographs taken from the helicopter, and the site descriptions were inadequate for the contractor to be certain that he had located them.

SRL FIELD DATA FORM

SITE CODE							DATE				TEAM NO.		SURFACE SITE DATA										FORMATION		ODOR														
Sheet	Map Code	Site Number					Mo.	Day	Yr.	Hr.			Sample Type	Rock Type	Sed Size	Width	Depth	Flow	Level	Veg Type	Veg Density	Relief	No. of Sample Composites	Activities Contaminants (List up to four)															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
HAVE A GOOD DAY																																							
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
pH		SPECIFIC CONDUCTANCE $\mu\text{mhos/cm}$					WATER TEMP. $^{\circ}\text{C}$		Drops H_2SO_4		ml Water		ALKALINITY		ml OF WATER ION-EXCHANGED		WELL DEPTH		Condepth		Well Class.		Where Sample Taken		SCINTILLOMETER READING				Inform. Request		DO NOT USE		CARD CODE						
ADDRESS (use / to separate lines)																																							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
IN THE CASE OF EACH CIRCLED ENTRY SPACE, ENTER MOST APPROPRIATE DESIGNATORS LISTED BELOW																																							
<p>(20)</p> <p>A Other sediment (8)</p> <p>B Other resin (9)</p> <p>C Well water (9)</p> <p>D Spring water (9)</p> <p>E Stream sediment + water (8)</p> <p>F Stream sediment only (8)</p> <p>G Soil (8)</p> <p>H Talus (8)</p>										<p>(21)</p> <p>1 Other (explain)</p> <p>2 Volcanic - Felsic</p> <p>3 Volcanic - Mafic</p> <p>4 Plutonic - Felsic</p> <p>5 Metamorphic</p> <p>6 Clastics - coarse</p> <p>7 Sandstone</p> <p>8 Shale</p> <p>9 Carbonate</p>										<p>(22)</p> <p>1 Other (explain)</p> <p>2 Pebbles & coarser</p> <p>3 Sand</p> <p>4 Silt & clay</p> <p>5 Organic muck</p>										<p>(23 and 24)</p> <p>1 Dry</p> <p>2 < 1/4'</p> <p>3 1/4' - 1'</p> <p>4 1' - 2'</p> <p>5 2' - 4'</p> <p>6 4' - 8'</p> <p>7 8' - 16'</p>									
<p>(25)</p> <p>1 Dry</p> <p>2 Slow</p> <p>3 Moderate</p> <p>4 Fast</p> <p>5 Torrent</p>										<p>(26)</p> <p>1 Dry</p> <p>2 Low</p> <p>3 Normal</p> <p>4 High</p>										<p>(27)</p> <p>1 Other</p> <p>2 Forest</p> <p>3 Desert scrub</p> <p>4 Grassland</p> <p>5 Saltbush</p> <p>6 Marsh</p>										<p>(28)</p> <p>1 Sparse</p> <p>2 Moderate</p> <p>3 Dense</p>									
<p>(29)</p> <p>1 0 - 10'</p> <p>2 10 - 50'</p> <p>3 50 - 200'</p> <p>4 > 200'</p>										<p>(32 thru 35)</p> <p>1 Other</p> <p>2 None</p> <p>3 Chemical</p> <p>4 Smelting</p> <p>5 Mining</p> <p>6 Garbage</p> <p>7 Farming</p> <p>8 Grazing</p> <p>9 Oil Field</p>										<p>(40)</p> <p>1 Other</p> <p>2 None</p> <p>3 H₂S</p> <p>4 Oil</p>										<p>(62)</p> <p>1 Certain</p> <p>2 Probable</p> <p>3 Possible</p> <p>4 Educated guess</p> <p>5 Unknown</p>									
<p>(63)</p> <p>1 Other</p> <p>2 Domestic</p> <p>3 Municipal</p> <p>4 Livestock</p> <p>5 Irrigation</p> <p>6 Industrial - commercial</p>										<p>(64)</p> <p>1 Others</p> <p>2 Immediately after storage tank</p> <p>3 Before storage tank</p> <p>4 Direct from pump</p> <p>5 Direct from well or spring</p> <p>6 From municipal system</p>										<p>(77)</p> <p>Enter "X" when analysis information is requested</p>										<p>(80)</p> <p>Enter number in parentheses () for column 20 options</p>									
<p>Sampler(s) Signature(s)</p> <p>Field Supervisor (initials)</p>																																							
<p>Standard Letters and Numbers A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9</p>																																							

FIGURE 4. SRL Field Data Form for Western Quadrangles

Analytical Standards

Sediment Standards SRL 2.2, 3.1, and 4.1 were analyzed along with NURE sediment samples. Analyses of these standards provide routine checks for the analytical equipment and software. Tables 1a, 1b, and 1c contain the results from the standards run during the same time period as the Marble Canyon sediment samples. These results give a good estimate of the precision of the data and can be used in estimating bias between this and other SRL reports.

