Selected Annotated Bibliography of the Geology of Sandstone-type Uranium Deposits in the United States

GEOLOGICAL SURVEY BULLETIN 1059-C

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Selected Annotated Bibliography of the Geology of Sandstone-type Uranium Deposits in the United States

By ROBERT E. MELIN

SELECTED BIBLIOGRAPHIES OF URANIUM GEOLOGY

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INTRODUCTION

Uranium is a vital and strategic metal in modern civilization. A large and steady supply of the fissionable material is essential to the use of atomic energy whether for peaceful or military purposes.

Today, uranium is mined in the United States principally from sandstone-type deposits such as those on the Colorado Plateau. In other parts of the world most uranium is mined from conglomerates as in the Witwatersrand of South Africa and the Blind River area of Ontario, Canada, and from vein-type deposits as at Shinkolobwe, Belgian Congo; Joachimsthal, Czechoslovakia; and at Great Bear Lake and Lake Athabaska in northern Canada.

Sandstone-type deposits of uranium and other metals are disseminated in continental sedimentary clastic rocks, and are localized primarily by stratigraphic rather than structural controls. The principal domestic source of uranium has been from sandstone-type uranium deposits on the Colorado Plateau where the bulk of uranium ore has been produced from the Chinle formation (Shinarump[1] and sandstone members) of Triassic age and the Morrison formation of Jurassic age. These ores were mined first for radium, later for vanadium, and finally for uranium. Summaries of the geology of these deposits are given in reports by Fischer (1937, 1942, 1950, and 1955), Hess (1933), and Coffin (1921).

[1] The Shinarump member of the Chinle formation now includes the strata formerly known as the Shinarump conglomerate.

U. S. Geological Survey Map MR 2, by R. W. Schnabel (1955), shows the location of the more important uranium deposits in the United States, and U. S. Geological Survey Map MF 16, by W. I. Finch (1955), shows the location of deposits and occurrences of uranium on the Colorado Plateau.

The U. S. Geological Survey Bulletin 1030-A, "Search for uranium in the United States," by V. E. McKelvey (1955), is a report on the search for, and study of, uranium deposits and uraniferous rocks in the United States. The geology of many types of uranium deposits is reviewed, and the locations of the different types of deposits are indicated on small-scale base maps of the United States.

Irwin S. Parrish assisted the author in the compilation of the indexes and reviewed the entire report.

This compilation was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

EXPLANATION OF THE BIBLIOGRAPHY

The annotations in this bibliography are of selected reports that relate to the geology of sandstone-type uranium deposits in the United States that were available on June 30, 1955. Also included are pertinent reports contributed to the International Conference on Peaceful Uses of Atomic Energy, August 1955, at Geneva, Switzerland; these reports were published in 1956 by the United Nations as volume 6, "Geology of uranium and thorium," and were among those published by the U. S. Geological Survey as Professional Paper 300, "Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955."

The annotated reports have been selected on the basis of permanent value or interest. Because the Colorado Plateau is the center of the uranium mining industry in the United States, certain reports on the stratigraphy, structure, and general geology of parts of the Colorado Plateau have been included even though the discussions are not related directly to uranium deposits.

The annotations are arranged alphabetically by author; if an author has written more than one report, the reports are listed chronologically. Co-authors are indexed alphabetically under "Authors." The annotations are numbered consecutively for purposes of indexing.

The alphabetical indexes are an author index; a subject index;

a geographical index of localities mentioned in the reports; and an index of formations. The numbers after each entry in an index correspond to the reference number. The index map shows the location of most areas mentioned in the annotations.

Geologic names listed are those of the various authors and do not necessarily follow the usage of the U. S. Geological Survey.

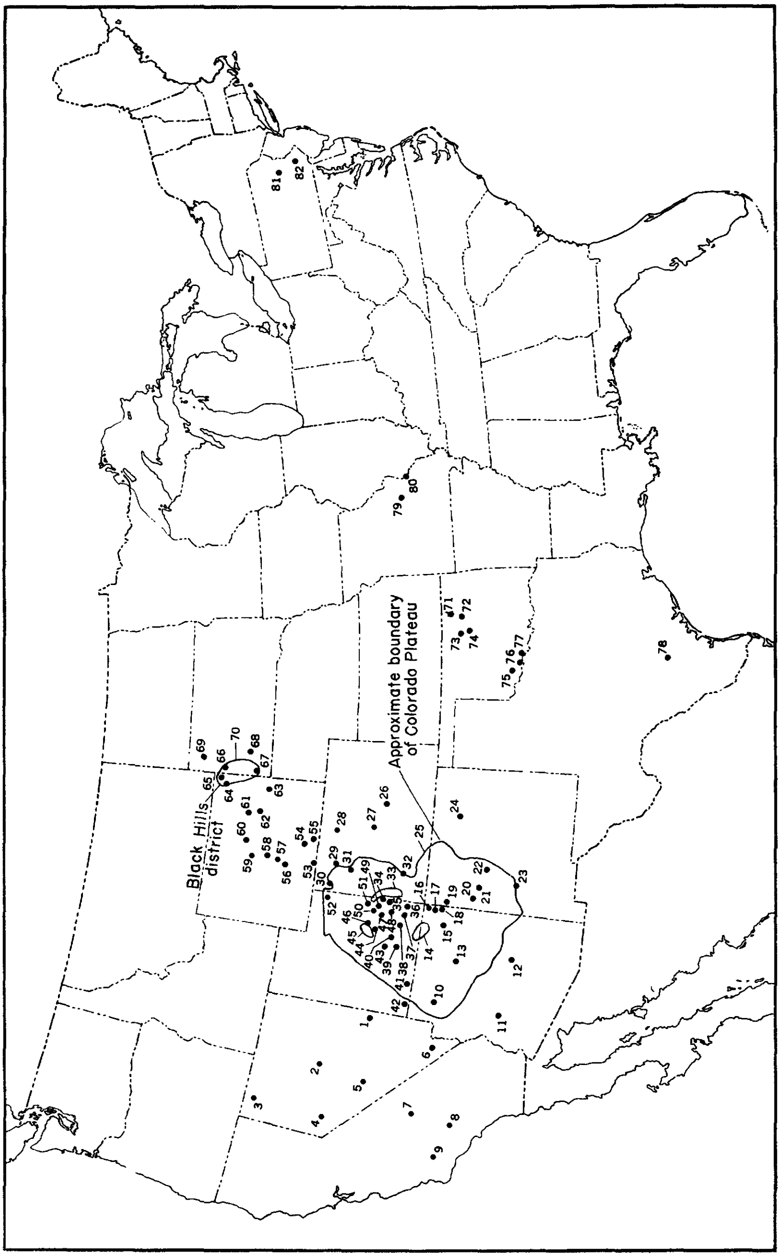

FIGURE 4. — Index map of the United States showing the location of uranium-bearing sandstones by deposits, groups of deposits, and districts. For annotations concerning these localities see the geographic index.

Localities shown in figure 4

Hawthorne area, Lincoln County, Nev.	1
Lander County, Nev.	2
Virgin Valley opal district	3
Lyon County, Nev.	4
Tonopah area, Esmeralda County, Nev.	5
Clark County, Nev.	6
Olancha, Calif.	7
Rosamond prospect	8
Taft-McKittrick area	9
Ridenour mine	10
Aguila area	11
Red Bluff prospect	12
Cameron area	13
Monument Valley (includes Copper Canyon, Hunts Mesa, Nokai Mesa, Hoskinnini Mesa and Monument No. 1, Monument No. 2, Skyline and Whirlwind mines)	14
Black Mesa	15
Carrizo Mountains area	16
Chuska Mountains, Red Rock district and Lukachukai Mountains areas (includes Mesa V, Mesa VI, and Mesa VII mines)	17
Cove Mesa and Kinusta Mesa areas	18
Sanastee area, Grants district	19
Becenti, Butler, Diamond 2, and Hogback 4 mines, Grants district	20
Dakota, Silver Spur, Small Stake, and Section 9 mines, Grants district	21
Jackpile and Woodrow mines, Grants district	22
Datil area	23
Guadalupita — Coyote district	24
Colordo Plateau	25
Mike Doyle prospect	26
Shirley May Mine	27
Lucky Strike claim, Troublesome Creek area	28
Meeker area	29
Skull Creek area	30
Rifle and Garfield mines	31
Graysill mine, Placerville area	32
Uravan mineral belt (includes Atkinson Creek quadrangle, Bull Canyon quadrangle, Egnar-Gypsum Valley quadrangle, Gateway area, Long Park, Paradox Valley, Pine Mountain quadrangle, Roc Creek and Uravan district)	33
La Sal Creek and Wray Mesa (includes Gray Dawn mine)	34
Big Indian Wash — Lisbon Valley area (includes Mi Vida mine, Big Buck mine, Purple Paint claim, and Small Fry Claim)	35
Montezuma Canyon	36
Blanding district	37
Happy Jack mine, White Canyon district	38
Circle Cliffs area (includes Hot Shot and Yellow Jacket mines)	39
Trachyte district, Henry Mountains	40
Bulloch group	41
Silver Reef (Harrisburg) district, (includes Chloride Chief and Silver Point claims)	42
Capitol Reef (includes Oyler mine, Fruita area)	43
Little Wild Horse Mesa	44
San Rafael Swell (includes Brown Throne, Clifford Smith, Dalton, Dirty Devil, Dolly, Green Vein, Hard Pan, Hertz, Lone Tree, Pay Day, South Fork, and Wickiup claims, and Temple Mountain district)	45
Area southwest of Green River	46
"C" Group	47
Indian Creek — Lockhart Canyon area	48
Richardson area, Moab district	49
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Miller Hill area	54
Saratoga area	55
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Gas Hills area, Wind River Basin	58
Lysite — McComb area, Wind River Basin	59
Mayoworth area	60
Pumpkin Buttes area, Powder River Basin	61
Converse County (Powder River Basin)	62
Lance Creek area	63
Carlile area	64
Aladdin area	65
Belle Fourche area	66
Edgemont district (includes Craven Canyon and Gould lease)	67
White River Badlands	68
Cedar Canyon	69
Black Hills	70
Osage County, Okla.	71
Pawnee County, Okla.	72
Noble County, Okla.	73
Payne County, Okla.	74
Tillman County, Okla.	75
Cotton County, Okla.	76
Jefferson County, Okla.	77
Karnes County, Texas	78
Franklin County, Mo.	79
Sainte Genevieve County, Mo.	80
Jim Thorpe area, Carbon County, Pa.	81
Bucks County, Pa., and Hunterdon County, N. J.	82

BIBLIOGRAPHIES OF URANIUM

Bibliographies that contain additional references to sandstone-type uranium deposits are listed below:

Allen, R. E., 1953, Uranium and its compounds, a bibliography of unclassified literature: U. S. Atomic Energy Comm. TID-3041, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Cooper, Margaret, 1953, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States — Part 1, Arizona, Nevada, and New Mexico: Geol. Soc. America Bull., v. 64, no. 2, p. 197-234.

Cooper, Margaret, 1953, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States — Part 2, California, Idaho, Montana, Oregon, Washington, and Wyoming: Geol. Soc. America Bull., v. 64, no. 10, p. 1103-1172.

Cooper, Margaret, 1954, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States — Part 3, Colorado and Utah: Geol. Soc. America Bull., v. 65, no. 6, p. 467-590.

Cooper, Margaret, 1955, Bibliography and index of literature on uranium and thorium and radioactive occurrences in the United States — Part 4, Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas: Geol. Soc. America Bull., v. 66, no. 3, p. 257-326.

Cooper, Margaret, 1953, Selected bibliography on uranium exploration and the geology of uranium deposits: U. S. Atomic Energy Comm. RME-4007, issued by U. S. Atomic Energy Comm. Tech Inf. Service, Oak Ridge, Tenn.

Postell, P. E., and Voress, H. E., 1953, Unclassified bibliographies of interest to the atomic energy program: U. S. Atomic Energy Comm. TID-3043, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Wallace, J. H., and Smith, H. B., 1955, Bibliography of U. S. Geological Survey trace elements and related reports to June 1, 1954: U. S. Geol. Survey Bull. 1019-B, p. 63-144.

