UNITED STATES GEOLOGICAL SURVEY

trace elements investigations report

TEI-328A

GEOLOGIC ASPECTS OF THE RESOURCE APPRAISAL OF URANIUM DEPOSITS IN PRE-MORRISON FORMATIONS OF THE COLORADO PLATEAU:

An Interim Report

By
W. I. Finch

This preliminary report is released without editorial and technical review for conformity with official standards and nomenclature, to make the information available to interested organizations and to stimulate the search for uranium deposits.

May 1953

Prepared by the Geological Survey for the
UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service, Oak Ridge, Tennessee

GEOLOGY AND MINERALOGY

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GEOLOGIC ASPECTS OF THE RESOURCE APPRAISAL OF URANIUM DEPOSITS IN PRE-MORRISON FORMATIONS OF THE COLORADO PLATEAU

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ABSTRACT

In December 1951 a reconnaissance resource appraisal was begun of uranium deposits in pre-Morrison formations, particularly the Shinarump conglomerate, on the Colorado Plateau and the adjoining regions. Selected mines were mapped in detail. The objectives of the pre-Morrison resource appraisal program are (1) to obtain a general evaluation of uranium deposits in pre-Morrison formations particularly the Shinarump conglomerate; (2) to determine areas favorable for exploration or areas in which geologic studies are desirable; (3) to determine the distribution and habits of uranium occurrences and related features in the pre-Morrison rocks in order to outline areas favorable for ore deposits; and (4) to compare uranium deposits in pre-Morrison formations with uranium deposits in the Morrison formation in order to establish factors common to uranium deposits of the Colorado Plateau.

The study was done by the U. S. Geological Survey on behalf of the Atomic Energy Commission. This report is preliminary in nature and the ideas are presented as an hypothesis to be tested by future work.

The Triassic formations, particularly the Shinarump conglomerate, and the Jurassic Morrison formation contain most of the uranium deposits on the Colorado Plateau. Since deposits in the Morrison formation were appraised prior to 1947 by the U. S. Geological Survey, this study was concentrated

mainly on the uranium deposits of the Shinarump conglomerate. The Triassic rocks include the Moenkopi formation, the Shinarump conglomerate, and the Chinle formation.

The Lower Triassic Moenkopi formation consists of pale reddish-brown siltstone and sandstone which are horizontally-and ripple-laminated. The formation ranges from a knife-edge to about 1,000 feet in thickness, and in general it thickens to the west. Channel scours, filled with Shinarump conglomerate, have been cut into the upper Moenkopi surface. Alteration of 1 foot or more of the Moenkopi is prevalent immediately below the overlying Shinarump; in places this zone contains uranium and copper minerals near deposits in the Shinarump.

The Upper Triassic Shinarump conglomerate consists mainly of channel fillings of light-colored sandstone and conglomerate. The Shinarump although absent in places generally thickens southward. Three roughly parallel belts which reflect facies changes trending northwest are: (1) a belt of deeply-scoured channels in Monument Valley, (2) a belt of shallow-scoured channels in White Canyon and to the northwest, and (3) a belt of continuous sandstone beds north of White Canyon which trends northwest into the San Rafael Swell. The continuous sandstone beds pinch out north of the junction of the Green and Colorado Rivers. The majority of the uranium deposits are found in the Shinarump conglomerate near the edges of these facies changes.

The Upper Triassic Chinle formation consists dominantly of pale-red and variegated claystone and siltstone, with some gray limestone and sandstone beds. The formation ranges from a knife-edge to about 1,200 feet in thickness. Uranium deposits are found in the Chinle in several places, notably in the Cameron-Holbrook area, Ariz., and in the Silver Reef district, Utah.

The uranium deposits may be divided on the basis of their major metal content into vanadium-uranium, copper-uranium, and uranium types. The major minerals in the vanadium-uranium deposits consist of carnotite and tyuyamunite. The copper-uranium type of deposits are characterized by uraninite, chalcocite, covellite, and secondary copper-uranium minerals. The uranium type of deposits are usually rich in uraninite and contain few if any secondary minerals. The common gangue materials associated with nearly all of the deposits are limonite, calcite, gypsum, and carbonaceous matter.

Most of the uranium deposits are tabular bodies, irregular in plan, in which the ore minerals impregnate the rock. Carbonaceous material is commonly associated with ore. The deposits range in size from a few tons to many thousand tons.