Periodically, DOE intersite comparison standards are analyzed. An independent quality assurance program based on these standards is conducted for DOE by Ames (Iowa) Laboratory (D'Silva, et al.).

DESCRIPTION OF DATA TABLES

This section of the report summarizes the types of data tabulated on microfiche. Detailed descriptions of the tables and definitions of abbreviations can be found on the microfiche labeled **USER'S GUIDE**. Groundwater analyses and site descriptions are tabulated in Tables A-1 and A-2, both of which can be found on the microfiche titled **MARBLE CANYON TABLES**. Sediment analyses and site descriptions are tabulated in Tables B-1, B-2, and B-3, which are also on the microfiche titled **MARBLE CANYON TABLES**.

Table A-1 begins with the sample's SRL identification number, which is composed of four letters and a three-digit number. The first two letters identify the quadrangle. MC is the two-letter designator for the Marble Canyon $1^\circ \times 2^\circ$ NTMS quadrangle. The third and fourth letters define which 15-minute quadrangle contains the sampling site (see chart below).

TABLE 1

Accuracy and Precision of Analyses of SRL Sediment Standards

a. SRL 2.2 Standard

<u>Element</u>	<u>Number*</u>	<u>Mean, ppm</u>	<u>Standard Deviation</u>	<u>Coefficient of Variation, %</u>	<u>Nominal Value ppm**</u>
U	183	21.1	3.4	15.9	22.2
Th	174	106	15.9	15.0	125
Hf	165	134	29.9	22.4	173
Al	183	8300	4000	48.8	6500
Ce	159	499	83	16.5	614
Fe	172	7300	2200	29.6	6700
Mn	179	262	116	44.3	300
Sc	175	3.1	2.8	90.5	3.9
Na	178	147	101	69.2	145
Ti	180	11,800	2800	24.1	13,200
V	182	31.8	5.8	18.2	34.7
Dy	179	23.5	9.7	41.1	<22
Eu	115	2.5	1.7	68.5	2.5
La	174	284	81.9	28.7	301
Lu	162	2.3	0.4	18.7	2.9
Sm	164	37.2	14.9	40.2	51.3
Yb	158	15.2	3.59	23.1	18.2

* Number of determinations.

** See Reference SRL-138, No. 16 [GJBX-160(79)], pp. 20-22.

TABLE 1 (Continued)

b. SRL 3.1 Standard

<u>Element</u>	<u>Number*</u>	<u>Mean, ppm</u>	<u>Standard Deviation</u>	<u>Coefficient of Variation, %</u>	<u>Nominal Value ppm**</u>
U	175	41.1	4.7	11.5	41.3
Th	167	142	22.9	16.2	162
Hf	64	6.1	3.4	56.4	7.4
Al	174	39,400	5700	14.5	30,600
Ce	149	772	126	16.3	903
Fe	167	15,300	3700	24.4	15,200
Mn	17	273	2020	73.8	289
Sc	169	4.0	1.2	30.2	4.2
Na	169	932	180	19.6	901
Ti	136	5300	1100	20.4	6100
V	170	45.3	7.9	17.4	54.4
Dy	162	51.2	19.7	38.4	50†
Eu	138	3.8	1.6	42.3	3.9
La	168	414	69.7	16.9	443
Lu	152	4.0	0.8	19.2	4.4
Sm	158	63.8	29.9	46.8	69.2
Yb	157	28.7	5.28	18.2	29.9

* Number of determinations.

** See Reference SRL-138, No. 16 [GJBX-160(79)], pp. 20-22.

† Only one laboratory reported a value for dysprosium.