ANNOTATED BIBLIOGRAPHY

1 Anderson, E. C., 1955, Occurrences of uranium ores in New Mexico: N. Mex. Bur. Mines and Min. Res. Circ. 29, 38 p.

This publication is a directory of the uranium mines and prospects in New Mexico. The name, location, and ownership of the mines and prospects are given, and the lithology and host formation of each are indicated. The mines and prospects are indicated on a map of New Mexico at a scale of about 1:2,500,000. Occurrences in a number of counties are reported, and uranium minerals and guides to ore are listed.

2 Argall, G. O., Jr., 1943, The occurrences and production of vanadium: Colo. School Mines Quart., v. 38, no. 4, 56 p.

This paper is a comprehensive study of vanadium, with emphasis upon the vanadium deposits of the Colorado Plateau. It describes the history, uses, production, occurrence, mining, and milling of vanadium and its ores. Because carnotite, one of the most important vanadium minerals in the deposits on the Colorado Plateau, also contains uranium, this report refers in part to uranium. The deposits occur mostly in sandstone of the Shinarump conglomerate of Triassic age and the Entrada and Morrison formations of Jurassic age. The widely scattered ore bodies form irregularly tabular masses that lie almost parallel to the sandstone beds, but do not coincide with the beds in detail. The ore occurs in lenses, flat tabular bodies, in well-defined channels, in rolls, and as zones of ore surrounding trees whose original constitutients have been replaced by silica or calcite or both.

The vanadium is recovered from carnotite by roasting the crushed ore with common salt in order to convert the vanadium to a water-soluble sodium vanadate. The calcine is then leached with water, and the vanadium is precipitated from solution by adjustment of the pH. Variations of this process are used for different types of sandstone ore. If the ore contains more than 6 percent of lime it is neutralized with acid before roasting.

An extensive bibliography on vanadium is included.

3 Argall, G. O., Jr., 1954, Why Anaconda's uranium mines are unique: Min. World, v. 16, no. 10, p. 54-59.

This report outlines the exploration and mining procedures used by the Anaconda Copper Mining Company in its uranium operations in the Grants district, New Mexico. The ore body at the Jackpile mine is in the Westwater Canyon member of the Morrison formation of Jurassic age, and is partly overlain by and partly cut by a post-ore diabase sill that is from 3 to 7 feet thick. The deposit is being mined by open-pit methods. The uranium deposit at the Woodrow mine occurs in the Morrison formation in a "ring fault" or "breccia pipe." The structure has the shape of an upright though slightly tilted cone with a diameter of about 30 feet at the surface. The central part has apparently dropped about 15 feet. The ore minerals, which are principally uraninite and coffinite, are associated with pyrite and asphaltic material.

4 Bain, G. W., 1950, Geology of the fissionable materials: Econ. Geology, v. 45, no. 4, p. 273-323.

Mineralogic and geologic characteristics of deposits of uranium and thorium are discussed. Occurrences are classified under primary or hypogene types, sedimentary or bedded deposits, and oxidized bodies. Primary deposits are now the principal source of supply, but all varieties of sedimentary occurrences give promise of large sustained production. Geology and resources of producing areas or potentially producing areas of the world are reviewed.

5 Bain, G. W., 1952, Uranium deposits in southwestern Colorado Plateau: U. S. Atomic Energy Comm. RMO-982(rev.) 59 p. issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Part of the southwestern Colorado Plateau was studied to test results from experimental simulation of Colorado Plateau-type uranium deposits. The sedimentation pattern of the Shinarump conglomerate of Triassic age and the ore occurrences conform to laboratory experiments.

Almost all the uranium in the Shinarump is in a jasperoid conglomerate in the lowest part of ancient stream channels. Bain asserts that the uranium was originally contained in the jasperoid pebbles.

The deposits can be geographically zoned on the basis of their mineralogic character into an eastern vanadium-excessive zone, a central vanadium-sufficient zone, and a western and southern vanadium-deficient zone.

Many mines, prospects, and occurrences are described, including the Graysill mine near Placerville, Colo., the Monument No. 1, Monument No. 2, Skyline, and Whirlwind mines in the Monument Valley district, and the Yellow Jacket and Hot Shot mines in the Circle Cliffs area. The Graysill mine is a vanadium deposit in the Entrada formation of Jurassic age, and the other mines are uranium or vanadium-uranium deposits in channel sediments of the Shinarump.

6 Bain, G. W., 1952, Uranium in the Dirty Devil Shinarump channel deposit: U. S. Atomic Energy Comm. RMO-66, 40 p. issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium occurs in the Shinarump conglomerate of Triassic age at the Dirty Devil No. 6 mine, Emery County, Utah. The deposit is in conglomeratic sediments which fill a channel cut into the underlying Moenkopi formation of Triassic age. Although carnotite and tyuyamunite are present, hydrocarbons apparently contain most of the uranium. Base-metal sulfides also are present. Bain suggests that the uranium in the deposit was derived from jasperoid pebbles in the Triassic river gravels, and that the pebbles were derived from a leptothermal uranium deposit.

7 Baker, A. A., 1933, Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 841, 95 p.

Exposed sedimentary formations in the Moab district range in age from Early Pennsylvanian to Late Cretaceous. Rock types include evaporites, limestone, shale, mudstone, sandstone, arkose, and conglomerate. One small igneous plug is present. The beds have been folded into low anticlines and shallow synclines during several periods of deformation. Some of this deformation is due to the intrusion of salt plugs. The beds are cut by numerous small normal faults. The report includes a geologic map and a geologic structure map of the area at a scale of 1:62,500.

Disseminated deposits of uranium and vanadium minerals in the area are irregularly distributed in the Salt Wash sandstone member of the Morrison formation of Jurassic age.

8 Baker, A. A., 1935, Geologic structure of southeastern Utah: Am. Assoc. Petroleum Geologists Bull., v. 19, no. 10, p. 1472-1507.

Southeastern Utah, lying within the Colorado Plateau, is characterized by several types of structural features, including (a) huge asymmetrical upwarps, (b) domes associated with laccolithic intrusions, (c) the southern edge of the Uinta Basin structural depression, (d) a north-trending zone of normal faults at the west edge of the Plateau, and (e) a group of numerous folds, faults, and faulted folds that are found in a limited area near Moab. Folding has occurred in the region several times since the end of the Mississippian, but the principal deformation that is reflected in the structure of the surface rocks took place at the end of the Cretaceous or early in the Tertiary and, therefore, was related to the Laramide orogeny. The large domical uplifts have a northerly trend and are strongly asymmetric, with the steep limb toward the east; they were formed at the end of the Cretaceous, possibly as a reflection in the surface rocks of more or less vertical uplifting along deep-seated reverse faults. The group of numerous smaller folds, faults, and faulted anticlines in the part of the region near Maob also is belived to have been formed near the end of the Cretaceous; the deformation is obviously related to the presence of the plastic salt-bearing beds of the Pennsylvanian Paradox formation beneath the surface rocks, because the structural features of this type near Moab are typically developed only within the area underlain by the Paradox formation and because the salt-bearing beds have been intruded into the overlying rocks at the crests of some of the folds. Events in the Tertiary structural history of the region include the intrusion of igneous rocks in four isolated mountain groups, the downwarping of the Uinta Basin, and the development of the zone of normal faults at the west edge of the plateau; it is not possible to determine the order of these events, or to determine whether they represent different modes of expression of one period of crustal disturbance. — *Author's abstract*

9 Baker, A. A., 1936, Geology of the Monument Valley, Navajo Mountain region, San Juan County, Utah: U. S. Geol. Survey Bull. 865, 106 p.

The geology of an area in southeastern Utah is described. Exposed sedimentary formations range in age from Pennsylvanian to Quaternary, have an aggregate average thickness of about 8,000 feet, and most are of continental origin. Small volcanic necks and dikes of Tertiary age crop out at three places. The principal geological structure is a gentle westerly dip off of the Monument upwarp, but this is interrupted by several small transverse folds and the large dome of Navajo Mountain. The report includes a geologic map of the area at a scale of 1 : 96,000.

Small copper deposits (and more recently uranium deposits) have been found in this area in the Shinarump conglomerate of Triassic age.

10 Baker, A. A., 1946, Geology of the Green River Desert, Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U. S. Geol. Survey Bull. 951, 122 p.

Exposed formations in this region range in age from Pennsylvanian to Late Cretaceous and have an aggregate thickness of about 6,500 feet. The rocks consist of interbedded marine and continental sedimentary formations; the formations are described. The most conspicuous structural feature in the area is the steeply dipping monocline along the east side of the San Rafael Swell. The southern part of the area includes part of the gently dipping northern end of the Monument upwarp. The rocks are broken by numerous small normal faults, of which most have small displacements. The report includes a geologic map and a structural geologic map of the region at a scale of 1 : 62,500.

Uranium and vanadium deposits in the area include those at Temple Mountain in the Shinarump conglomerate of Triassic age and those southwest of Green River, which are in the Salt Wash member of the Morrison formation of Jurassic age.

11 Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1936, Correlation of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 183, 66 p.

Jurassic formations on the Colorado Plateau and adjacent areas are described, redefined, and correlated. The rock units are subdivided into the Glen Canyon group (Wingate sandstone, Kayenta formation, Navajo sandstone), the San Rafael group (Carmel formation, Entrada sandstone, Curtis formation, Summerville formation), and the Morrison formation. Ten series of columnar sections are presented and discussed, the distribution and thickness of the formations are shown, and the conditions of deposition are interpreted.

12 Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., 1947, Revised correlations of Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 9, p. 1664-1668.

The authors have modified the correlations proposed in their paper of 1936. The most important change concerns the Wingate and Entrada sandstones. The Wingate sandstone at its type locality at Fort Wingate, N. Mex., is now correlated with the Entrada. It is proposed that the name Wingate be retained for the sandstone forming the lower part of the Glen Canyon group, with the understanding that the original type locality of the Wingate be abandoned.

13 Bales, W. E., Bell, Henry, and Wilmarth, V. R., 1953, Uranium-vanadium deposits near Edgemont, Fall River County, S. Dak., [abs.]: Geol. Soc. America Bull., v. 64, no. 12, p. 1540.

Uranium and vanadium minerals were found near Edgemont, Fall River County, in the southern part of the Black Hills, South Dakota, in the Lakota and Fall River sandstones of the Inyan Kara group

(Early Cretaceous). Uranium occurrences are known in the Deadwood formation and Minnelusa sandstone (Paleozoic) and have been reported from the Pierre shale (Late Cretaceous). Most high-grade deposits are in an area of approximately 20 square miles on the gently dipping southwest flank of the Black Hills uplift. Minor northward-trending anticlines lie east and west of the known mineralized area. These folds may be related to northward-trending shear zones of complex structure in the Precambrian rocks that crop out about 10 miles to the north.

The ore bodies apparently were localized by (1) thin bedding rather than massiveness of the sandstone beds, (2) local changes in dip, (3) minor faults, and (4) fracture zones.

The ore minerals are carnotite, tyuyamunite, rauvite(?), hewettite, metahewettite, autunite, and other unidentified uranium minerals. They form fracture fillings and disseminations through sandstones and shales, with a gangue of calcite, gypsum, and limonite.

Geologic guides useful in prospecting for uranium in the Edgemont area are (1) a brick-red staining of the sandstone near deposits of uranium and vanadium minerals, (2) abrupt, local changes of dip, (3) thin-bedded — rather than thick-bedded — sandstone, (4) abundant organic material in sedimentary rocks, and (5) proximity to northward-trending fracture zones. — *Authors' abstract*

14 Barrett, D. C., 1953, Preliminary report of reconnaissance in the Bighorn Basin, north-central Wyoming and south-central Montana: U. S. Atomic Energy Comm. RME-4027, 19 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Airborne and ground reconnaissance for uranium was conducted in the Bighorn Basin. No occurrences of economic importance were found. Sedimentary rocks ranging in age from Cambrian to lower Tertiary are exposed in the structural and topographic Bighorn Basin. Small occurrences of uranium were found in the Flathead sandstone of Cambrian age, the Chugwater formation of Triassic age, the Morrison and Cloverly formations of Jurassic and Cretaceous age, the Frontier and Mesaverde formations of Cretaceous age, and in the Wasatch formation of Eocene age.