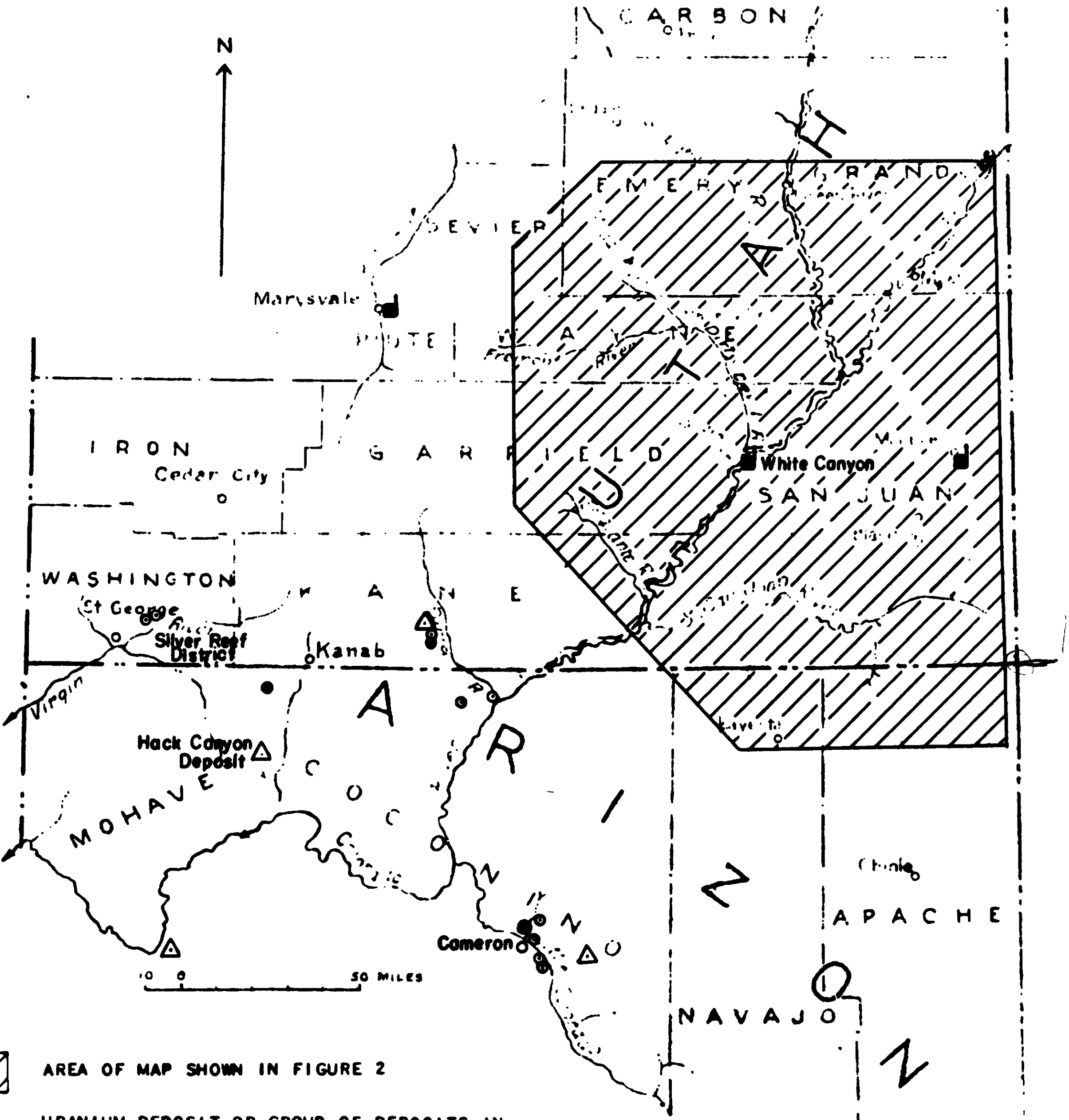
The most important guides to ore are: (1) thickening of sandstone and conglomerate beds, (2) mudstone alteration, (3) carbonaceous material, (4) iron staining, (5) clay and mudstone, and (6) sulfides. No one guide by itself is sufficient to find ore deposits. In general, uranium deposits in the Morrison and Shinarump formations have common characteristics but are dissimilar in some characteristics.

Three belts of ground favorable for containing bigger and better-than-average deposits have been roughly outlined in the region studied. One belt is formed by the alinement of significant deposits and geologically favorable ground at: (1) Temple Mountain and the southern part of the San Rafael district, (2) in the central part of the Green River district, and (3) in the Big Indian Wash area. Associated with this belt is the outcrop of a purple-white alteration band of Moenkopi and Shinarump formations. The significance of this alteration band to favorable ground is not completely understood. The other two belts of favorable ground determined by significant deposits and geologic criteria are located in the White Canyon and Monument Valley districts.

INTRODUCTION

In December 1951 the U. S. Geological Survey began a reconnaissance resource appraisal of uranium deposits in pre-Morrison formations on the Colorado Plateau and adjoining regions. This work is done on behalf of the Atomic Energy Commission. The objectives of this work are (1) to obtain a general evaluation of uranium deposits in pre-Morrison formations, particularly the Shinarump conglomerate; (2) to determine and recommend areas favorable for exploration or areas in which geologic mapping or other specialized geologic studies are desirable; (3) to determine the distribution and habits of uranium occurrences and related features in the pre-Morrison rocks in order to outline areas favorable for ore deposits; and (4) to compare uranium deposits in pre-Morrison formations with uranium deposits in the Morrison formation in order to establish factors common to uranium deposits of the Colorado Plateau.

Since deposits in the Morrison formation were studied similarly prior to 1947 by the U. S. Geological Survey, this study was concentrated mainly in the Shinarump conglomerate. Uranium deposits in pre-Morrison formations were studied and mapped in all the major uranium districts of the Colorado Plateau and outlying regions in Utah, Arizona, and New Mexico (figs. 1 and 2). Study was concentrated on deposits in the Shinarump



AREA OF MAP SHOWN IN FIGURE 2

URANIUM DEPOSIT OR GROUP OF DEPOSITS IN SHINARUMP CONGLOMERATE

URANIUM DEPOSIT OR GROUP OF DEPOSITS IN CHINLE FORMATION

URANIUM DEPOSIT OR GROUP OF DEPOSITS IN PRE-MORRISON FORMATIONS OTHER THAN SHINARUMP OR CHINLE

URANIUM MILL

Figure 1. INDEX MAP OF PART OF THE COLORADO PLATEAU, SHOWING THE AREA ILLUSTRATED IN GREATER DETAIL ON FIGURE 2 AND THE GENERAL DISTRIBUTION OF DEPOSITS OUTSIDE THAT AREA

conglomerate or lithologic units of that approximate stratigraphic position. Most of the work was of a reconnaissance nature but selected mines were mapped in detail.

GEOLOGIC SETTING

Stratigraphy

Uranium deposits occur in nearly every exposed pre-Morrison formation of the Colorado Plateau. A generalized table showing only those pre-Morrison formations containing uranium deposits is given in table 1. Sedimentary rocks older than Pennsylvanian are not exposed in the part of the Plateau studied.

A generalized section of Triassic and Jurassic rocks is given in table 2. Because Triassic rocks contain the majority of the uranium deposits in pre-Morrison formations, a brief description of Triassic rocks is given in this report. Detailed descriptions of other pre-Morrison formations may be found in the selected references listed at the end of this report.