TABLE 1 (Continued)

c. SRL 4.1 Standard

<u>Element</u>	<u>Number*</u>	<u>Mean, ppm</u>	<u>Standard Deviation</u>	<u>Coefficient of Variation, %</u>	<u>Nominal Value ppm**</u>
U	179	0.53	0.08	15.6	0.58
Th	77	2.8	1.2	43.8	2.1
Hf	121	3.0	1.3	43.6	4.4
Al	180	73,000	11,100	15.2	66,700
Ce	100	48.4	16.2	33.4	44
Fe	172	75,700	11,300	14.9	87,300
Mn	175	1760	290	16.8	1970
Sc	172	15.4	4.3	27.9	21
Na	177	16,900	2600	15.5	15,100
Ti	162	23,100	5500	23.9	25,200
V	177	240	41.8	17.1	273
Dy	34	3.9	3.1	80.4	<22
Eu	81	1.4	0.9	63.4	1.2
La	151	15.8	4.20	26.5	18.6
Lu	87	0.24	0.12	51.5	0.28
Sm	143	3.1	1.8	59.2	4.2
Yb	32	2.6	1.4	54.7	1.6

* Number of determinations.

** See Reference SRL-138, No. 16 [GJBX-160(79)], pp. 20-22.

† Only one laboratory reported a value for dysprosium.

Numbers from 001 to 499 designate surface sites. Numbers from 501 to 999 designate ground-water sites. The first sediment sample, therefore, taken from the extreme northeastern portion of the Marble Canyon 1° x 2° NTMS quadrangle would be MCAH001.

Other entries on Table A-1 include a DOE identification number; pH, conductivity, alkalinity, and scintillometer readings; analyses for U, Br, Cl, F, He, Mn, Na, and V; and the ratio of uranium-to-conductivity (multiplied by 1000 for convenience; U x 1000/cond.). All entries are self-explanatory except those noted below (see **USER'S GUIDE** also).

DOE ID is a 28-digit number that includes the following parts:

Digit Number

1-2	State (See Table 1 in the USER'S GUIDE)
4-10	Latitude of site
12-19	Longitude of site
21	Laboratory code (4 = SRL)
23-24	Sample type (See Table 2 in the USER'S GUIDE)
26-28	Replication code. Generally only original samples (-000) are reported in the Data Reports.

Table A-2 shows SRL identification number; concentrations of Al, Dy, and Mg; sampling date; sample collection team number; and the following characteristics of the well or spring that was sampled:

WATRTEMP	Water Temperature, in °C.
WELDEPTH	Depth of well in feet.
DPHCONF	Confidence in depth measurement.*
WELCLASS	Classification of well use.*
SMPPOINT	Point in plumbing system where water was taken.*
WELLODOR	Presence of hydrogen sulfide or other odor.

* Definitions of entries under these headings are detailed in the **USER'S GUIDE**.

Sediment analyses and site descriptions are tabulated in Tables B-1, B-2, and B-3, which are on the microfiche labeled MARBLE CANYON TABLES.

Table B-1 includes SRL and DOE identification numbers similar to those described above for ground-water sites. Table B-1 also includes scintillometer readings, pH, conductivity, and alkalinity of stream water, plus elemental concentrations of U, Th, Hf, Ce, Fe, Mn, Na, Sc, Ti, and V.

Table B-2 (Supplementary Data - Sediments) includes the SRL identification number and concentrations of Al, Dy, Eu, La, Sm, Yb, and Lu.

Table B-3 (Supplementary Data - Sediments) includes the SRL identification number and the following entries:

SAMPTYPE	Type of soil, sediment, etc., sampled (see Table 2 in the USER'S GUIDE).
ROCKTYPE	Type of rock underlying sampling site.*
SEDSIZE	Dominant size of particles in sediment at site.*
STRWIDTH	Size and flow rate of stream at sampling site.*
STRDEPTH	
STRFLOW	
STRLEVE	
VEGTYPE	Dominant type of vegetation at site.*
VEGDENS	Vegetation density at site.*
RELIEF	Local relief at site.*
COMPOSIT	Number of subsamples blended into sample.
CONTAMN1	Activities or contaminants that may affect the material sampled.*
CONTAMN2	
CONTAMN3	
CONTAMN4	
FRMATION	The rock formation that underlies the site.*
ODOR	Odors detected in sampled material.*

* Definitions of entries under these headings are detailed in the **USER'S GUIDE**.

WATERTEMP	Water temperature in °C.
SAMPDATE	Date sample was collected.
TEAM	Numerical designator of sample collection team.