15 Behre, C. H., Jr., and Barton, P. B., Jr., 1953, Progress report on interpretation and valuation of uranium occurrences in the Bird Spring and adjacent mining districts, Nevada: U. S. Atomic Energy Comm. RME-3057, 7 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium occurrences in the Bird Spring and Spring Mountain Ranges, Clark County, Nev., are regionally and structurally of three types: (1) along fractures in a sandy zone in the Kaibab formation of Permian age; (2) in fractures and cement of Tertiary lavas, tuffs, and gravels and the immediately underlying Paleozoic rocks; and (3) in the oxidized parts of cupiferous and ferruginous fissure veins and replacement deposits. None of these occurrences is economically important.

16 Behre, C. H., Jr., and Barton, P. B., Jr., 1954, Interpretation and valuation of uranium occurrences in the Bird Spring and adjacent mining districts, Nevada: U. S. Atomic Energy Comm. RME-3091, 35 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium occurrences in the region southwest of Las Vegas, Clark County, Nev., are of two types: (1) those associated with base-metal vein deposits and (2) those occurring as superficial near-surface disseminations and fracture coatings.

Small deposits of the second type are distributed widely in the area in Tertiary(?) tuffs and gravels and in Pennsylvanian and Permian sedimentary rocks. The uranium was probably derived from tuffs formerly overlying the area. Most of the occurrences are in cuts along the railroad, and none has present economic significance.

The uranium deposits in the base-metal mines are also described. These may have a different origin from the second type of deposits, and they merit further study.

17 Bell, Henry, 3d, Gott, G. B., Post, E. V., and Schnabel, R. W., 1956, Lithologic, structural, and geochemical controls of uranium deposition in the southern Black Hills, South Dakota: U. S. Geol. Survey Prof. Paper 300, p. 345-349; Geology of uranium and thorium, United Nations, v. 6, p. 407-411.

The uranium deposits in the southern part of the Black Hills in South Dakota occur in non-marine sandstone beds in the Inyan Kara group of Early Cretaceous age. The rocks in the area dip generally southward away from the Black Hills uplift. The principal ore minerals are carnotite and tyuyamunite; lesser amounts of corvusite and rauvite are present. Factors that influenced the localization of the uranium deposits include the lithologic, structural, and geochemical environments.

Uranium deposits have been found in three types of sandstone. They are a fine-grained sandstone, generally less than 5 feet thick, interbedded with laminated carbonaceous siltstone; a thick cross-bedded noncarbonaceous sandstone, generally fine-to medium-grained, with many scour and fill structures; and lenses of fine-grained homogeneous sandstone separated by thin beds of mudstone.

Uranium deposits are most numerous in areas of abrupt changes in dip or in areas where abnormally low dips coincide with favorable lithologies. Most of the deposits have a halo of purplish-pink iron oxide stain, and, in a few deposits, a spatial relationship exists between carbonate-cemented sandstone and uranium minerals.

18 Benson, W. E., Trites, A. F., Jr., Beroni, E. P., and Feager, J. A., 1952, Preliminary report on the White Canyon area, San Juan County, Utah: U. S. Geol. Survey Circ. 217, 10 p.

Copper-uranium deposits in the White Canyon area in southeast Utah occur mostly in the Shinarump conglomerate of Triassic age, but some have also been found in the Moenkopi and Chinle formations, also of Triassic age. More than 2,000 feet of sedimentary rocks that range in age from Carboniferous to Jurassic(?) are present. The regional dip is 1°-2° SW., and jointing is prominent in some places. The Shinarump conglomerate consists of lenticular beds of sandstone, conglomeratic sandstone, clay, and siltstone. Plant remains are common in the rocks that fill channels cut into the underlying Moenkopi formation. The thickness of the Shinarump conglomerate ranges from a feather edge up to 75 feet. The largest concentrations of copper and uranium minerals occur in the lower part of the Shinarump conglomerate and seem to be controlled by ancient channel fills, fractures, and by carbonaceous material and clay. Unoxidized minerals include pitchblende and base-metal sulfides; oxidized copper and uranium minerals are found near the outcrops. The origin of the deposits is not known but is thought by the authors to be hydrothermal. The age of pitchblende from the Happy Jack mine, determined by the lead-uranium method, is 55 to 60 million years.

19 Beroni, E. P., 1954, Permian red-bed deposits, southwestern Oklahoma; *in* Geological investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 213-216, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The most promising uranium-bearing localities in Oklahoma are in the Permian Red Beds in Tillman, Cotton, and Jefferson Counties. At a property in Cotton County a uranium-bearing zone about 25 feet long and 2 to 4 feet thick is in a sandstone lens about 300 feet wide, 25 feet thick and 600 feet long. The lens projects about 10 feet into the underlying rocks, and the mineralized zone is in this lower 10 feet.

20 Beroni, E. P., and King, R. U., 1952, The Mike Doyle carnotite deposit, El Paso County, Colo.: U. S. Geol. Survey TEM-133A, 6 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Mike Doyle carnotite prospect is located on a hogback in the foothills of the Colorado Front Range about 10 miles south of Colorado Springs. Carnotite occurs as coatings on fracture surfaces and on carbonized wood fragments in quartzitic sandstone of the Morrison formation of Jurassic age. The sandstone is commonly silicified along fractures, especially where carnotite is present, and the fractures contain slickensided iron-stained gouge. Uranium-bearing material also occurs in a carbonaceous shale underlying the sandstone. Samples of the rock contained from 0.052 to 0.068 percent uranium.

21 Beroni, E. P., and McKeown, F. A., 1952, Reconnaissance for uraniferous rocks in northwestern Colorado, southwestern Wyoming, and northeastern Utah: U. S. Geol. Survey TEI-308A, 41 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A reconnaissance for uraniferous rocks was conducted in adjacent parts of Colorado, Wyoming, and Utah. No deposits were found that are commercially exploitable under present conditions.

Small copper-uranium deposits are associated with fossil plant material in sandstone and shale of the Uinta formation of Eocene age in the Uinta Basin in Utah; samples contained as much as 0.01 percent uranium. A fresh-water limestone also in the Uinta formation, contained 0.019 percent uranium. The uranium deposits at the Snow and Bonniebell claims, Uintah County, Utah, are in sandstone of the Mesaverde formation of Late Cretaceous age; samples contained as much as 0.09 percent uranium. Copper-uranium deposits near Skull Creek, Moffat County, Colo., are in sandstone of the Entrada and Curtis formations of Jurassic age and are associated with carbonaceous material; samples contained as much as 0.16 percent uranium. The uranium deposits at the Lucky Strike claims, Grand County, Colo., are associated with iron and manganese stains on sandstone and clay of the North Park formation of Miocene(?) age; one sample contained 0.016 percent uranium. The uranium deposits at the Fair-U claims, Routt County, Colo., are in Precambrian crystalline rocks and contain as much as 0.04 percent uranium.

22 Beroni, E. P., McKeown, F. A., Stugard, Frederick, Jr., and Gott, G. B., 1953, Uranium deposits of the Bulloch group of claims, Kane County, Utah: U. S. Geol. Survey Circ. 239, 9p.

Uranium deposits occur near the contact of the Dakota formation of Cretaceous age with the Summerville formation of Jurassic age on the Bulloch group of claims in southwest Utah. The area is part of the Markagunt fault block, and the rocks dip about 5° NE. Uranium minerals are finely disseminated in clay, fossil carbonaceous material, and in sandstone and conglomerate. Carnotite, tyuyamunite, and autunite were recognized, but another mineral (unidentified) probably contains most of the uranium. The deposits are small and of marginal grade. The uranium probably has been recently deposited or redistributed by ground water.

23 Black, R. A., 1956, Geophysical exploration for uranium on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 721-726; Geology of uranium and thorium, United Nations, v. 6, p. 766-771.

Geophysical investigations, other than radiometric, have been conducted in the Colorado Plateau region by both federal agencies and private contractors to test the applicability of standard geophysical methods in exploration for uranium. Field tests have been made of electrical, seismic, magnetic, gravimetric, and electromagnetic methods. Although the uranium deposits are found in many different stratigraphic horizons, most of the geophysical work has been in areas where the uranium is concentrated in the Morrison formation of Jurassic age and the Shinarump conglomerate of Triassic age.

Methods so far tested have not proved capable of directly detecting the uranium minerals because of the small percent of uranium ore in relation to the amount of host rock, but some have proved to be of value in the detection and delineation of such geologic guides to ore as thickening of the ore-bearing Salt Wash member of the Morrison formation and the channels filled with the Shinarump conglomerate.

24 Boardman, R. L., Ekren, E. B., and Bowers, H. E., 1956, Sedimentary features of upper sandstone lenses of the Salt Wash member and their relations to uranium-vanadium deposits in the Uravan district, Montrose County, Colorado: U. S. Geol. Survey Prof. Paper 300, p. 221-226; Geology of uranium and thorium, United Nations, v. 6, p. 331-334.

A detailed study of the upper sandstone lenses of the Salt Wash member of the Morrison formation of Jurassic age in the Uravan district gives a general picture of the deposition, extent, and structure of these sandstone lenses and of the relation of sedimentary features to ore features throughout the area.

The individual sandstone lenses are commonly enclosed by relatively impermeable mudstone beds and are not extensive regional aquifers. The sedimentary trends in the Uravan district are, in general, east. The long axes of the ore bodies and the trends of favorable ground are nearly parallel to the strike of the sedimentary features. No direct correlation exists between fractures and faults related to regional structures and trends, or to features related to ore.

25 Bodine, M. W., Jr., 1954, Mineralogy of the Carlile deposit, Crook County, Wyo.; in Annual report for June 30, 1953 to April 1, 1954, Columbia University, New York, New York; U. S. Atomic Energy Comm. RME-3096 (Pt. 1), p. 16–35, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Carlile uranium deposit is in the Lakota sandstone, the basal member of the Inyan Kara group of Early Cretaceous age. The area is on the northwest slope of the Black Hills uplift; the regional dip is about 3° NW. Carnotite is disseminated in the basal 8 feet of the upper sandstone unit of the Lakota sandstone, and is associated with, and forms halos around, fossilized carbonaceous material. The host rock is cross bedded and overlies a dense, impervious mudstone. An ore body in a slump block below and east of the open-pit and underground mine on the rim appears to have been once a part of the upper ore body. Coffinite(?), doloresite(?), and rauvite(?) have been tentatively identified in specimens of carbonized wood from the deposit; also present are carnotite, metarossite, pyrite, aluminite, limonite, gypsum, calcite, manganese oxides, and alum minerals. Calcite, the original cement of the sandstone, has been almost completely removed. Secondary quartz overgrowths formed on quartz grains after removal of the calcite; later, carnotite and limonite coated and partially replaced the quartz grains and overgrowths.

26 Boutwell, J. M., 1905, Vanadium and uranium in southeastern Utah: U. S. Geol. Survey Bull. 260, p. 200-210.

Uranium and vanadium deposits in certain areas in Utah are described. The deposits near Richardson contain carnotite and other vanadium minerals. The minerals coat fractures and impregnate or replace the sandstone host rock along a fracture zone. The host formation is probably of Jurassic age. The carnotite deposits about 15 miles southwest of Green River are probably also in rocks of Jurassic age. The mineral impregnates the sandstone and is in close association with carbonaceous material. Several other uranium and vanadium deposits in the region have been reported.

27 Boyle, T. L., 1956, Airborne radiometric surveying: Geology of uranium and thorium, United Nations, v. 6, p. 744-747.

Established procedures and techniques of aerial prospecting, using light aircraft equipped with scintillation counters designed to detect the emissions of gamma radiation by uranium daughter products, are discussed. Flight elevations of 50 to 100 feet at an air speed of 70 miles per hour have proved the most effective mode of flight.