Moenkopi formation

The Lower Triassic Moenkopi formation in most places consists of red to chocolate-brown claystone, siltstone, and fine-grained silty and clayey sandstone. Lighter-colored beds are present in some places, especially in the San Rafael Swell and in the area between the Colorado and Green Rivers. Limestone strata are present in places, such as in the San Rafael Swell, where the Sinbad limestone member is well-developed. Thin-bedded,

Table 1.—Stratigraphic distribution of uranium deposits in pre-Morrison formations of the Colorado Plateau

System	Formation	Chief metals [1]	Examples of localities
Jurassic (?)	Summerville formation	U-V	Gypsum Valley, Montrose County, Colo.
	Todilto limestone	U-V	Grants and Laguna districts, N. Mex.
	Entrada sandstone	V-U	Rifle and San Juan districts, Colo.
	Navajo sandstone	V-U	Rifle district, Colo.
	Kayenta formation	V-U	Hosteen Nez, Ariz.
	Wingate sandstone	V-U	Temple Mountain, Utah
Triassic	Chinle formation	V-U-Cu	Silver Reef district, Utah Cameron-Holbrook area, Ariz.
	Shinarump conglomerate	Cu-V-U	Eastern Utah, northeastern Ariz.
	Moenkopi formation	Cu-V-U	Associated with deposits in Shinarump
Permian	Cutler formation	V-U	Big Indian Wash, Utah
	Toroweap formation	Cu-V-U	Hack Canyon, Ariz.
	Hermosa formation	U-V	Gypsum Valley district, Colo.

[1] Probable order of abundance

TABLE 2. GENERALIZED SECTION OF TRIASSIC AND JURASSIC ROCKS OF PART OF UTAH, ARIZONA, AND SOUTHWESTERN COLORADO

SYSTEM	GROUP	FORMATION	THICKNESS (FEET)	CHARACTER AND DISTRIBUTION
JURASSIC		MORRISON FORMATION	300 - 500	BRUSHY BASIN SHALE MEMBER; VARICOLORED SHALE (OR MUDSTONE), SOME SANDSTONE LENSES; FORMS SLOPES; WIDESPREAD
			200 - 400	SALT WASH SANDSTONE MEMBER; LIGHT-COLORED SANDSTONE AND RED MUDSTONE; FORMS CLIFFS AND BENCHES; WIDESPREAD. *Carnotite-bearing*
	SAN RAFAEL GROUP	SUMMERVILLE FORMATION	0 - 400	RED AND GRAY SHALE, THIN SANDSTONE; FORMS SLOPES; THICKENS WESTWARD
		CURTIS FORMATION	0 - 250	GLAUCONITIC SANDSTONE, GREENISH SHALE, GYPSUM; PRESENT ONLY IN CENTRAL UTAH
		ENTRADA SANDSTONE	0 - 1,000	LIGHT-COLORED MASSIVE, CLIFF-FORMING SANDSTONE IN COLORADO AND EASTERN UTAH; THICKENS WESTWARD AND BECOMES RED, EARTHY SANDSTONE. *Vanadium-bearing*
		CARMEL FORMATION	0 - 600	RED EARTHY SANDSTONE IN COLORADO AND EASTERN UTAH; THICKENS WESTWARD AND BECOMES GRAY AND RED SHALE, LIMESTONE AND GYPSUM
JURASSIC(?)	GLEN CANYON GROUP	NAVAJO SANDSTONE	0 - 2,000	LIGHT-COLORED MASSIVE SANDSTONE; CLIFF-FORMING; THINS TO EXTINCTION IN WESTERN COLORADO, THICKENS WESTWARD
		KAYENTA FORMATION	0 - 300	RED SANDSTONE, IRREGULARLY BEDDED; BENCH-FORMING; ABSENT IN EASTERN PART OF REGION
		WINGATE SANDSTONE	0 - 400	RED MASSIVE SANDSTONE, CLIFF-FORMING, ABSENT IN EASTERN PART OF REGION
TRIASSIC		CHINLE FORMATION	10 - 1,200	PALE-RED VARIEGATED CLAYSTONE AND SILTSTONE, SANDY, MINOR BEDS OF DENSE LIMESTONE, THICKENS SOUTHWARD *Vanadium-bearing*
		SHINARUMP CONGLOMERATE	0 - 350	LIGHT-COLORED SANDSTONE AND CONGLOMERATE, FORMS BENCH, THICKENS SOUTHWARD, ABSENT IN PLACES *Uranium-bearing*
		MOENKOPI FORMATION	0 - 1,000	PALE REDDISH-BROWN SILTSTONE, HORIZONTALLY AND RIPPLE-LAMINATED, THICKENS WESTWARD

micaceous sandstone, and siltstone which commonly show ripple-lamination, distinguish the Moenkopi from other formations. The Moenkopi formation ranges from a knife-edge to about 1,000 feet in thickness.

The lower contact of the Moenkopi formation is unconformable in most places with the underlying Permian strata. The upper surface of the Moenkopi has been eroded by the streams which deposited the Shinarump conglomerate. These channels removed all of the Moenkopi in places. In the Monument Valley district, the streams cut through the Moenkopi into the Permian strata.

One foot or more of Moenkopi strata immediately below the overlying Shinarump conglomerate is generally altered from red or chocolate brown to gray, green, and light brown. In places uranium and copper minerals are found in the upper part of this altered zone. Secondary copper minerals are especially common along the Monekopi-Shinarump contact beneath or near uranium deposits.

Shinarump conglomerate

The Upper Triassic Shinarump conglomerate was deposited on an erosional surface developed on the Moenkopi formation. The Shinarump consists mainly of light-colored (commonly brown or gray) strata of sandstone, conglomeratic sandstone, conglomerate, siltstone, and mudstone. Conglomeratic strata are generally more common near the base of channels. Pebbles consist mainly of quartz, quartzite, chert, silicified limestone, siltstone, and sandstone. Sand grains consist mainly of quartz, feldspar, and mica. Considerable reworked Moenkopi in the form of blocks and smaller particles is found along the bottoms and edges of channels.

Mica, which is prevalent, probably originates from the Moenkopi. Fossil plant remains are common. Some of the fossil wood is silicified and some is carbonized. All or nearly all uranium deposits are in sandstone containing carbonized wood, but not all carbonized wood has uranium deposits associated with it. Most of the light brown, gray, and green mudstone of the Shinarump is thought to be altered from red mudstone.