Site descriptions and field measurements are recorded on the SRL Field Data Form (Figure 4). Data are recorded in the spaces numbered 1 through 80. The spaces have self-explanatory labels. Spaces whose numbers are circled are filled with one of the choices listed beneath the appropriate number on the Field Data Form. Some data are listed differently on the Field Data Form and in the data tables on microfiche. For example, well water samples are coded as Sample Type "C" on the Field Data Form and are reported as Sample Type "52" in Table A-1. Details of how the Field Data Form is used can be found in the USER'S GUIDE and in Price and Jones (1979).

Elemental Analyses

Concentrations of each element are reported in parts per million (ppm) by weight for sediment samples and in parts per billion (ppb) for water samples. Values have been rounded to appropriate significant figures. Note that elemental (not oxide) concentrations are quoted in this table. Values below detection limits are indicated by a minus (-). For example, -3 means that the sample contains less than 3 ppm of that element. If background is high, a period (.) is used to indicate that the element was not detected, and that an estimate of the detection limit is not available for that element. Missing data are indicated by "M". All analytical results are missing when there was insufficient sample for analysis.

RESULTS AND DISCUSSION OF THE DATA

High uranium values fall into two groups: one group is in the western part of the quadrangle, near the Colorado River; the other group lies predominantly in map units BG and BH, near the southeastern corner of the sampled area.

The area in the western part of the Marble Canyon 1° x 2° NTMS quadrangle surrounds known uranium deposits and extends downstream of them. In addition to above-average uranium values, the area shows high cerium, lanthanum, scandium, iron, manganese, titanium, and vanadium values. High hafnium, samarium, thorium, and lutetium values have been found at several sites. The uranium-to-thorium and uranium-to-hafnium ratios are generally

higher than the average values for the quadrangle. However, the uranium-to-lanthanum ratios in this area are not unusually high. This western part of the quadrangle is underlain by Kaibab limestone and by the Toroweap Formation, which includes some cross-bedded sandstone.

The high values of so many elements in the area (Table 2) suggests that dense minerals in general have been concentrated in the sampled sites. The high uranium-to-thorium and uranium-to-hafnium ratios and the low values of the uranium-to-lanthanum ratios in the area suggest that uranium mineralization here may be typical of vanadium-bearing Colorado Plateau deposits or may be associated with an unusually lanthanum-rich (or thorium-poor) monazite.

The Chinle Formation, a host rock for many uranium deposits, outcrops around the area described above. The Chinle Formation was probably an important source of sediments in this area.

The second area lies predominantly in map units BG and BH. In addition to high uranium values, this area generally shows high thorium, lanthanum, cerium, samarium, dysprosium, ytterbium, lutetium, and hafnium values. Several sites contain high vanadium, titanium, manganese, iron, and scandium values. These high values suggest that sediments in this area are generally enriched in dense minerals. The low uranium-to-lanthanum and uranium-to-thorium ratios in this area, suggest that rare-earth minerals such as monazite or xenotime contribute much of the uranium in the sediments. Several values of the uranium-to-hafnium ratio are high in this area. The high values of this ratio imply that zircon is not a major uranium contributor. This area is underlain by alluvium, and by the Yale Point Sandstone and the Wepo Formation, which include some coal strata and some sediments deposited in continental and nearshore environments. Weathering of these rocks could have left a surficial residue that is richer in dense minerals than are unweathered rocks.

ACKNOWLEDGMENTS

The geologic and mineral occurrence information for the Marble Canyon 1° x 2° NTMS quadrangle was compiled by Dr. J. Dale Nations, Department of Geology, Northern Arizona University, Flagstaff, Arizona. The hydrologic information was provided by Harry E. LeGrand, Raleigh, North Carolina.