Flight techniques used in airborne prospecting are applicable only to exposed and nearly exposed mineralization and do not eliminate the need for ground prospecting. A mantle of from 2 to 4 feet of barren soil will effectively absorb gamma radiation.

28 Branson, C. C., Burwell, A. L., and Chase, G. C., 1955, Uranium in Oklahoma, 1955: Okla. Geol. Survey, Mineral Rept. 27, 22 p.

Uranium in Oklahoma occurs in sandstone lenses in Permian red beds, in asphaltic pellets, in phosphatic black shales, in oil field brines, and in some thin coal seams.

Sandstone lenses in the Garber formation of Permian age containing radioactive bituminous material occur locally beneath a crossbedded bituminous gray sandstone in the southwestern part of Oklahoma. In southern Cotton County, a lens of radioactive bituminous sandstone about 1 foot thick and 10 feet long lies within a lens of bituminous sandstone about 15 feet thick and 100 feet long. The larger lens thins laterally into red shales of the Garber formation of Permian age. Carbonized wood and a green copper mineral are present in the radioactive lens. There is a similar occurrence in southern Jefferson County.

In Pawnee, Payne, Osage, and Noble Counties there are several small areas of non-commercial copper deposits with associated radioactive carbonized wood. These deposits are at several levels in red sandstones of Permian age.

29 Brooke, G. L., Shirley, R. F., and Swanson, M. A., 1951, Geological investigations of the Trachyte district, Henry Mountains, Utah: U. S. Atomic Energy Comm. RMO-912, 7 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits occur in sandstone of the Salt Wash member of the Morrison formation of Jurassic age in the Trachyte district on the east flank of the Henry Mountains. The Salt Wash member consists of alternating sandstone and mudstone; sandstone predominates and is commonly crossbedded. Carnotite and vanoxite are found along the edges of channels associated with fossil logs and carbonaceous trash. Locally, base-metal sulfides have been found. The vanadium-uranium deposits are small, and most of the material mined has been mineralized logs and the closely surrounding mineralized sandstone.

30 Bucher, W. H., and Gilkey, A. K., 1953, Fracture pattern and uranium ore of the Zuni uplift, New Mexico [abs.]: Geol. Soc. America Bull., v. 64, no. 12, p. 1402.

The Zuni uplift has a relatively flat top; its shape is due to more or less well-defined flexures, and in each structural unit of the uplift, the dominant joints in the sediments tend to parallel the nearest fault or flexure. This suggests that the Zuni uplift is the result of differential upward movement along faults cutting the crystalline basement.

The association of uranium with fluorite in the Todilto limestone in the Grants region, and the elongation of the ore-rich areas parallel to the local fracture pattern, suggests a causal relation between ore and fractures.

31 Burwell, Blair, 1920, Carnotite mining in southwestern Colorado: Eng. Min. Jour., v. 110, no. 16, p. 755-758.

The exploration and mining procedures used in exploiting the carnotite deposits in the McElmo formation (Morrison formation) of Jurassic age in southwestern Colorado are described. The ground is prospected by drilling; selective mining practices are used to maintain the grade of ore. The deposits are irregular in size, shape, distribution, and grade of ore. The author suggests that the uranium and vanadium were originally disseminated in the mass of the host formation. A downward migration of uranium and vanadium took place in ground waters containing sulfates, and the metals were precipitated under the influence of carbonaceuos material. Inferred reserves of ore containing more than 1.5 percent U_3O_8 and 4.5 percent V_2O_5 are 100,000 tons. "The carnotite region of southwestern Colorado possesses great potentialities for future production."

32. Burwell, Blair, 1932, Mining methods and costs at the vanadium mine of the United States Vanadium Corporation, Rifle, Colo.: U. S. Bur. Mines Inf. Circ. 6662, 9 p.

The mining methods, costs, and geology of this mine are described. The vanadium minerals are disseminated in sandstone of the McElmo formation of Jurassic age. (The host rock is now considered to be the Entrada sandstone of Jurassic age.) Most of the ore is in the lower part of a crossbedded gray sandstone that is from 50 to 75 feet thick. The ore body ranges in thickness from a few inches to 30 feet. A cross section through the mine shows a close relation between the distribution of the ore and the crossbedding. The dip of the rocks is 15°–25° south, and the ore body trends northeast.

33 Butler, A. P., Jr., 1955, Some factors in the appraisal of part of domestic uranium resources: Mines Mag., v. 45, no. 3, p. 91-94, 108.

The author discusses the rate of discovery of uranium deposits and some concepts useful in estimating the amount of uranium resources and in judging where the chances are best for finding concealed uranium deposits. Uranium resources, as defined in this paper, are those materials that might be marketed under present price schedules, if composition, size, and location, both geographically and in depth, make it economically feasible to do so.

The rate of discovery of uranium deposits since 1947 is two to three times the rate in previous years, and the rate of discovery of larger deposits is also greater. About 6 percent of the deposits contain about 70 percent of the reserves. If this applies to the bulk of the undiscovered resources, the major part of our uranium resources are in deposits big enough to look for, even if buried at considerable depth.

A method of estimating the ultimate uranium resources is presented. The method is based on the assumption that the proportion of the outcrop of a formation that is mineralized with ore-grade material more than one foot thick would correctly reflect the proportion of the whole area of the formation so mineralized.

The host rocks of the known uranium deposits have a number of features in common. Except for the Todilto limestone near Grants, N. Mex., all the deposits are in clastic rocks, generally sandstones, deposited by flowing water, probably in a continental environment. Nearly all of the sandstones contain some mineral material other than quartz sand. Many of the formations contain considerable amounts of fine-grained volcanic ash or minerals derived from volcanic ash. Recognition of these and other features that may restrict the search will assist in converting hypothetical resources to usable reserves.

34 Butler, B. S., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U. S. Geol. Survey Prof. Paper 111, 672 p.

The vanadium-uranium deposits and some of the copper, silver, and manganese deposits of Utah are characteristically lenticular bodies in sandstone and are associated with fossil plant remains. The sandstone is usually light gray and coarse grained to conglomeratic. Carnotite, the principal vanadium-uranium mineral, impregnates the sandstone and replaces the calcareous or clayey cement. The deposits are regarded as having been formed by circulating waters that collected the metals disseminated through the sedimentary rocks and deposited them on contact with carbonaceous matter, earlier sulfides, or other precipitating agents. The circulation in some places is believed to have been of artesian character and consequently controlled by structural features. Brief descriptions are given of uranium-vanadium deposits in the Richardson, Temple Mountain, White Canyon, Henry Mountains, La Sal Mountains, Fruita, and San Rafael River areas.

35 Butler, G. M., and Allen, M. A., 1921, Uranium and radium: Arizona Bur. Mines, Bull. 117, 26 p.

This report is a brief general description of the history mineralogy, occurrence, uses, and recovery of uranium and vanadium. Carnotite deposits in the Carrizo Mountains in Apache County in northeastern Arizona are in the lower part of the McElmo formation (now the Morrison formation) of Jurassic age. Some of the ore layers are a maximum of 4 feet thick.

36. Cannon, H. L., 1952, The effect of uranium-vanadium deposits on the vegetation of the Colorado Plateau: Am. Jour. Sci., v. 250, no. 10, p. 735-770.

Biogeochemical studies were conducted by the U. S. Geological Survey in the Thompson district, Grand County, Utah, to determine the effect of uranium-vanadium deposits on plants growing near those deposits. The deposits contain, in addition to uranium and vanadium, unusual amounts of selenium, and plants rooted in soils derived from the deposits accumulate small amounts of these metals. Plants growing on mine dumps and areas of mine seepage show physiological symptoms of ill health, but those rooted in undisturbed ore do not. A uranium tolerant flora has been recognized and a list of the plants compiled. The flora, characterized by selenium-indicator plants, can be used as a guide to exploration.

37 Cannon, H. L., 1953, Geobotanical reconnaissance near Grants, N. Mex.: U. S. Geol. Survey Circ. 264, 8 p.

The application of botanical methods of prospecting for uranium was investigated in uranium-bearing areas near Grants, McKinley County, N. Mex. The uranium minerals occur in the Todilto limestone and in the Westwater Canyon member, (this part of the Westwater Canyon member has subsequently been correlated with the Brushy Basin member of the Morrison formation) of the Morrison formation, both of Jurassic age. Samples taken from juniper and pinon trees rooted in the Todilto limestone were analyzed for uranium. It is concluded that this is a feasible method of exploration for uranium deposits in the Todilto limestone. Selenium-indicator plants may be used to prospect for uranium deposits in the Westwater Canyon member, but they apparently do not grow on the Todilto limestone. The geology of the area and the deposits are briefly discussed.

38 Cannon, H. L., 1954, Botanical methods of prospecting for uranium: Min. Eng., v. 6, no. 2, p. 217-220.

Botanical methods of prospecting for metalliferous ores are based on the premise that deposits at depth may affect surface vegetation. This may be manifested as unusual concentrations of the metals within the bodies of the plants growing on or near the deposits, or as the presence of particular plants which flourish in the anomalous geochemical environment. Both may be used in botanical prospecting for uranium.

The technique of prospecting for uranium by plant analysis consits of taking large samples of twigs or leaves from trees or shrubs of the same species at regular intervals throughout the area to be prospected. The samples are then analyzed for uranium. The laboratory analysis must be precise and is therefore time-consuming and costly. A uranium content of several parts per million is considered anomalous.

A plant may be used as an indicator in botanical prospecting if its distribution is controlled by any factor related to the chemistry of the ore deposit. Since some uranium deposits contain unusual concentrations of selenium and sulfur, selenium- and sulfur-indicator plants may be used as a guide to these ore deposits. Photographs of some species of these plants are included in the paper.

Botanical prospecting for uranium is useful wherever deposits are less than 70 feet from the surface and where selenium and uranium are readily available to plant roots.

39 Cannon, R. S., Jr., 1952, Geological Survey's work on isotope geology of uranium and thorium and their decay products: U. S. Geol. Survey TEI-209, 12 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A program of research on the isotope geology of the uranium and thorium series is being carried on by the Geological Survey. Work is in progress on uranium-lead relationships in uranium ores of the Colorado Plateau region, on uranium-thorium-lead relationships in granite, on geological variations in the isotopic composition of lead, and on radon and helium in natural gas. A continuing program of systematic studies will try to establish methods in this field on a surer footing, and to apply the methods to the solution of important geologic and mineral-resource problems. — *Author's abstract*

40 Carithers, L. W., and Clinton, N. J., 1956, Uranium in shoreline sandstones of terrestrial and marine origin, Colorado Plateau: Geology of uranium and thorium, United Nations, v. 6, p. 383-386; see also, Clinton, N. J., and Carithers, L. W., 1956, Uranium deposits in sandstones of marginal marine origin: U. S. Geol. Survey Prof. Paper 300, p. 445-449.

At Black Mesa, Ariz., and in the San Juan Basin of New Mexico, uranium minerals occur in sandstones deposited in marginal marine or near-shore terrestrial environment in the Curtis formation of Jurassic age and in some members of the Mesaverde group of Late Cretaceous age. The occurrences are associated with local facies changes and with accumulations of carbonaceous material; all are in or near regions of post-Cretaceous tectonic disturbances.

41 Cater, F. W., Jr., 1954, Geology of the Bull Canyon quadrangle, Colorado: U. S. Geol. Survey Map GQ 33 (with text).

42 Cater, F. W., Jr., 1955, Geology of the Gateway quadrangle, Colorado: U. S. Geol. Survey Map GQ 55 (with text).

43 Cater, F. W., Jr., 1955, Geology of the Pine Mountain quadrangle, Colorado: U. S. Geol. Survey Map GQ 60 (with text).

The Bull Canyon, Gateway, and Pine Mountain quadrangles are among eighteen 7½-minute quadrangles in the carnotite-producing area of southwestern Colorado that are being mapped as part of a study of the carnotite deposits. The Atkinson Creek quadrangle has been mapped by E. J. McKay and his report is included in this bibliography. Reports on the other fourteen quadrangles are in preparation. The regional geology and the stratigraphy, structure and mineral deposits of the region are described in the text on each map; the texts are essentially similar.