The principal sedimentary structures over most of the region are channel fillings. Cross-stratification and irregular bedding are common within the channels. Small-scale scour-and-fill structures within main channels are common. The deeper scours are found in an irregular belt, whose northern limit trends northwestward from Monument Valley into the Circle Cliffs area. To the north and west of Monument Valley, the Shinarump is absent in an irregular belt about 10 miles wide. Adjoining this belt on the northeast is a belt in which the Shinarump conglomerate is discontinuous; where present, the Shinarump mostly fills shallow scours and it is mainly absent between these scours. This characteristic is well-developed in the White Canyon district, the area near the junction of the Dirty Devil and Colorado Rivers, and in the Capitol Reef area. North and more or less parallel to the belt of shallow channels, the Shinarump forms a continuous outcrop of variably thick sandstone in the San Rafael Swell, in the area near the junction of the Colorado and Green Rivers, and in the area north of the Abajo Mountains. This continuous ledge of Shinarump conglomerate pinches out along an east-west line north of the junction of the Colorado and Green Rivers, as shown on figure 2. The relationship of this pinchout to the uranium deposits will be discussed later.

The Shinarump conglomerate ranges from a knife-edge to about 350 feet in thickness. The maximum depth of scour observed was about 125 feet in the Hoskinnini Mesa area, Utah (fig. 2). The overlying Chinle is conformable with the Shinarump and in many places the Shinarump grades into the Chinle.

Most of the uranium deposits in pre-Morrison formations in the area covered by this report are found in the Shinarump conglomerate or at a comparable stratigraphic position. Every known deposit is in the lower third of the thicker parts of channels and lenses.

Chinle formation

The Upper Triassic Chinle formation consists mainly of pale-red, purple, gray, and green claystone, siltstone, and mudstone. Variegated beds generally predominate. Sandstone and conglomeratic sandstone form persistent ledges in places and permit subdivision of the formation into members. The members of the Chinle differ from place to place and have not been completely correlated. Minor beds of dense limestone and limestone-pebble conglomerate are found in places. Silicified wood is common and in places is radioactive. A large amount of bentonite is present in the Chinle, especially in the basal parts.

The Chinle is commonly capped by Wingate sandstone and forms a steep slope above the benches of Shinarump conglomerate. Because the Chinle seldom forms a wide outcrop, large shallow drilling areas for exploration of buried deposits in the Shinarump are generally lacking.

The Chinle formation ranges from 10 feet in thickness in one place in the San Rafael Swell to about 1,000 feet in thickness in northern Arizona. The contact with the overlying Jurassic Wingate sandstone is generally conformable, but locally an unconformity is present.

Important uranium deposits are found near the base of the Chinle in the Holbrook-Cameron area, Arizona. These deposits are found in poorly consolidated bentonitic sandstones that contain abundant amounts of charcoal-like material. These deposits may be source beds for uranium deposits in the Shinarump and older formations.

Structure and igneous rocks

The structural setting of the Colorado Plateau has been given by Luedke and Shoemaker (1952). The main structural features of the Colorado Plateau include domes and monoclinal folds with intervening basins, and normal faults. Igneous rocks of Tertiary age crop out mainly in laccolithic mountains, dikes, plugs, and flows.

No significant relationship of the uranium deposits to structural features was found. Outcrop patterns of the formations containing the uranium deposits have been controlled to a large extent by structural and igneous features. Thus, a false zoning of deposits may be conceived because of the lack of knowledge of the distribution of deeply buried deposits. Field evidence of distinct fault or fracture control of the deposits in the Shinarump is lacking. However, a few deposits, such as those in the Wingate at Temple Mountain and Richardson Basin (15 miles northeast of Moab, fig. 2) and at Roc Creek, Montrose County, Colo., exhibit fracture control.

ORE DEPOSITS

The following discussion is concerned with uranium deposits in the Shinarump conglomerate or at a comparable stratigraphic position, unless otherwise noted. Some generalities presented here may have exceptions.

Mineralogy

The mineralogy of the deposits is complex and different from place to place. Secondary minerals have developed in the oxidized zones of the deposits. The complex mineralogy is discussed in a progress report by Weeks (1952). Only the more common ore and associated minerals will be discussed in this report.

Principal uranium minerals

Uraninite has been noted at numerous localities and is now considered to be a common to rather abundant mineral in the unoxidized zones of the deposits. It occurs mainly associated with sulfides, especially chalcocite, pyrite, and covellite, and with carbonaceous material. Occurrences include minute intermixtures commonly with carbonaceous material and sulfides, sandstone impregnations, and masses up to several inches or more across.

The secondary uranium minerals formed depend upon the other elements present, especially vanadium and copper. Secondary uranium minerals include hydrous oxides, carbonates, sulfates, phosphates, arsenates, vanadates, and silicates. The most abundant secondary minerals of uranium and vanadium include carnotite and tyuyamunite, the calcium and potassium uranyl vanadates, respectively.

Vanadium and copper minerals

Several vanadium minerals, including oxides and hydrous oxides and iron-vanadium mineral species which have not been named, occur at the Monument No. 2 and Temple Mountain mines (fig. 2).

Copper minerals are common in the deposits of Shinarump and are especially abundant in the White Canyon district (fig. 3) and Circle Cliffs area (fig. 2). The common copper minerals include chalcopyrite, chalcocite, bornite, covellite, and secondary minerals such as malachite, azurite, and torbernite. Other species are found in smaller amounts in some deposits.

Other minerals

In most places oxides of iron and manganese are widespread and abundant. Hematite is more widespread and abundant in the deposits of the Shinarump than in deposits of the Morrison. Pyrite and/or marcasite are common minerals and abundant in places; they are generally associated with carbonaceous material, commonly plant remains. Galena has been observed in many places. Calcite is found along fractures and bedding planes and in many places cements the sandstone. An interstitial white clayey material which may represent altered chert, feldspar, or volcanic material is common. Gypsum is common and in places abundant on oxidized outcrops.

Types of deposits

The uranium deposits may be divided into several types according to the principal ore metals. This classification of deposits is based on the production data, which report uranium, vanadium, and copper, or on sample data where production data are lacking. In general the principal ore metals are obvious by the mineralogy, but this is not always true and care must be exercised when mineralogy alone is used to classify deposits. In this classification the ratio of the metal to uranium must be 1:1 or greater to fall into the types described.