TABLE 2

Statistical Summary of Field Measurements and Elemental Analyses—Sediment; Marble Canyon

Field Measurement or Element	n*	Measured Values		Mean††	Log Mean‡	Log. Std.§	Standard Deviation
		Maximum**	Minimum†				
Scintillometer Reading	865	115	3	21.3			9.0
U	865	16.4	0.4		0.14	0.20	
Th	557	44.0	3.0		0.70	0.18	
Hf	786	92.0	3.0		0.89	0.20	
Al	861	84,900	100		4.42	0.17	
Ce	613	164	5.0		1.35	0.24	
Fe	822	41,400	2900		3.96	0.20	
Mn	850	1150	30		2.27	0.22	
Na	851	14,300	500		3.36	0.24	
Sc	829	13.9	0.4		0.35	0.23	
Ti	697	10,000	400		3.28	0.23	
V	847	100	10		1.28	0.24	
Dy	308	17.1	0.5		0.33	0.28	
Eu	115	4.4	0.4		0.11	0.23	
La	822	85.0	2.0		0.97	0.23	
Lu	531	1.6	0.1		-0.69	0.21	
Sm	810	11.0	1.0		0.19	0.20	
Yb	314	7.7	0.5		0.24	0.18	

* Number of observations

** Elemental concentrations in ppm.

† Minimum or detection limit.

†† Mean of values above detection limit; $[(\sum \log_{10} x)/n]$.

‡ Log units.

CITED REFERENCES

- Austin, S. R., 1964, **Mineralogy of the Cameron Area, Coconino County, Arizona**: USAEC Report RME-99, 99 pp. Available from NTIS, Springfield, Virginia.
- Birdseye, H. S., 1958, "Uranium Deposits in Northern Arizona;" in **Guidebook of the Black Mesa Basin**: New Mex. Geol. Soc., Guidebook, Ninth Field Conference, pp. 161-163.
- Brown, E. H., Babcock, R. S., and Clark, M. D., 1974, "A Preliminary Report on the Older Precambrian Rocks in the Upper Granite Gorge of the Grand Canyon;" in **Geology of Northern Arizona, Part 1**: Karlstrom, T. N. V., et al., editors, Geol. Soc. Amer., Rocky Mtn. Section Mtg., Flagstaff, Arizona, pp. 2-33.
- Butler, A. P., Jr. and Byers, V. P., 1969, "Uranium," in **Mineral and Water Resources of Arizona**: Arizona Bur. Mines, Bull. 180, pp. 282-292.
- Clinton, N. J. and Carithers, L. W., 1956, **Uranium Deposits in Sandstones of Marginal Marine Origin**: U.S. Geol. Surv., Prof. Paper 300, H. A. Page, et al., eds. pp. 445-449.
- D'Silva, A. P., Floyd, M. A., and Haas, W. J., Jr., **Multilaboratory Analytical Quality Control for the Hydrogeochemical and Stream Sediment Reconnaissance**: Iowa State University, Ames Laboratory, Ames, Iowa. A series of monthly reports sponsored by USDOE. Available from NTIS, Springfield, Virginia.
- Haynes, D. D., and Hackman, R. J., 1978, **Geology, Structure, and Uranium Deposits of the Marble Canyon 1° x 2° Quadrangle, Arizona**: U.S. Geol. Surv., Miscellaneous Investigations Series Map I-1003 (2 Sheets).

- Hendricks, J. D., and Lucchitta, I., 1974, "Upper Pre-Cambrian Igneous Rocks of Grand Canyon, Arizona;" in **Guidebook for Geology of Northern Arizona. Pts. I and II:** Karlstrom, T. N. V., et al., editors, Geol. Soc. Amer., Rocky Mtn. Section Mtg., Flagstaff, Arizona.
- Huntoon, P. W., 1974, "Synopsis of the Laramide and Post-Laramide Structural Geology of the Eastern Grand Canyon, Arizona"; in **Guidebook for Geology of Northern Arizona, Part I:** Karlstrom, T. N. V., et al., editors, Geol. Soc. Amer., Rocky Mtn. Section Mtg., Flagstaff, Arizona, pp. 327-335.
- Johnson, H. S., Jr. and Thordarson, W., 1966, **Uranium Deposits of the Moab, Monticello, White Canyon, and Monument Valley Districts, Utah and Arizona:** U. S. Geol. Surv., Bull. 1222-H, pp. 1-53.
- Johnson, P. W., and Sanderson, R. B., 1968, **Spring Flow into the Colorado River, Lees Ferry to Lake Mead, Arizona:** Arizona State Land Dept., Water Resources Dept. Report No. 34, 26 pp.
- Keith, S. B., 1969, **Mineral and Water Resources of Arizona:** Ariz. Bur. Mines, Bull. 180.
- Keith, S. B., 1970, "Uranium," in **Coal, Oil, Natural Gas, Helium and Uranium in Arizona:** Peirce, H. W., Keith, S. B., and Wilt, J. C., editors, Ariz. Bureau of Mines, Bull. 182.
- Levings, G. W., and Farrar, C. D., 1977, **Maps Showing Ground-Water Conditions in the Southern Part of the Black Mesa Area, Navaho, Apache, and Coconino Counties, Arizona - 1976:** U.S. Geol. Survey, Water-Resources Investigation 77-41 (Open-File Report).
- McGuinness, C. L., 1963, **The Role of Ground Water in the National Water Situation:** U.S. Geol. Survey, Water-Supply Paper 1800, 1121 pp.
- McKee, E. H. and Noble, D. C., 1974, "Rb-Sr Age of the Cardenas Lavas, Grand Canyon, Arizona;" in **Guidebook for Geology of Northern Arizona, Part I:** Karlstrom, T. N. V., et al., editors, Geol. Soc. Amer., Rocky Mtn. Section Mtg., Flagstaff, Arizona, pp. 87-96.