The map area is underlain by sedimentary rocks that range in age from Late Paleozoic to Quaternary except in the northeastern part where crystalline Precambrian rocks crop out along the flanks of the Uncompahgre Plateau. Over most of the region the sedimentary beds are flat lying, but in places they are disrupted by high-angle faults or are folded into northwest-trending monoclines, shallow synclines, and strongly developed anticlines.

The uranium-vanadium deposits are mostly restricted to the upper layer of sandstone lenses in the Salt Wash member of the Morrison formation of Jurassic age. The ore consists mainly of sandstone impregnated with uranium- and vanadium-bearing minerals, but rich concentrations are also associated with thin mudstone partings, beds of mudstone pebbles, and carbonized fossil plant material. The ore bodies range from small irregular masses that contain a few tons of ore to large tabular masses containing many thousands of tons; most ore bodies are relatively small and contain only a few hundred tons. Margins of ore bodies may be vaguely or sharply defined. Layers of ore lie essentially parallel to the bedding; most of the deposits occur in the thicker parts of sandstone lenses and commonly near the base of the lenses. The trend of the long direction of the deposits and the trend of the rolls in the sandstone are roughly parallel to the trend of the fossil logs and to the average or resultant dip of the crossbedding in the sandstone.

44 Chase, G. W., 1954, Occurrence of radioactive material in sandstone lenses of southwestern Oklahoma: Okla. Geol. Survey, Mineral Rept. 26, 8 p.

Sandstone lenses of Permian age containing radioactive bituminous material occur in a few places beneath a gray crossbedded bituminous sandstone in the southern part of Jefferson and Cotton Counties, Okla. The sandstones are probably near the base of the Garber sandstone.

45 Chester, J. W., 1951, Geology and mineralization of Hunts Mesa, Monument Valley, Ariz.: U. S. Atomic Energy Comm. RMO-801, 9 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Copper-uranium ore deposits on Hunts Mesa occur in the Shinarump conglomerate of Triassic age that fills ancient stream channels cut into the underlying Moenkopi formation. Secondary copper and uranium minerals are found in each of the two exposed channels. Even though the Shinarump conglomerate forms the cap of the mesa, the outcrops of the channels are poorly exposed.

46 Coffin, R. C., 1921, Radium, uranium, and vanadium deposits of southwestern Colorado: Colo. Geol. Survey Bull. 16, 231 p.

This paper is the result of a study of the carnotite region of southwestern Colorado. Separate chapters are devoted to geography, stratigraphy, structure, economic geology of the carnotite deposits, description of selected areas, and miscellaneous economic materials. Carnotite is an ore mineral of uranium, vanadium, and radium. At the time of this report, radium and vanadium were the metals sought.

Most of the carnotite deposits occur in one of two zones in the lower half of the McElmo formation of Jurassic age [redefined in part as the Morrison formation]. The lower zone is from 60 to 125 feet above the base of the formation, and the more productive upper zone is from 275 to 325 feet above the base. The host rock is generally a light-colored massive crossbedded sandstone, and the ore is frequently underlain by beds of clay. Carnotite usually impregnates the sandstone and cements the sand grains, but it may also replace fossil wood or fill fractures and vugs. The carnotite deposits occur in the sandstone as lenses, seams, and irregular pockets whose long dimensions follow in general the bedding of the sandstone. The deposits are irregular in plan. Cylindrical masses of ore called "trees" or "logs" are found in the deposits.

The deposits have only a superficial relation to faulting, and they have no relation to depth. Structural relations, if any, are not clear. The age of the ore cannot be determined except within wide limits.

The author suggests that the minerals which eventually formed the present carnotite deposits were deposited with the sands of the host formation at the time of sedimentation. The character of the parent material is not clear. The minerals subsequently were transported and redeposited by waters which traveled laterally through the beds.

The report includes descriptions of several claims and groups of claims within the carnotite region.

47 Comstock, S. S., 1956, Scintillation drill-hole logging: Geology of uranium and thorium, United Nations, v. 6, p. 722-725.

The use of a scintillation-type drill-hole-logging unit is now a part of the uranium exploration drilling program. The scintillation logging unit, designed for efficient one-man operation, is mounted in a four-wheel drive Jeep station wagon. Gamma ray pulses detected by a subsurface probe are recorded on a paper chart. These gamma ray curves are used to obtain geological information and semiquantitative radiometric analysis of the mineralized zones.

48 Cook, K. L., and Moss, C. K., 1952, Geophysical observations in parts of the Grants district, McKinley County, N. Mex.: U. S. Geol. Survey TEI-244, 16 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Geophysical observations near Haystack Mesa in the Grants district had the dual objective of investigating the unusual occurrence of negative aeromagnetic anomalies in close association with airborne radioactivity anomalies and of investigating other geophysical methods which might assist in the search for uranium ores in the Grants district. Ground magnetometer tests indicate that the apparent correlation shown in the airborne data is fortuitous and cannot be attributed to a genetic relationship between uranium mineralization and the intrusion of dikes or the extrusion of the basaltic lava flow.

49a Craig, L. C., Holmes, C. N., Cadigan, R. A., Freeman, V. L., Mullens, T. E., and Weir, G. W., 1951, Preliminary report on the stratigraphy of the Morrison and related formations of the Colorado Plateau region: U. S. Geol. Survey TEI-180, 64 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

49b Craig, L. C., and others, 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U. S. Geol. Survey Bull. 1009-E, p. 125-168.

The Jurassic rocks of the Colorado Plateau region are divided into three units: Lower Jurassic Glen Canyon group, the Upper Jurassic San Rafael group, and the Upper Jurassic Morrison formation. The Glen Canyon group consists mainly of eolian and fluvial sediments, the San Rafael group consists of marine and marginal marine sediments, and the Morrison formation consists of fluvial and lacustrine sediments. Stratigraphic studies were concentrated on the Morrison formation.

The lower part of the Morrison formation consists of the Salt Wash and the Recapture members, and the upper part consists of the Westwater Canyon and the Brushy Basin members. The Salt Wash and the Brushy Basin members are present in eastern Utah, western Colorado, northeastern Arizona, and northwestern New Mexico, but the Recapture and the Westwater Canyon members are present only in northeastern Arizona, northwestern New Mexico and in relatively small areas in adjacent parts of Utah and Colorado. The Salt Wash and Brushy Basin members cannot be differentiated in central and eastern Colorado.

The Salt Wash, Recapture, and Westwater Canyon members are characterized by sequences of interstratified sandstone and red or green mudstone, but the Brushy Basin member consists mainly of variegated claystone with a few lenticular beds of conglomeratic sandstone. The Salt Wash, Recapture, and Westwater Canyon members were deposited as large alluvial plains or "fans" by systems of braided and aggrading streams. The Brushy Basin is composed largely of clay derived from volcanic ash that had been deposited in a lacustrine environment. The material in the Salt Wash sandstone member and in the fluvial part of the Brushy Basin shale member probably was derived from an area of sedimentary rocks in west-central Arizona, and the material in the Recapture shale and Westwater Canyon sandstone members was probably derived from an area of intrusive and extrusive igneous rocks, metamorphic rocks, and sedimentary rocks in west-central New Mexico. The fluvial sediments become coarser as the source is approached, and the members are subdivided into facies on the basis of particle size.

The carnotite deposits of the Morrison formation are essentially confined to the Salt Wash member; these lie entirely within the sandstone and mudstone facies of the Salt Wash. Most of the carnotite deposits occur in areas where sandstones of the Salt Wash are relatively well sorted and probably have a relatively high permeability.

50 Curran, T. F. V., 1911, Carnotite in Paradox Valley, Colo.: Eng. Min. Jour., v. 92, no. 27, p. 1287-1288.

Carnotite ore bodies in Paradox Valley crop out at about the same stratigraphic level, have a blanket form, and are a maximum 4 feet thick. The ore as mined contains from 6 to 15 percent uranium oxide. The economic geography of the area is discussed, and some of the mines and claims are briefly described.

51 Curran, T. F. V., 1913, Carnotite: Eng. Min. Jour., v. 96, no. 25, p. 1165-1167, no. 26, p. 1223-1225.

The history of the carnotite industry on the Colorado Plateau is discussed. Carnotite ore bodies occur in a series of thin-bedded sandstones and shales (Morrison formation of Jurassic age). The best deposits are in western Montrose County, but the carnotite field encompasses an area of several thousand square miles in western Colorado and eastern Utah. The second part of the report is a discussion of the production, refining, and utilization of uranium and radium.

52 Dane, C. H., 1935, Geology of the Salt Valley anticline and adjacent area, Grand County, Utah: U. S. Geol. Survey Bull. 863, 184 p.

Exposed sedimentary formations in this area range in age from Pennsylvanian to Late Cretaceous; crystalline Precambrian rocks are exposed on the Uncompahgre Plateau in the northeastern part of the area. The Salt Valley anticline, a salt structure, is a prominent fold broken by many faults; its crest is in part dropped into a structural trough. For the most part the rocks are tilted at low angles and warped into broad folds. The rocks in the eastern part of the area are displaced by many normal faults. The report includes a geologic map and a structure contour map of the area at a scale of 1:62,500.

Vanadium-uranium deposits at Polar Mesa and in an area southeast of Thompson, Utah, are in the Salt Wash member of the Morrison formation of Jurassic age. Carnotite and other vanadium and uranium minerals replace carbonaceous material and impregnate light-colored lenticular sandstone beds.

53 Davidson, D. F., 1953, Distribution of coarse- and fine-grained rocks in the Wasatch formation and their relationship to uranium deposits, Powder River Basin, Wyo.: U. S. Geol. Survey TEM-676, 12 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Wasatch formation of Eocene age in the Powder River Basin apparently grades from predominantly coarse-grained rocks at the southern end to fine-grained rocks at the northern end of the basin. The uranium deposits occur in the central part of the basin where the two rock types are mixed. The significance of this relation is not known, and further studies are recommended.

54 Davidson, D. F., 1953, Reconnaissance for uranium in the Powder River Basin, Wyo.: U. S. Geol. Survey TEM-677, 32 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A reconnaissance was made for uranium deposits in a large part of the Powder River Basin, Wyo., other than the Pumpkin Buttes area. No uranium deposits of economic quality were found, but some rocks of the Tertiary Fort Union formation and the Cretaceous Inyan Kara group are sufficiently uraniferous to justify further search in these formations.

55 Davis, D. L., and Hetland, D. L., 1956, Uranium in clastic rocks of the Basin and Range province: U. S. Geol. Survey Prof. Paper 300, p. 351-359; Geology of uranium and thorium, United Nations, v. 6, p. 387-391.

Uranium occurs in lake bed sediments and waterlaid tuffs of Tertiary age in several areas in the Basin and Range province of Nevada and California.

Rocks in the Virgin Valley in northwestern Nevada are waterlaid vitreous tuff and diatomaceous earth beds of early Pliocene age that contain discontinuous layers of opal. Carnotite occurs as fracture coatings or fine layers in the opal lenses, and a yellow fluorescent mineral, possibly schroeckingerite, is disseminated in the tuff. The volume of mineralized material is large, but the average uranium content is below commercial standards.

A deposit in Lander County, Nev., is in water-laid tuff which contains thin beds of opal. Uranium minerals have not been observed in hand specimens. The greatest radioactivity appears to be confined to minor fractures in the tuffs. Select samples from the deposit contain commercial amounts of uranium, but most of the material is submarginal.

Lake bed sediments of Miocene age near Tonopah, Nev., are finely stratified pyroclastic material and diatomaceous earth interbedded with discontinuous lenses of uraniferous opal. Uranium minerals have not been identified, but anomalous radioactivity can be detected in an area about 1 mile wide and 8 miles long. A similar deposit in Lyon County, Nev., consists of a diatomaceous earth bed with carnotite coatings along minor fractures.