Vanadium-uranium deposits

The vanadium-uranium type is generally considered as a carnotite-bearing deposit in the Morrison formation. This type is distributed in several areas of the Shinarump. The belt of deposits from the Monument No. 2 mine to the Whirlwind mine in Monument Valley contains principally vanadium-uranium. Minor amounts of copper are present in the deposits of this belt. Another area containing vanadium-uranium deposits is in the San Rafael district. A vanadium-rich area exists at Temple Mountain in the San Rafael district. Most of the deposits in the San Rafael district contain large amounts of carbonaceous material, commonly called "asphaltite", which for the most part masks carnotite. The "asphaltic" deposits may be considered a sub-type under vanadium-uranium deposits. The new deposits in the Big Indian Wash area, San Juan County, Utah, thought to be in the Shinarump, are of the vanadium-uranium type.

Copper-uranium deposits

The Happy Jack mine in the White Canyon district is the type example of a copper-uranium deposit. The copper minerals are commonly sulfides that have been oxidized in the weathered zones. Other copper-uranium deposits are found in the White Canyon district and elsewhere. Copper minerals are found in other types of deposits in minor amounts or as rich concentrations along certain horizons but do not attain high proportions in ore grade material. The better copper-uranium deposits contain copper sulfides, especially chalcocite and covellite. The value of the copper at the present scale of prices seldom exceeds 10 percent of the total value of the ore.

Uranium deposits

Many deposits contain only small amounts of copper and/or vanadium and can be classed as primarily uranium type deposits. Deposits of this type are unique and commonly escape detection by the prospector because there is a general lack of secondary minerals to suggest the location of the deposit. The major producing areas of this type are the Grants district, N. Mex., and the Cameron-Holbrook area, Ariz.

Habits of uranium ore deposits

Most of the uranium ore deposits are tabular, irregular in outline, and in general follow the bedding but locally cut across the bedding. The ore minerals impregnate the rock in different concentrations. Rich concentrations are generally found in logs, in sandstone containing abundant carbonaceous fragments, in carbonaceous trash, along minute fractures, and along bedding planes. Logs of rich concentrations of carnotite are found in the Monument No. 2 mine, Monument Valley, Ariz. Vertical fractures containing sulfides have been observed in the Happy

Jack mine, White Canyon district, Utah, and the Shirarump No. 1 mine, Seven Mile Canyon area, Utah. It has been noted that the poorer uranium deposits are those associated only with carbonaceous material and show little or no impregnation of uranium minerals in the rock. Although carbonaceous material is generally associated with most deposits, not all of the carbonaceous material within or near a deposit is uranium-bearing.

The size of individual ore bodies ranges from a few tons to many thousand tons apiece. Within a single area deposits differ greatly in size. In general, the average thickness of the ore zone rarely exceeds 6 feet with maximum thickness rarely over 25 feet. The minimum thickness mined is usually about 1 foot. The grade of minable material ranges from 0.10 percent U_3O_8 to over 1.00 percent U_3O_8. Thin high-grade layers account for little tonnage of deposits in the Shinarump. The lime content of the ore is variable but rarely exceeds 6 percent except in the area between the Green and Colorado Rivers.

Uranium minerals are found in all types of sediments, but sandstone, mudstone, and conglomerate predominate. In the Seven Mile Canyon area, the uranium minerals are found in limestone-pellet conglomerate and limy siltstones at the base of the Chinle or at a stratigraphic position comparable to the Shinarump conglomerate. An association of the deposits with clay beds and irregular clay masses in the Monument Valley and White Canyon districts is evident.

Alteration of the mudstone or other rocks underlying the Shinarump is widespread, but increase in thickness or degree of alteration near deposits is not evident in most places as it is with many deposits in the

Morrison. Limonite and commonly hematite are abundant in the deposits. Secondary copper is common, especially on the edges and near the base of the deposits. In the oxidized portion of the Yellow John No. 1 mine, White Canyon district, Utah, the ore body is surrounded by successive zones of limonite, secondary copper minerals, and hematite. Similar zoning of other deposits is indicated in some places. Unoxidized deposits are more common among the copper-uranium and uranium types than the vanadium-uranium type.

Guides to ore deposits

Guides to ore have been developed by other writers in several areas of detailed work in Utah and Arizona (Trites and Finnell, 1952; Trimble and Lewis, 1952; Smith et al., 1952; and Witkind et al., 1952). An attempt is made here to present the guides which are regional in nature and useful for the delineation of broad areas favorable for ore deposits. The guides are presented more or less in order of decreasing frequency of occurrence and increasing power of limiting the conditions favorable for ore deposits.

Thickening of beds

The majority of deposits are found in channels or lenses which are commonly thicker than the adjacent strata. However, great thickness is not necessarily a guide to ore; for example, the Happy Jack mine in the White Canyon district, Utah, is in a thin shallow channel or lens; whereas the thick deep channels in western Monument Valley contain no known ore deposits. The local thickening of beds favorable as host rock (dominantly sandy beds) is more important than the actual thickness of such beds. Scour is not an essential guide in parts of the San Rafael Swell for scouring at the base of the Shinarump is not conspicuous, but the sandstone beds in the Shinarump are lenticular and vary in thickness. Within a channel or lens the lower one-third, and more commonly the basal few feet, are the most favorable places for ore bodies. Not all channels or lenses contain ore deposits, so other factors must be taken into account to narrow the search.

Alteration of mudstone and underlying beds

The alteration of reddish or dark-colored rock beneath the Shinarump to brownish, greenish, or light-colored rock accompanies all ore deposits in the Shinarump conglomerate, but it is also present away from deposits. Alteration of underlying sediments is thought to be related to reactions when the Shinarump was deposited rather than resulting from reactions of the ore-bearing solutions. Unlike the alteration accompanying carnotite deposits in the Morrison formation (Weir, 1952), alteration associated with the Shinarump is too widespread to be of great help in ore-finding.

Carbonaceous material

Carbonaceous material is associated to some degree with all sandstone-type uranium deposits. No obvious relationship seems to exist, however, between the volume of carbonaceous material and the volume of uranium-bearing material. Not all of the carbonaceous material is radioactive within or near a deposit. The main types of carbonaceous material are charcoal, dull and vitreous coal, and asphalt-like material.

In the San Rafael Swell asphalt-like material proves to be an important guide to ore. However, much asphalt-like material is found outside of favorable areas and ore deposits so that this guide must be used in conjunction with other guides. If the fossil wood is mostly silicified, the channel or lens is generally barren of uranium minerals.