NOAA, 1977, **Records of Annual Precipitation:** U.S. Department of Commerce, National Climatic Center, Asheville, North Carolina.

Price, V., and Jones, P. L., 1979, **Training Manual for Water and Sediment Geochemical Reconnaissance:** SRL Document DPST-79-219, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, South Carolina. DOE-GJO Document No. GJBX-XX(79).*

Roden, M. F., Smith, D., and McDowell, F. W., 1979, **Age and Extent of Potassic Volcanism on the Colorado Plateau:** Earth and Planetary Sci. Letters, Vol. 43, pp. 279-284.

SRL-138, **Savannah River Laboratory Quarterly and Semiannual Reports, Hydrogeochemical and Stream Sediment Reconnaissance, National Uranium Resource Evaluation Program:** E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, South Carolina.

<u>No.</u>	<u>Period</u>	<u>SRL Doc. No.</u>	<u>DOE-GJO Doc. No.*</u>
1	January-March 1975	DPST-75-138-1	GJBX-5(76)
2	April-June 1975	DPST-75-138-2	GJBX-6(76)
3	July-September 1975	DPST-75-138-3	GJBX-7(76)
4	October-December 1975	DPST-75-138-4	GJBX-8(76)
5	January-March 1976	DPST-76-138-1	GJBX-17(76)
6	April-June 1976	DPST-76-138-2	GJBX-27(76)
7	July-September 1976	DPST-76-138-3	GJBX-63(76)
8	October-December 1976	DPST-76-138-4	GJBX-6(77)
9	January-March 1977	DPST-77-138-1	GJBX-35(77)
10	April-June 1977	DPST-77-138-2	GJBX-55(77)
11	July-September 1977	DPST-77-138-3	GJBX-90(77)
12	October-December 1977	DPST-77-138-4	GJBX-37(78)
13	January-March 1978	DPST-78-138-1	GJBX-66(78)
14	April-September 1978	DPST-78-138-2	GJBX-13(79)
15	October 1978-March 1979	DPST-79-138-1	GJBX-86(79)
16	April-September 1979	DPST-79-138-2	GJBX-160(79)
17	October 1979-March 1980	DPST-80-138-1	(in process)

SRL-146, SRL-NURE Data Reports, E. I. du Pont de Nemours & Co.,
Savannah River Laboratory, Aiken, South Carolina.

No.	NTMS 1° x 2° Quadrangle	SRL Doc. No.	DOE-GJO Doc. No.*
1	Winston-Salem†	DPST-77-146-1	GJBX-66(77)
2	Spartanburg	DPST-77-146-2	GJBX-09(78)
3	Charlotte	DPST-78-146-1	GJBX-40(78)
4	Greenville	DPST-78-146-2	GJBX-47(78)
5	Winston-Salem††	DPST-78-146-3	GJBX-58(78)
6	Greensboro	DPST-78-146-4	GJBX-74(78)
7	Knoxville	DPST-78-146-5	GJBX-75(79)
8	Scranton	DPST-78-146-6	GJBX-02(79)
9	Athens	DPST-78-146-7	GJBX-20(79)
10	Harrisburg	DPST-79-146-1	GJBX-31(79)
11	Portland	DPST-79-146-2	GJBX-28(79)
12	Glens Falls	DPST-79-146-3	GJBX-44(79)
13	Augusta	DPST-79-146-4	GJBX-45(79)
14	Dyersburg	DPST-79-146-5	GJBX-58(79)
15	Poplar Bluff	DPST-79-146-6	GJBX-63(79)
16	Hartford	DPST-79-146-7	GJBX-94(79)
17	Williamsport	DPST-79-146-8	GJBX-152(79)
18	Newark	DPST-79-146-9	(in process)
19	Albany	DPST-79-146-10	GJBX-140(79)
20	Atlanta	DPST-79-146-11	GJBX-129(79)
21	Delta, Richfield†††	DPST-79-146-12	GJBX-161(79)
22	Walker Lake	DPST-79-146-13	GJBX-107(80)
23	McDermitt, Wells†††	DPST-79-146-14	GJBX-117(80)
24	Reno	DPST-79-146-15	GJBX-108(80)
25	Death Valley	DPST-79-146-16	(in process)
26	Flagstaff††††	DPST-79-146-17	(in process)
27	Marble Canyon	DPST-79-146-18	(this report)