Near Hawthorne, Nev., a yellow secondary uranium mineral occupies a series of closely spaced vertical fractures in a tuffaceous sandstone. Yellow uranium minerals have been found in a thin bed of soft, waterlaid tuff in the Panaca formation of Pliocene(?) age in Lincoln County, Nev.

Near Olancha, Calif., the gently dipping Coso lake beds of Pliocene age contain autunite on fracture surfaces and in iron-stained zones.

56 Davis, W. E., 1951, Electrical resistivity investigations of carnotite deposits in the Colorado Plateau: U. S. Geol. Survey TEM-232, 25 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Investigations of the use of geophysical methods in prospecting for carnotite deposits on the Colorado Plateau indicate that electrical resistivity methods combined with other geologic data can be used successfully to locate areas favorable for drilling. Broad positive resistivity anomalies of small magnitude were observed over most of the deposits investigated, all of which are in the Salt Wash member of the Morrison formation of Jurassic age. The anomalies are related to thickening of the ore-bearing sandstone; mineralized ground in most places is also associated with this thickening. Electrical resistivity measurements can be successfully made at depths of as much as 400 feet. The investigations were conducted on Calamity and Outlaw Mesas in Mesa County, and at Long Park in Montrose County, Colo.

57 Denson, N. M., Zeller, H. D., and Stephens, J. G., 1956, Water sampling as a guide in the search for uranium deposits and its use in evaluating widespread volcanic units as potential source beds for uranium: U. S. Geol. Survey Prof. Paper 300, p. 673-680; Geology of uranium and thorium, United Nations, v. 6, p. 794-800.

In the western United States several thousand samples of water issuing from widespread volcanic units of Tertiary age and from the underlying sedimentary rocks were analyzed for uranium. These determinations have proved a useful guide in delimiting areas where uranium deposits are likely to occur. Most ground water contains less than 2 parts per billion uranium. However, water from seeps and springs in volcanic and tuffaceous sedimentary terranes as well as from areas of known uranium deposits may contain from 10 to 250 parts per billion.

Although many of the volcanic rocks of Tertiary age contain appreciable amounts of uranium, not all of them make the uranium available to the ground water system in equal amounts. The ground water from units of Oligocene and Miocene age, irrespective of their geographic location, have a higher uranium content than does ground water issuing from other volcanic units.

58 deVergie, P. C., 1953, Preliminary drilling at the Nash Car area, White Canyon district, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4032, 13 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Copper-uranium deposits in the Nash Car area occur in the Shinarump conglomerate of Triassic age in gray sandstone and conglomerate at or near the base of ancient stream channels cut into the underlying Moenkopi formation of Triassic age. The conglomerate is as much as 10 feet thick, is 100 to 150 feet wide, and is of unknown length. Chalcopyrite and pyrite replace carbonaceous material and are disseminated in the surrounding sandstone. Secondary copper minerals and limonite appear on the weathered outcrop. No uranium minerals are visible although in a few places the rock contains ore-grade quantities of uranium. The report includes a map that shows where drilling has been done, and geologic sections compiled from the logs of cores obtained during the drilling.

59 deVergie, P. C., and Carlson, W. A., 1953, Investigation of the "C" group area, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4011, 13 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits on the "C" group of claims about 20 miles southwest of Moab on the west side of the Colorado River, are in sandstone lenses of the Shinarump conglomerate of Triassic age near the base of a large ancient stream channel cut about 50 feet into the underlying Moenkopi formation of Triassic age. Carbonaceous material is abundant in the ore zone, and uraninite and base-metal sulfides impregnate the sandstone and replace carbonaceous material. The host rock is a coarse- to fine-grained sandstone cemented by calcite. (What was formerly called Shinarump conglomerate in this area is now correlated with a sandstone member of the Chinle formation of Triassic age.)

60 Dix, G. P., Jr., 1953, Reconnaissance of the uranium deposits of the Lockhart Canyon—Indian Creek area, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4038, 20 p., issued by the U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Copper-uranium deposits occur in the Bogus Tongue member of the Cutler formation of Permian age in the Lockhart Canyon — Indian Creek area. Exposed consolidated sedimentary rocks in the area range in age from Permian to Jurassic, and the beds are essentially horizontal. The Bogus Tongue member, which is about 670 feet thick, is predominantly red and consists of siltstone, sandstone, and cross-bedded arkose. The mineral deposits are associated with discontinuous lenses of white arkose which, presumably, were once red. Small amounts of copper and uranium minerals occur as concretions and along bedding planes and arkose-mudstone contacts, but the better deposits are those in which the uranium and copper minerals are disseminated in the arkose lenses. The recognized uranium minerals are uranophane, zeunerite, and trögerite. Copper sulfides are present in the concretions, and secondary copper minerals are present in the other types of deposits.

61 Dix, G. P., Jr., 1954, The uranium deposits of Big Indian Wash, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4022 (Rev.), 15 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits in the Big Indian Wash area have been found in the Cutler formation of Permian age and in the Chinle formation of Triassic age. The area is on the southwest flank of the Lisbon Valley anticline, and the rocks dip about 15° SW. Formations exposed in the area range in age from Pennsylvanian to Cretaceous. The upper part of the Cutler formation consists of mudstone, siltstone, and lenses of coarse-grained arkosic sandstone. The uranium minerals, carnotite and becquerelite, are disseminated in the lenses of arkosic sandstone. Uranium deposits in the Chinle formation are in a gray, medium-grained micaceous sandstone near the base of the formation. The uranium minerals, uraninite, carnotite, and tyuyamunite, are associated with carbonaceous material, pyrite, montroseite, and roscoelite. The largest mine in the area, the Mi Vida mine, is in the Chinle formation. The deposits at the Big Buck mine and the Purple Paint and Small Fry claims are in the Cutler formation.

62 Dodd, P. H., 1950, Happy Jack Mine, White Canyon, Utah: U. S. Atomic Energy Comm. RMO-660, 23 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The uranium deposit at the Happy Jack mine is in a lenticular, coarse-grained sandstone bed near the middle of the Moenkopi formation of Triassic age. Subsequent investigations (Benson, and others, 1952) have shown that the host bed is at the base of the Shinarump conglomerate of former usage of Triassic age. The porous, permeable sandstone bed thickens to about 20 feet at the portal of the mine; the thick section is presumably due to the filling of an ancient stream channel. This channel appears to be the major control of the deposit. Pitchblende and base metal sulfides occur in the unoxidized portion of the deposit, and secondary copper and uranium minerals occur near the outcrop. The uranium content is depleted near the outcrop due to surficial leaching. The mineral assemblage indicates the deposit may be of hydrothermal origin. Exposed consolidated sedimentary rocks in the area range in age from Permian to Jurassic, and dip 1°-3° W.

63 Dodd, P. H., 1956, Some examples of uranium deposits in the Upper Jurassic Morrison formation on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 243-262; Geology of uranium and thorium, United Nations, v. 6, p. 615-633.

Important quantities of radium, vanadium, and uranium ore have been produced on the Colorado Plateau from the Morrison formation of Late Jurassic age. The Morrison formation still contains large reserves of ore.

The uranium deposits in the Morrison formation, although differing in detail, have many characteristics in common. The author describes several deposits to demonstrate the flat-lying tabular to irregular outline of the ore bodies, the concordance of ore bodies with bedding, the elongation of ore bodies in the direction of sedimentary structures, and the general correlation between ore bodies and types of lithology. Criteria for evaluating ore possibilities are discussed. Subsurface geologic maps based on drilled-hole data are presented.

A general hypothesis that explains the localization of the mineral deposits without recourse to speculation on origin and genesis of the deposits is presented to show the basis of current methods of exploration.

64 Droullard, R. F., and Jones, E. E., 1951, Investigations of uranium deposits near Sanastee, N. Mex.: U. S. Atomic Energy Comm. RMO-909, 7 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium-vanadium deposits occur in the Recapture member of the Morrison formation of Jurassic age in the Sanastee area, San Juan County, N. Mex. Vanadium minerals and carnotite-type minerals are disseminated in fine- to medium-grained sandstone in the upper part of the Recapture member. The deposits, which are generally less than 20 feet in outcrop length, are contained within slightly radioactive altered zones.

65 Duschatko, R. W., 1953, Fracture studies in the Lucero uplift, New Mexico, Final report: U. S. Atomic Energy Comm. RME-3072, 49 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Lucero uplift is a transitional tectonic element situated along the boundary of the Colorado Plateau and the Rio Grande graben belt of central New Mexico. The eastern margin of the structure has been complexly faulted during two (or more) periods of Tertiary deformation. Evidence is presented in support of the hypothesis that both stages of tectonic development involved primarily vertical movement along sharp monoclinal flexures possibly emanating from displacement along deep seated fracture zones. The composite fracture pattern developed over the uplift indicates that the faults and joints are essentially parallel and were produced by a common cause. The dominant fracture pattern is regional and indicates primary east-west lateral elongation with secondary north-south stretching of the sediments due to bending of the rock between the primary fractures. — *Author's abstract*

66 Ellsworth, P. C., and Hatfield, K. G., 1951, Geology and ore deposits of Mesa VI, Lukachukai district, Arizona: U. S. Atomic Energy Comm. RMO-802, 12 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Vanadium-uranium deposits on Mesa VI are in a fine- to medium-grained sandstone unit in the Salt Wash member of the Morrison formation of Jurassic age. The mineralized sandstone lies about 60 feet above the base of the formation and is underlain by a blue-green mudstone. Carnotite and vanoxite occur in mudstone seams and impregnate the sandstone. Light-tan sandstone, the most favorable host rock in the Lukachukai Mountains, is relatively scarce on Mesa VI. The most mineralized zone is part of a structural flat about 1,000 feet southwest of the axis of the Lukachukai syncline.

67 Ellsworth, P. C., and Mirsky, Arthur, 1952, Preliminary report on relation of structure to uranium mineralization in the Todilto limestone, Grants district, New Mexico: U. S. Atomic Energy Comm. RME-4020, 15 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Investigation of the structure of the Todilto limestone of Jurassic age in the Grants district indicates a genetic relation between the folds in the Todilto limestone and the joints resulting from the Zuni uplift. Drill-hole data show that the larger ore bodies in the Todilto limestone are on anticlines. The ore bodies are elongate in a manner that suggests control by a conjugate joint system; they appear to trend in general conformity with the folds.

68 Erickson, R. L., Myers, A. T., and Horr, C. A., 1954, Association of uranium and other metals with crude oil, asphalt, and petroliferous rock: Am. Assoc. Petroleum Geologists Bull., v. 38, no. 10, p. 2200-2218.

Some crude oil, natural asphalt, and petroliferous rock are appreciably radioactive, but little is known about the actual uranium content and the chemical nature of the uranium compound or compounds in these materials. Semiquantitative spectrographic analyses of the ash of 29 samples of crude oil, 22 samples of natural asphalt, and 27 samples of oil extracted from petroliferous rock indicate that metals such as vanadium, nickel, copper, cobalt, molybdenum, lead, chromium, manganese, and arsenic are consistently present — at some places in exceptionally high concentrations — in this type of organic matter. The chemical analyses show that the uranium content of crude oil is consistently much lower than the uranium content of the natural asphalt and oil extracted from petroliferous rock. — *Author's abstract*

The association of uranium with organic materials may have a direct bearing on the genesis of some types of uranium deposits. Many uranium deposits in Utah, such as those in the San Rafael Swell, Emery County; Circle Cliffs, Garfield County; and Capitol Reef, Wayne County, occur on the flanks of breached anticlinal structures that have served as geologic traps for the accumulation of petroleum.

69 Everhart, D. L., 1950, Reconnaissance examinations of copper-uranium deposits west of the Colorado River: U. S. Atomic Energy Comm. RMO-659, 19 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Several small copper-uranium deposits have been found in southwestern Utah along the contact of the Shinarump and Moenkopi formations of Triassic age. The deposits are highly localized and and apparently erratic in their distribution. The deposits contain secondary copper, uranium, and copper-uranium minerals which impregnate sandstone and coat parting planes of shale. The deposits described are in the Capitol Reef, Circle Cliffs, Silver Reef and other areas. The deposits at Silver Reef are not at the Shinarump-Moenkopi contact, but higher in the section — in the Silver Reef sandstone member of the Chinle formation of Triassic age. Exploration of the region had only begun in 1950, and the known deposits had not been exploited.