Other guides

1. Iron staining.--Limonite and hematite staining is common in most deposits. The Geological Survey geologists have the impression that iron staining of rocks increases in and towards deposits. A quantitative analysis of this guide needs to be made.

2. Clay and mudstone material.--Clayey material in one form or another is associated with uranium deposits throughout the entire region. This clay, which may represent altered chert, feldspar, or volcanic material, is commonly interstitial to sand grains. In the Monument Valley and White Canyon districts the channels containing more mudstone beds or irregular masses of mudstone near their base usually contain the largest and highest grade ore deposits. The mudstone may act either as physical or chemical traps for uranium minerals.

3. Sulfides.--In copper-uranium deposits, sulfides, especially copper sulfides, are an important guide to larger and higher grade ore deposits. Chalcocite and covellite are better indicators for large deposits than chalcopyrite. Chalcopyrite and pyrite are too widespread to be of much use as guides.

4. Complex mineralogy.--The presence of cobalt and phosphorous minerals may be a guide to large deposits. Many of the large deposits have a complex mineralogy whereas the small ones have few mineral species.

Comparison of uranium deposits in Shinarump and Morrison formations

The following is a tabulation of like and different characteristics observed by the writer in deposits of the Shinarump and the Morrison formations. For a complete description of deposits in the Morrison formation the reader is referred to Fischer (1942).

Deposits found in both formations:

(1) Contain abundant limonite staining and limonite coating individual grains.

(2) Contain interstitial white clay (altered chert, feldspar, or volcanic material).

(3) Are accompanied by alteration of mudstone or clays contained in and below the formations. Alteration is less important as a guide to ore in the Shinarump because alteration is more widespread and local thickening of the altered zone beneath uranium deposits is not marked in most places.

(4) Contain abundant carbonaceous material associated with the uranium minerals.

(5) Are for the most part enclosed within thicker parts of sedimentary units which thicken either as lenses or channels. The change of thickness seems to be more important than thickness as such.

(6) Are apparently controlled by permeability and porosity factors in connection with certain types of sedimentary structures.

Deposits found in the Shinarump conglomerate or in approximately the same stratigraphic position have the following characteristics which differ from those of the Morrison formation:

(1) Uranium deposits in the Shinarump are found in all types of sediments such as sandstone, conglomerate, siltstone, limestone, and shale whereas deposits in the Morrison are confined to sandstones of uniform characteristics and mudstones.

(2) Uranium-bearing rock cannot in most cases be distinguished from barren rock. This masked mineralogy presents problems in mining, prospecting, and geologic mapping. Uranium-bearing rock in the Morrison can be distinguished clearly by the contrasting color with barren rock.

(3) Uranium deposits show oxidized and unoxidized zones more clearly in the Shinarump than in the Morrison. Uraninite is more abundant and common than in the Morrison.

(4) Uranium deposits from place to place in the Shinarump conglomerate show a greater mineralogic and major element association difference, i.e., deposits may be classified as V-U, Cu-U, and U deposits. Most of the deposits in the Morrison are of the V-U type.

(5) Uranium deposits in the Shinarump conglomerate contain more visible gypsum associated with the ore than those in the Morrison.

(6) Hematite is widespread and in places more abundant in deposits of the Shinarump than in the Morrison.

DISTRIBUTION OF URANIUM DEPOSITS

Reconnaissance of uranium deposits of the Colorado Plateau permits an analysis of the distribution of significant uranium deposits in the Shinarump and the definition of favorable areas. This analysis is a preliminary working hypothesis because a limited amount of time and study have been spread thinly over a large area; and furthermore, the region has not been thoroughly prospected or developed.

Significant uranium deposits are considered in this report as those that have production or reserves of several hundred or more tons of ore-grade material or have characteristics thought to be favorable for the development of ore. The known significant deposits in the Shinarump conglomerate are clustered in areas which have in places recognizable boundaries. The favorable areas have trends which may be projected into unexplored ground. It is in these favorable belts that deposits comparable to the Monument No. 2, Happy Jack, and Temple Mountain mines are thought to exist. The validity of the proposed favorable belts may be tested by further prospecting and exploration. One scrap of evidence supports the concept of the northernmost belt for recently a new, large deposit called the Mi Vida mine, Monticello district, San Juan County, Utah (fig. 2) has been discovered approximately along the projection of the belt. In the following section a short appraisal is given of various areas based on distribution of significant deposits and geologic evidence of favorable ground.

San Rafael district, Green River district, and adjoining area to the south and east

This broad area, the San Rafael district, the Green River district, and adjoining area to the south and east (fig. 3), is considered as a unit because of the possible significance of certain relationships. The areas thought to be more favorable for the discovery of uranium of larger size and higher grade are shown in figure 2. The individual favorable areas in the central parts of the two districts and the favorable area to the east in Big Indian Wash, Monticello district, aline in east-west trend. This belt crosses many major structural features. Aside from the distribution of significant deposits, geologic data lend support to a belt of favorable ground.

An unfavorable belt in which no significant deposits have been developed lies to the south of the favorable belt. This area includes