† Sediment only.

†† Ground water only.

††† SRL analyses of samples collected by Lawrence Livermore Laboratory.

†††† Abbreviated report; geologic, hydrologic, and data discussion sections are omitted.

Thornbury, W. D., 1965, **Regional Geomorphology of the United States:**
John Wiley & Sons, Inc., New York, N. Y., 609 pp.

U.S. Bureau of Census, **Census of Population, 1970, and Census
of Agriculture, 1970**, Washington, D.C.

Wilson, E. D., 1962, **A Resume of the Geology of Arizona:** Ariz.
Bureau of Mines, Bull. 171, 140 pp.

* DOE-GJO reports are available on microfiche from the Grand
Junction Office, DOE, for \$6.00. Prepaid orders should be sent
to Bendix Field Engineering Corporation, Technical Library, P.O.
Box 1569, Grand Junction, CO 81501. Checks or money orders
should be made out to Bendix Field Engineering Corporation, the
operations contractor for DOE's Grand Junction Office.

RELATED GEOLOGIC BIBLIOGRAPHY

- Akers, J. P., 1960, Current Assistance in Water-Development Program of Navaho Tribe, Arizona and New Mexico: Arizona Geol. Soc., Digest, Vol. 3, p. 45.
- Evenson, C. G., 1958, "The Shinarump Member of the Chinle Formation;" in **Guidebook of the Black Mesa Basin**: New Mexico Geol. Soc., Ninth Field Conference, pp. 95-97.
- Fenneman, N. M., 1931, **Physiography of the Western United States**: McGraw-Hill Book Co., Inc., New York, N.Y., 534 pp.
- Fischer, R. P., 1969, "Vanadium;" in **Mineral and Water Resources of Arizona**: Arizona Bur. Mines, Bull. 180, pp. 293-296.
- Harshbarger, J. W., Repenning, C. A., and Irwin, J. H., 1957, **Stratigraphy of the Uppermost Triassic and the Jurassic Rocks of the Navaho Country**: U.S. Geol. Survey, Prof. Paper 291.
- Hunt, C. B., 1956, **Cenozoic Geology of the Colorado Plateau**: U.S. Geol. Survey, Prof. Paper 279, 99 pp.
- Kelley, V. C., 1958, "Tectonics of the Black Mesa Basin Region of Arizona;" in **Guidebook of the Black Mesa Basins**: New Mex. Geol. Soc., Guidebook, Ninth Field Conference, pp. 137-144.
- Kerr, P. F., 1958, **Uranium Emplacement in the Colorado Plateau**: Geol. Soc. Amer., Bull. 69, pp. 1075-1112.
- King, R. U., 1969, "Molybdenum and Rhenium;" in **Mineral and Water Resources of Arizona**; Ariz. Bur. Mines, Bull. 180, pp. 230-238.
- Miller, D. S. and Kulp, J. L., 1963, **Isotopic Evidence on the Origin of the Colorado Plateau Uranium Ores**: Geol. Soc. Amer., Bull. 74, pp. 609-630.
- Page, H. A. and Repenning, C. A., 1958, "Late Cretaceous Stratigraphy of Black Mesa Navaho and Hopi Indian Reservations;" in **Guidebook of the Black Mesa Basin**: New Mexico Geol. Soc., Ninth Field Conference, pp. 115-122.