70 Everhart, D. L., 1951, Geology of uranium deposits — a condensed version, with mineral tables by Muriel Mathez: U. S. Atomic Energy Comm. RMO-732, 34 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium ore deposits have been found in many different geologic environments in igneous, metamorphic, and sedimentary rocks. In this report the deposits in igneous and metamorphic rocks and those in sedimentary rocks are described separately.

The carnotite deposits on the Colorado Plateau occur mostly in sedimentary rocks of Triassic and Jurassic age, and the copper-uranium deposits occur mostly in rocks of Triassic age. The carnotite deposits are irregular tabular bodies that in outline conform to the bedding, but cut across the bedding in detail. The deposits are associated with fossil vegetable material in ancient stream channels. The copper-uranium deposits are mostly at the base of ancient channels at the base of the Shinarump conglomerate of Triassic age. Pitchblende and base-metal sulfides are in the unoxidized parts of these deposits. Uraniferous asphalt deposits occur in Triassic rocks at Temple Mountain, Utah. Uranium deposits in limestone, uraniferous phosphorite, and black shale are discussed. Ore sampling procedures and the field use of radiation detection instruments are described.

71 Everhart, D. L., 1954, Origin of uranium deposits — a progress report: Min. Eng., v. 6, no. 9, p. 904-907.

The uranium deposits of the world exhibit a broad variety of character and geologic environment. Uranium has a high solubility over a wide range in pH, temperature, and pressure, but there are a number of very effective precipitants, including carbonaceous matter and high base-exchange clays.

The origin of the uranium deposits in many geologic environments is reasonably clear. The disseminated deposits in sedimentary rocks, particularly those deposits on the Colorado Plateau, are in greatest doubt as to origin. The field relations of most of these deposits suggest that primary structures in the sediments were instrumental in localizing the deposits. In a few areas, however, field relations strongly suggest that the deposits may be genetically related to faults, fractures, or salt dome structures.

Two main hypotheses have been advanced to explain the origin of the Colorado Plateau ores. One is that the ores are penesyngenetic. The second hypothesis holds that the deposits are telethermal; that is, the ore-bearing solutions are presumed to have originated at depth from an igneous source, ascended along fractures, and mixed with ground waters from which the uranium was precipitated in favorable beds and sedimentary traps. A third idea is that ground waters removed the uranium from slightly uraniferous sedimentary rocks and transported it to an environment suitable for precipitation.

72 Faul, Henry, (ed.), 1954, Nuclear geology: New York, John Wiley and Sons, Inc., 414 p.

This volume, a symposium on nuclear phenomena in the earth sciences, is a text covering the field between geology and nuclear physics. The first chapter is an introduction to nuclear physics and an outline of some techniques used in the study of radioactivity and isotopes. Chapters 2, 3, and 4 discuss the natural occurrence of radioactive elements. The thermal, physical, and chemical effects of radioactivity and nuclear methods of geophysical exploration and well logging are considered in chapters 5, 6, and 7, and techniques and results of absolute age determinations are discussed in detail in chapters 8 and 9. The last chapter discusses the origin of the earth.

73 Finch, W. I., 1953, Geologic aspects of the resource appraisal of uranium deposits in pre-Morrison formations of the Colorado Plateau — an interim report: U. S. Geol. Survey TEI-328A, 35 p.,

issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A reconnaissance to determine uranium resources in pre-Morrison formations of the Colorado Plateau was made primarily of deposits in the Shinarump conglomerate of Triassic age. The uranium deposits in Triassic rocks may be divided on the basis of their principal metal content into three types — vanadium-uranium (carnotite), copper-uranium (uraninite and copper sulfides), and uranium (uraninite). The gangue minerals associated with nearly all the deposits are limonite, calcite, and gypsum. Most of the uranium deposits are irregular tabular bodies; the ore minerals have impregnated the host rock. Carbonaceous material is commonly associated with the ore. The most important guides to ore are the thickening of sandstone and conglomerate beds, alteration of associated mudstones, and the presence in the sandstone of carbonaceous material, iron oxide stains, clay and mudstone, and sulfides. Three belts of ground that may contain large uranium deposits have been outlined. One belt extends from the southern part of the San Rafael district to the Big Indian Wash area, Utah; another is in the White Canyon area, Utah; the third extends northwesterly across the Monument Valley district of Arizona and Utah.

74 Finch, W. I., 1954, Geology of the Shinarump No. 1 uranium mine, Seven Mile Canyon area, Grand County, Utah: U. S. Geol. Survey Circ. 336, 14 p.

The Shinarump No. 1 uranium deposit is about 12 miles north of Moab, Utah, on the west flank of the Moab anticline and about 700 feet west of the Moab fault. The rocks dip about 8° NW; the formations are of sedimentary origin and range in age from Permian to Jurassic. Uraniferous material occurs mainly in three zones in the lower 25 feet of the Chinle formation of Triassic age. The Shinarump No. 1 deposit is in the lowest zone, which consists of from 5 to 10 feet of siltstone with some interbeds of mudstone, sandstone, and conglomerate. The ore deposit is not in a channel fill but in flat-bedded sedimentary rocks that were deposited on an irregular surface. The deposit consists of discontinuous, irregular, lenticular layers of mineralized rock that, in general, follow the bedding. The ore minerals occur in the more poorly sorted parts of the siltstone and in stringers of coarse sand in the siltstone. The rocks near the deposits are bleached from red to gray and green. Uraninite, the principal uranium mineral, is associated mainly with chalcopyrite and pyrite. The uraninite occurs as small grains disseminated in the siltstone and as a replacement of wood. Rich concentrations of uranium occur in seams as much as half an inch thick along bedding planes. The uraninite was deposited later than or simultaneous with most of the sulfides; some of the chalcocite was deposited later than the uraninite. The Shinarump No. 1 deposit is thought to be of hydrothermal origin and to have been formed in Late Cretaceous or early Tertiary time. Guides to ore in the area are the presence of bleached siltstone, carbonaceous material, and copper sulfides.

75 Finch, W. I., 1955, Preliminary geologic map showing the distribution of uranium deposits and principal ore-bearing formations of

the Colorado Plateau region: U. S. Geol. Survey Map MF 16 (with text).

The locations of nearly 3,000 uranium deposits and occurrences on the Colorado Plateau are indicated on this map; those from which more than 1,000 tons of ore have been produced are distinguished by color.

The history of production, the general geology, the principal uranium-bearing formations, and the ore deposits are described in the text. The uranium is commonly associated with vanadium or copper and with carbonaceous material in rather well-defined irregular-shaped bodies. The ore minerals generally impregnate the host rock. The most important uranium-bearing formations are the Shinarump and Chinle formations of Triassic age, and the Entrada, Todilto, and Morrison formations of Jurassic age. Except for those in the Todilto limestone, most of the deposits are in light-colored sandstones.

76 Finch, W. I., 1956, Uranium in terrestrial sedimentary rocks in the United States exclusive of the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 321-327; Geology of uranium and thorium, United Nations, v. 6, p. 600-604.

Large uranium deposits occur in Cretaceous sandstone formations in the Black Hills region of South Dakota and Wyoming and in Tertiary tuffaceous sandstone formations in several areas in Wyoming, Texas, and Nevada. Small deposits occur in terrestrial sedimentary rocks in Pennsylvania, Colorado, Oklahoma, New Mexico, and other places exclusive of the Colorado Plateau.

The carnotite deposits in the Black Hills are in sandstone beds in the Inyan Kara group of Cretaceous age. The deposits are generally similar to those on the Colorado Plateau. They consist of irregular tabular or lenticular layers that, in general, follow the bedding and have distinct boundaries. The Tertiary deposits occur most commonly as poorly defined bodies of disseminated uranium arsenate, silicate, and phosphate minerals in poorly bedded tuffaceous sandstone or sandy tuffaceous rocks. The relation of the deposits to sedimentary structures is obscure.

77 Fischer, R. P., 1937, Sedimentary deposits of copper, vanadium-uranium, and silver in southwestern United States: Econ. Geology, v. 32, no. 7, p. 906-951.

Widely distributed deposits of copper ("Red Beds" type), vanadium-uranium and silver, occurring in sandstones and shales of Permian, Triassic, and Jurassic age, exhibit many common features and are thought to have had a similar origin. Mineralization, although mostly discontinuous, is recurrent at certain stratigraphic horizons. Commonly the ore bodies are distinctly lenticular and in some cases it can be demonstrated that mineralization was restricted to a particular lens. Chalcocite pseudomorphs after plant fossils show undeformed cell structure, suggesting mineralization previous to deep burial. Geologic structures, such as faults and folds appear to be post-mineralization and show no genetic relationship to ore deposition.

This evidence opposes current ideas of mineralization by circulating meteoric waters or ascending thermal solutions, and it is believed that the concentration of the metals occurred at the time of deposition of the enclosing sediments. It is suggested that these metals may have been concentrated from dilute solutions by organisms. —*Author's abstract*

The vanadium-uranium deposits include the carnotite and vanadiferous sandstone ores of Colorado and Utah. Workable deposits are restricted to three formations: namely, the Shinarump conglomerate, the Entrada sandstone, and the Morrison formation; and in limited areas the deposits are restricted to certain horizons within these formations. The ore bodies are commonly lenticular. The mass of the ore is disseminated in sandstone, but the richest ore is associated with plant remains. Clay galls and thin shaly seams, rich in vanadium, are features common to many of these deposits. These ores show no apparent genetic relation to geologic structures such as faults and folds. — *Author's summary*

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

Deposits of vanadium-bearing sandstone are widely distributed in western Colorado and eastern Utah and have been the principal domestic source of vanadium, uranium, and radium. Except during a few years when operations were relatively small, deposits at one or more places in this region have been intensively mined since 1909. Production has increased considerably each year since 1937.

Most of the deposits are in the Morrison formation, but there are two important deposits in the Entrada sandstone and several small deposits in the Shinarump conglomerate. Recent X-ray studies indicate that the principal vanadium mineral, heretofore considered to be roscoelite, belongs to the hydrous mica group of clay minerals. This mineral, along with other vanadium minerals of minor importance, impregnates sandstone. Shale pebbles and clay films on bedding planes in ore-bearing sandstone are rich in absorbed vanadium, and fossil plants in and adjacent to ore bodies are richly mineralized with vanadium and uranium in places. Vanadium ore of milling grade contains from about 1 to 5 percent V_2O_5, and most of it contains less than 1 percent U_3O_8. Ore containing as much as 1½ percent U_3O_8 is usually sold as uranium ore. The vanadium-bearing hydrous mica is in part uniformly disseminated through the sandstone and in part concentrated along bedding planes and in thin zones that cut across bedding. As the zones that cut across bedding are curved or wavy, they are called rolls by the miners.

The ore bodies are spotty and form irregularly tabular masses that lie essentially parallel to the sandstone beds, but they do not follow the beds in detail. They range in content from a few tons of ore to many thousand tons. The trend of many elongate bodies is indicated by the orientation of the rolls within the ore, and this trend also suggests the probable alinement of any adjacent ore bodies; mapping of ore bodies and rolls is therefore an aid to prospecting and development.

No satisfactory explanation can yet be offered for the origin of these deposits. The ore bodies do not appear to have been localized by such geologic structures as fractures or folds, but within limited areas they are restricted to certain stratigraphic zones. — *Author's abstract*

79 Fischer, R. P., 1944, Simplified geologic map of the vanadium region of southwestern Colorado and southeastern Utah: U. S. Geol. Survey Strategic Minerals Inv. Prelim. Map 3-226 (with text).