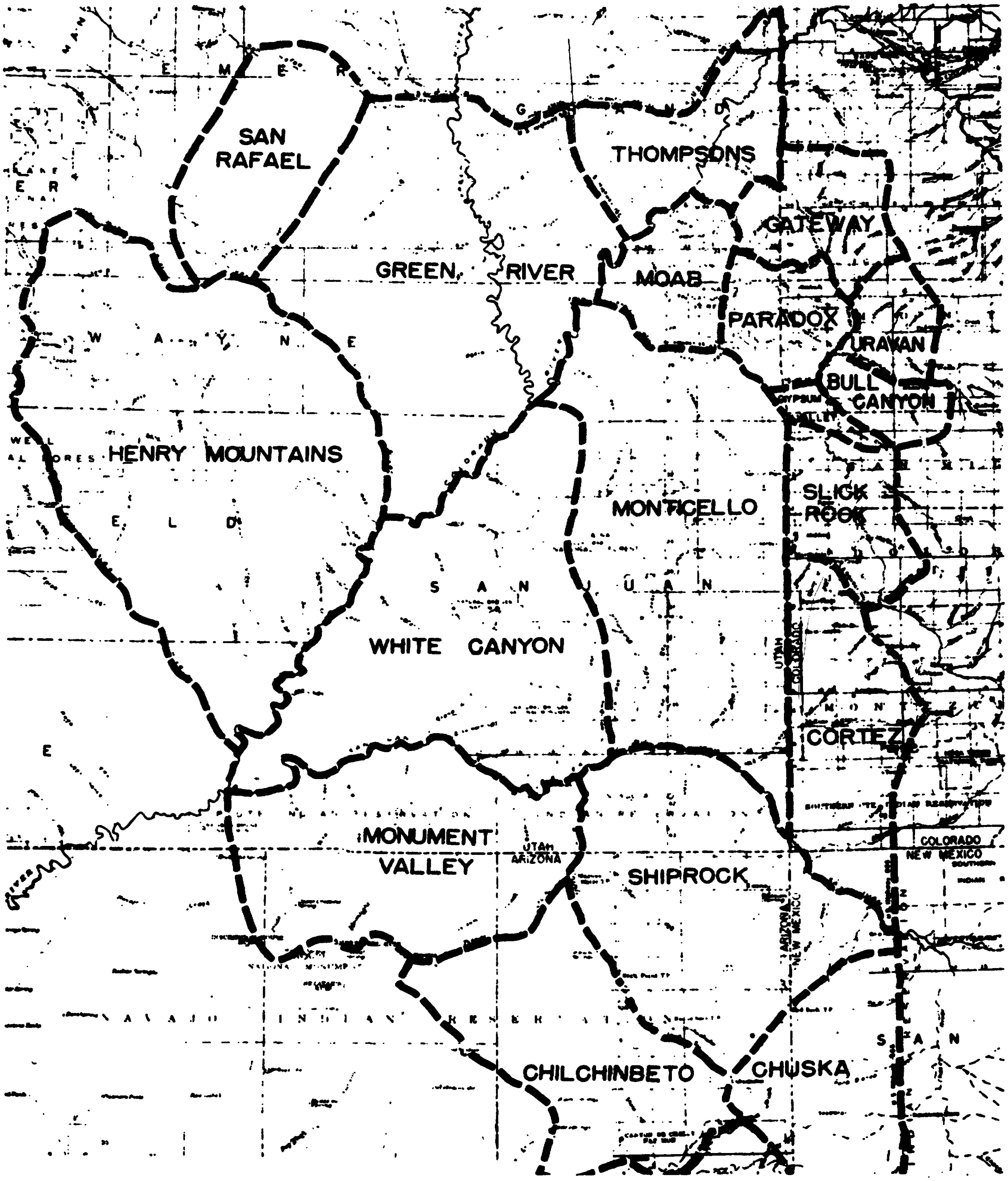


Figure 3. URANIUM MINING DISTRICTS OF THE COLORADO PLATEAU

outcrops of Shinarump conglomerate in the Capitol Reef area, areas north of the junctions of the Dirty Devil and Green Rivers with the Colorado River, and the area north of the Abajo Mountains. These areas have been extensively prospected and explored by private companies but to date only widespread low-grade uranium- and copper-bearing material has been found. The area north of the favorable area in the San Rafael Swell has not produced any significant deposits.

Faulting in the broad area defined at the beginning of this section has a predominant southeastward trend paralleling the belt. Although faulting has not been proven to have a bearing upon the uranium deposits, this observation is pointed out as possible support in connecting the favorable areas into a belt.

In the area between the Green and Colorado Rivers, a relationship seems to exist between the localization of most of the uranium deposits and the lithology of the Shinarump conglomerate (Trace Elements Research Quarterly Progress Report, 1952). McKnight's map (1940) of the inter-river area, shows a pinchout of the Shinarump conglomerate along an east-west line (fig. 2). A few isolated outcrops of Shinarump are present north of this line but were not mapped by McKnight because of the scale of his map. To date most of the uranium occurrences and all but two of the deposits thought to be significant lie north of this line. Basal alteration south of this pinchout line is slight. Field inspection of uranium deposits in this area indicates that most of the individual deposits are located at the margins of lenses and channels or where the course or conglomeratic beds pass in large part into siltstones and other finer sediments. This relation is most pronounced in the Seven Mile area, 12 miles northwest of Moab, Utah. This relation should prove useful as a guide to ore in physical exploration in the inter-river area. Because most deposits are located in less competent beds, many favorable outcrops are covered by talus. Geobotanical prospecting along these talus slopes might serve to evaluate the covered areas prior to any proposed exploration program. The pinchout if projected westward will necessarily turn northward and may be of significance for the discovery of uranium deposits under the Green River desert.

Purple-white band

A band which has a purplish-white color crops out in a belt from the west side of the San Rafael Swell eastward to the Colorado River and corresponds generally with the distribution of significant deposits. This band is not a lithologic unit but consists of altered lithologic types in the upper part of the Moenkopi formation and in the Shinarump conglomerate. In one place the zone crosses from the Moenkopi beds to a Shinarump channel. The uranium-bearing rock lies above the purple-white band within this channel. In general, the purple-white band rises stratigraphically from west to east. The band probably crosses the Shinarump-Moenkopi contact near the Green River.

The purple-white band consists of indurated beds of peculiar colors ranging from the original colors of the beds to shades of predominantly red, purple, and white as well as minor shades of yellow, brown, gray, and green. The gross color is a mottled purplish-white. The predominant minerals are hematite and limonite. Thin sections have not been studied for detailed mineralogy. No relationship exists between the spectrographic analysis of the purple-white band and uranium deposits. Rocks from this band are remarkably similar megascopically from one area to another. The band is usually tabular with sharp top and bottom boundaries but grades laterally into unaltered material. Unaltered remnants of bedded material are often found in the purple-white band.

The purple-white zone ranges in thickness from about 3 feet to 50 feet. At Temple Mountain, the purple-white band occurs as a blanket 15 to 25 feet thick only beneath the mineralized area about 10 to 20 feet below the Shinarump-Moenkopi contact. About 20 miles west of Temple Mountain the purple-white band is in contact with the channel containing the largest deposit in the area. The thickest development of the purple-white band is due east of Temple Mountain along the Colorado River. Here a 50-foot section of the purple-white band occurs in the Shinarump. Oddly enough the only deposits in the immediate vicinity are in the Wingate sandstone. The purple-white band is developed intermittently in the area between the Green and Colorado Rivers north of the pinchout of Shinarump. This band was observed locally in White Canyon and Monument Valley districts.