EXPLANATION

See sheet 1 for explanation of geologic symbols

Uranium deposit or prospect symbols are plotted directly over the deposit, which may be either a surface or subsurface occurrence. All deposits in Monument Valley are in the Shinarump Member of the Chinle Formation. The locations of uranium deposits and prospects were plotted from geologic source maps (see Geologic Sources, sheet 1) and from information supplied by the U.S. Energy Research and Development Administration (formerly the U.S. Atomic Energy Commission). Data on ore production from the U.S. Energy Research and Development Administration. Production totals are to October 1967.

URANIUM ORE DEPOSITS—Limits not plotable at map scale. 20,000 pounds (9,072 kg) U₃O₈ = 10 short tons (9,072 tonnes) U₃O₈ = 8.43 short tons (7.65 tonnes) U.

▲ Production totals more than 200,000 pounds (>90,072 kg) of U₃O₈
○ Production totals more than 20,000 but less than 200,000 pounds (>9,072 kg but <90,720 kg) of U₃O₈
● Production totals less than 20,000 pounds (<9,072 kg) of U₃O₈

✱ URANIUM PROSPECT—Rock contains 0.01 percent or more U₃O₈ or a uranium mineral, but no ore is known to have been produced; not all prospects are shown in areas of numerous deposits

HOST ROCKS FOR URANIUM DEPOSITS—The following stratigraphic units are listed in order of decreasing number of deposits:

Shinarump Member of Chinle Formation
Sandstone and mudstone member and Shinarump Member of Chinle Formation—In western part of map, usually in sandstone and mudstone member
Owl Rock and Petrified Forest Members of the Chinle Formation
Salt Wash Member of Morrison Formation
Navajo Sandstone
Redwall Limestone

CONTACT
FAULT—Dashed where approximately located; dotted where concealed.
Bar and ball on downthrown side
FOLDS—Showing direction of plunge
Anticline
Syncline
STRIKE AND DIP OF BEDS
STRUCTURE CONTOURS—Drawn on base of Dakota Sandstone except in area west of Echo Cliffs and south of Vermilion Cliffs where drawn on top of Kaibab Limestone. Solid where vertical accuracy within 125 feet (38 m); long dashed where vertical accuracy probably between 125 and 250 feet (38 and 76 m); short dashed where vertical accuracy possibly not within 250 feet (76 m). Arrow shows direction of dip. Hachures indicate closed contours of basin. Contour interval 250 feet (76.2 m). Datum is mean sea level.

INDEX SHOWING SOURCES OF STRUCTURE DATA

STRUCTURE SOURCES

Structure contours compiled from the following sources. (See sheet 1 for the complete reference.) Elevations of several datum surfaces were corrected to the base of Dakota Sandstone or to the top of Kaibab Limestone by applying the appropriate isopach interval.

1. Structure compiled directly from geologic-topographic maps. Supplementary well-log and stratigraphic-section data from Arizona State Land Department (1964, 1966).
2. Beaumont and Dixon (1965, pl. 1). Datum, top of Navajo Sandstone.
3. Petersen (1959). Datum, base of Navajo Sandstone.
4. _____ (1961). Datum, base of Navajo Sandstone.
5. Petersen and Phoenix (1959). Datum, base of Carmel Formation.
6. Petersen and Wells (1960). Datum, base of Navajo Sandstone.
7. Phoenix (1963, pl. 1). Datum, base of Navajo Sandstone.
8. Wells (1960, pl. 4). Datum, base of Navajo Sandstone in south half, base of Carmel Formation in north half.
9. Witkind and Thaden (1963, pl. 1). Datum, top of De Chelly Sandstone Member of Cutler Formation.

Base from U.S. Geological Survey, 1956-70
100,000-foot grid based on Arizona coordinate system, central and east zones
10,000-meter Universal Transverse Mercator grid ticks, zone 12

SCALE 1:250,000
0 5 10 15 20 25 MILES
0 5 10 15 20 25 KILOMETERS

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
DATUM IS MEAN SEA LEVEL

1978 MAGNETIC DECLINATION FOR THIS SHEET VARIES FROM 14° EAST FOR THE CENTER OF THE EAST EDGE TO 10° WEST FOR THE CENTER OF THE WEST EDGE. MEAN ANNUAL CHANGE IS 0.02° WEST.

Structure and uranium deposits

GEOLOGY, STRUCTURE, AND URANIUM DEPOSITS OF THE MARBLE CANYON 1°x2° QUADRANGLE, ARIZONA

Compiled by
Donald D. Haynes and Robert J. Hackman
1978