The cause of the relationship, if any, of the purple-white band to the deposits is not clear. It may be related to a ground-water table during Triassic time and have no relation to the deposits. Again it might be related to faulting, or to pathways of ore-bearing solutions, or the result of some other phenomenon. The significance is that the band seems to have an areal distribution that corresponds more or less to the distribution of significant uranium deposits.

White Canyon district

The significant deposits in the White Canyon district fall into two areas about 10 miles apart. The Happy Jack mine stands out by itself in a small area in the western part of White Canyon. The remainder of the significant deposits falls into a narrow belt which extends northeast across the heads of Red and White Canyons to Elk Ridge. The boundaries of this favorable area are well-defined in most places but erosion has removed the ore-bearing beds in places. The favorable area is from 2 to 8 miles wide and trends northeast toward the Abajo Mountains. The trend of the faulting and fracturing in the area is northeast. In general, the ore-bearing channels trend in a northeasterly direction. This favorable area is less regional in character than the one in the San Rafael and Green River districts and may prove to be part of a larger belt of ore deposits which would trend east-west and extend into the Circle Cliffs area. The deposits in this larger belt are of the copper-uranium type. The Circle Cliffs area which contains few known significant deposits has not been fully developed because of the lack of roads. Between the White Canyon and the Monument Valley districts the Shinarump is absent in most of the area, and where present does not contain any known uranium deposits.

Monument Valley district

The uranium deposits in Monument Valley are zoned according to their type and economic significance. The significant deposits fall in an arcuate belt, with a well defined boundary on the south and west, from the Monument

No. 2 mine on the east to the Whirlwind mine on the San Juan River on the north. The deposits are of the vanadium-uranium type. Most of the deposits to the south and west are of the copper-uranium type and thus far have not proved to be significant. Channels in the Shinarump in western Monument Valley contain exposures of secondary uranium and copper minerals which probably have precipitated from present-day circulating ground water. This secondary efflorescence may originate from buried deposits or from the general uranium content of the Shinarump conglomerate. The latter idea is favored by the writer.

It is interesting to note that the Temple Mountain mines, Happy Jack mine, and Monument No. 2 mine lie roughly along a straight line. With the present state of knowledge one cannot speculate as to the significance of this observation.

Other areas

Uranium deposits are found in the Shinarump and other pre-Morrison formations in areas outside of those described on the preceding pages (fig. 1). The author has noted no particular zoning of significant deposits in the outlying areas except for a hint of an east-west belt based on widely spaced points of uranium deposits from Grants-Laguna district, N. Mex., to Cameron-Holbrook areas, Ariz., and west to Silver Reef district, Utah. In Colorado scattered uranium deposits of only slight importance occur in rocks of various ages older than Morrison. Vanadium deposits occur in the Entrada sandstone in San Juan and Rifle districts in Colorado but these contain little uranium (Bush and Bryner, 1953).

The most important new area discovered late in 1952 extends from north of Cameron to Holbrook, Ariz. In the Paria River area north of Cameron only minor amounts of uranium have been found. The larger deposits are located near Cameron and Holbrook. All these deposits are near the base of the Chinle formation. The deposits are similar, and occur in unconsolidated beds of bentonite. These beds contain abundant amounts of charcoal-like material and some coarse sand grains. The deposits contain minor amounts of vanadium and copper. A characteristic brown alteration of the beds accompanies all deposits but not all similarly altered areas contain deposits. This area is not sufficiently developed to predict trends at this writing.

LITERATURE CITED

Fischer, R. P., 1942, Vanadium deposits of Colorado and Utah, a preliminary report: U. S. Geol. Survey Bull. 936-P, pp. 363-394.

McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 908.

Weir, D. B., 1952, Geologic guides to prospecting for carnotite deposits on the Colorado Plateau: U. S. Geol. Survey Bull. 988-B, pp. 15-27.

UNPUBLISHED REPORTS

Bush, A. L., and Bryner, Leonid, 1953, Preliminary report on the uranium and vanadium resources of the Entrada sandstone, western San Juan Mountains, Colorado: U. S. Geol. Survey Trace Elements Memo. Rept. 298.

Luedke, R. G., and Shoemaker, E. M., 1952, Tectonic map of the Colorado Plateau: U. S. Geol. Survey Trace Elements Memo. Rept. 301.

Smith, J. F., Jr.; Hinrichs, E. N.; Huff, L. C.; and Luedke, R. G., 1952, Preliminary report on geologic studies in the Capitol Reef area, Wayne County, Utah: U. S. Geol. Survey Trace Elements Memo. Rept. 538.

Trimble, D. E., and Lewis, R. Q., Sr., 1952, Preliminary report on geologic studies in Monument Valley, San Juan County, Utah: U. S. Geol. Survey Trace Elements Memo. Rept. 535.

Trites, A. F., and Finnell, T. L., 1952, Preliminary report on geologic investigations in White Canyon, San Juan County, Utah: U. S. Geol. Survey Trace Elements Memo. Rept. 540.

Weeks, A. D., 1952, Summary report on mineralogic studies of the Colorado Plateau through April 30, 1952: U. S. Geol. Survey Trace Elements Memo. Rept. 431.

Witkind, I. J.; Thaden, R. W.; and Lough, C. F., 1952, Preliminary report on geologic investigations in Monument Valley area, Arizona: U. S. Geol. Survey Trace Elements Memo. Rept. 536.

Trace Elements Research Quarterly Progress Report, 1952: U. S. Geol. Survey Trace Elements Inv. Rept. 280.

SELECTED REFERENCES

Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841.

Baker, A. A., 1935, Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U. S. Geol. Survey Bull. 865.

Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent areas, Grand County, Utah: U. S. Geol. Survey Bull. 863.

Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806-C, pp. 69-130.

Gregory, H. E., 1938, The San Juan country, a geographic and geologic reconnaissance of southeastern Utah: U. S. Geol. Survey Prof. Paper 188.

Gregory, H. E., and Moore, R. E., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U. S. Geol. Survey Prof. Paper 164.