The uranium-vanadium deposits in the Morrison formation of Jurassic age in southwestern Colorado and southeastern Utah are indicated on the map; the larger mines and groups of mines are named. The deposits in the northern part of the area are in a sandstone unit near the middle of the Morrison; the ore-bearing horizon is progressively lower in the section to the south. The ore bodies are irregularly tabular masses parallel to the sandstone beds, but they do not follow the beds in detail. The vanadium and uranium minerals impregnate the sandstone. Shale pebbles, clay layers, and fossil plants in or near the ore bodies may be richly mineralized.

80 Fischer, R. P., 1947, Deposits of vanadium-bearing sandstone; *in* Vanderwilt, J. W., Mineral resources of Colorado, p. 451-456: Colo. Min. Resources Board.

Deposits of vanadium-bearing sandstone occur in western Colorado and adjacent parts of Utah, Arizona, and New Mexico. The principal ore-bearing rocks are the Shinarump conglomerate of Triassic age, and the Entrada sandstone and Morrison formation of Jurassic age. The ore is sandstone impregnated with vanadium minerals, although some plant fossils are richly mineralized. The vanadium deposits form irregular, tabular layers whose long axes are nearly parallel to the bedding, but the deposits do not follow the beds in detail. The deposits are irregularly distributed and have a wide range in size. The limits of the vanadium-bearing sandstone generally are fairly well defined. Wherever the ore layer, or an edge of it, crosses the bedding in a smooth curve the structure is called a "roll." Fossil logs and the rolls in any one area usually have a common orientation. Attitudes of the host beds range from horizontal to steeply dipping, but most of the deposits are in gently dipping beds. Faulting is common, but the deposits apparently are not genetically influenced by faulting nor by Tertiary intrusive igneous rocks.

Origin and controls of the ore deposits have not been definitely established, but the deposits probably were formed by precipitation of the minerals from ground-waters before regional deformation and perhaps shortly after deposition of the ore-bearing beds. The source of the vanadium is not known, but it may have been adjacent beds which were slightly vanadiferous and in great volumes.

(Because of security restrictions in effect at the time of publication, the report does not mention uranium. However the ores from most vanadium deposits on the Colorado Plateau also contain uranium.)

81 Fischer, R. P., 1949, Federal exploration for carnotite ore: Colo. Mining Assoc., special pub., 14 p., Denver, Colo.

The Geological Survey is conducting an integrated program of exploration and geologic studies in the carnotite region of southwestern Colorado and the adjoining states on behalf of the U. S. Atomic Energy Commission. Exploration will mainly test ground away from known deposits, ground that has not been tested and probably will not be tested by private industry because of the high risk of a poor yield. The geological studies are directed mainly at determining conditions that localized the deposits, as a guide to ore-finding and an aid in evaluating the carnotite resources of the region.

A brief description of the carnotite deposits is given, with particular reference to the geologic features that are useful in guiding exploration. Most deposits are in lenticular sandstone beds, mainly in or near the thicker, central parts of the lenses, where the sandstone is medium-grained and rather thickly though somewhat irregularly bedded. Thin-bedded and fine-grained sandstone on the thinning edges of the lenses is less favorable for ore. It is suggested that ground-water solutions, from which the ore minerals probably were precipitated, circulated along the central parts of the sandstone lenses, and in doing so influenced the rock color, which is a useful guide in recognizing ground favorable for ore deposits. Most of the known deposits are in light yellowish-brown sandstone with associated mudstone or argillaceous material that has been altered from red to gray.

The general plan of exploration being used by the Geological Survey is described briefly. — *Author's abstract*

82 Fischer, R. P., 1949, Origin of the Colorado Plateau vanadium deposits [abs.]: Washington Acad. Sci. Jour., v. 39, no. 3, p. 109.

The vanadium deposits of the Colorado Plateau occur in sandstone beds of Mesozoic age. Most of them are restricted to a few stratigraphic horizons, along which they have a wide but spotty areal distribution. All the deposits have many common characteristics.

The ore minerals mainly impregnate sandstone, partly or completely filling the pore spaces of the rock. The ore bodies are irregularly shaped in plan and in section they form tabular or lenticular layers that lie nearly parallel to the bedding. These layers do not follow the beds in detail, however, and for this reason the ore in its present form can not be syngenetic but rather had to have been precipitated from solutions after the sands had accumulated.

Though the geologic environment of the vanadium deposits differs somewhat from place to place, no definite relationship has yet been demonstrated between the spatial distribution or the character of the deposits and geologic structures such as faults, folds, and and igneous intrusions. Considering all factors it is difficult to rationalize the localization and character of the deposits as originating from hydrothermal or ground-water solutions that might have been introduced into the ore-bearing beds along through-going, vertical structures resulting from regional deformation or igneous activity.

Nevertheless, the habits of the ore and the location of the deposits show a close relationship to sedimentary structures and conditions that would certainly influence at one time or another the flow of solutions along or through the ore-bearing beds. Recognizing these features, and believing that mineralization after regional deformation is unlikely, it is therefore suggested that the vanadium ore was precipitated from ground waters moving along the beds during a period of active circulation shortly after the sands accumulated. Precipitation probably was caused by relatively slight changes in composition of the waters, resulting from reactions in an environment of decaying organic matter, reactions at a water table, or the mixing of two solutions. — *Author's abstract*

83 Fischer, R. P., 1950, Uranium-bearing sandstone deposits of the Colorado Plateau: Econ. Geology, v. 45, no. 1, p. 1-11.

The uranium-bearing sandstone deposits of the Colorado Plateau are commonly referred to as "carnotite deposits." They have been the principal domestic source of uranium, radium, and vanadium. The deposits are largely restricted to a few stratigraphic zones, along which they have a wide but spotty areal distribution. The ore minerals mainly impregnate sandstone, though in places fossil plants are richly mineralized. Most of the ore bodies are small, but have a wide range in size, and within individual deposits the ore has a considerable range in thickness and grade. The deposits are irregularly tabular or lenticular, with their long axes nearly parallel to the bedding, but the ore does not folow the beds in detail.

The ore is thought to have been precipitated from ground-water solutions after the enclosing sands had accumulated and before regional deformation. Sedimentary structures that seem to have controlled the movement of these solutions and the features that probably localized the ore deposits are described, and their application as guides to ore finding is explained. — *Author's abstract*

84 Fischer, R. P., 1956, Uranium-vanadium-copper deposits on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 143-154; Geology of uranium and thorium, United Nations, v. 6, p. 605-614.

The uranium-vanadium-copper deposits of the Colorado Plateau region form a group of wide distribution and many common geologic characteristics. They have been the principal source of uranium and vanadium in the United States.

Structurally, the region has been relatively stable since Precambrian time. Exposed rocks consist mainly of late Paleozoic to Tertiary sedimentary strata that have been invaded by moderate-sized stocks and laccoliths of early Tertiary or perhaps Late Cretaceous age. Laramide deformation is expressed by several broad folds and sharp flexures, but in most places the sedimentary beds lie nearly horizontal.

The early ore minerals consist of copper sulfides and low-valent oxides and silicates of uranium and vanadium. These minerals alter to higher valent oxides of vanadium and to vanadates and other secondary uranium and copper minerals. Sandstone is the principal host rock, and the ore minerals mainly fill pore spaces, through partly replacing sand grains and associated argillaceous and carbonaceous material.

Ore bodies range from small masses only a few feet across to deposits several hundred feet across. The large ore bodies are mainly tabular, forming layers a few feet to as much as 20 feet thick that lie essentially parallel to bedding, but the layers are undulant and cut across the beds in places. Many ore bodies in sandstone are slightly elongate parallel to the trend of the stream that deposited the sandstone; some of the ore bodies in limestone are markedly elongate and follow lines of deformation.

Although these deposits have been found in many formations, ranging from late Paleozoic to middle Tertiary in age, deposits that have yielded significant production are mostly restricted to the Shinarump conglomerate and Chinle formation of Triassic age and the

Todilto limestone, Entrada sandstone, and Morrison formation of Jurassic age.

The deposits present peculiar problems of localization and genesis. In most places, the ore minerals were presumably introduced into their present positions by solutions moving laterally through the beds. Sedimentary structures, such as lenses, and associated argillaceous and carbonaceous material apparently influenced localization of many ore bodies. The regional distribution of deposits suggests to some geologists that regional deformation also influenced localization by providing pathways for vertical movement of solutions, and a few deposits show close association with such vertical pathways. Igneous activity and mineralization of definite hydrothermal origin are not closely associated with the deposits except in a few places.

Radioactive age determinations indicate that the deposits were formed in Late Cretaceous or early Tertiary time. If the ore metals were introduced into the host rock at this time, it seems likely that the metals were derived either from ascending hydrothermal solutions or by lateral or vertical secretion from the associated sediments. — *Author's abstract*

85 Fischer, R. P., Haff, J. C., and Rominger, J. F., 1947, Vanadium deposits near Placerville, San Miguel County, Colo.: Colo. Sci. Soc. Proc., v. 15, no. 3, p. 115-134.

The vanadium deposits near Placerville, discovered about 1900, occur in two belts in the Entrada sandstone of Late Jurassic age. The formations in the area are nearly horizontal sedimentary rocks of Permian to Cretaceous age which have been intruded by Tertiary igneous rocks and cut by numerous faults. The vanadium deposits seem to be older than the faults and intrusive rocks and thus not genetically related to them.

The ore, which is sandstone impregnated with vanadium minerals, forms a wavy layer within the upper 25 feet of the Entrada sandstone. The vanadium-bearing layer is nearly continuous and lies nearly parallel to the bedding but does not follow the bedding in detail. The layer averages a few inches in thickness, but locally it forms minable ore bodies from 1 foot to 20 feet thick. The ore bodies seem to be irregularly distributed and are either elongate or roughly circular in plan. Most of the elongate bodies occur where the vanadium-bearing layer cuts rather sharply across the bedding to form what the miner calls "rolls." The mineralization is believed to have taken place at a water table that existed before igneous activity and deformation. The genetic and structural conditions that controlled the localization of the ore bodies have not been definitely determined, and the exact locations of ore bodies cannot be predicted. A number of mines and prospects in the area are described.

86 Fischer, R. P., and Hilpert, L. S., 1952, Geology of the Uravan Mineral Belt: U. S. Geol. Survey Bull 988-A, p. 1-13.

The name "Uravan mineral belt" is applied to a narrow, elongate area in southwestern Colorado in which carnotite deposits in the Morrison formation have a closer spacing, larger size, and higher grade than those in adjoining areas. The belt extends from Gateway through Uravan to Slick Rock.

The deposits within the belt tend to be clustered in patches of favorable ground 1,000 feet or more in width and usually a mile or more in length. These patches of favorable ground, and the deposits within them, generally are elongate normal to the trend of the mineral belt. Similarly the fossil logs and the ore rolls within the deposits have a dominant orientation normal to the belt. The mineral belt probably was localized by geologic conditions extant during the time the ore-bearing Morrison formation was deposited. These geologic relations allow the projection of the belt under deep cover between points of exposure and offer the chance of discovering moderately large reserves of carnotite ore in the unexplored parts of the belt.

The U. S. Geological Survey has done intensive diamond-drill exploration in parts of the Uravan mineral belt since 1947. The concept of the geologic relations of the mineral belt and certain geologic features that can be recognized in drill core have been useful in guiding this exploration. These features, consisting of the thickness and color of the ore-bearing sandstone, the color of mudstone associated with the sandstone, and the presence of abundant carbonaceous material in the ore-bearing sandstone, are briefly described. Exploration is done in three stages. During the first stage, holes are drilled at a wide spacing, approximately 1,000 feet apart, to find and roughly delimit favorable ground. During the second stage, the favorable ground is drilled with holes at a moderate spacing, 100 to 300 feet apart, to search for ore deposits. In the third stage of drilling, offset holes are drilled at 50- or 100-foot intervals around a discovery hole to extend and roughly outline the deposit. — *Author's abstract*

87 Fischer, R. P., Stokes, W. L., and Smith, L. E., 1944, Geology of the Rifle Creek vanadium area, Garfield County, Colo.: U. S. Geol. Survey Strategic Minerals Inv. Prelim. Rept., 5 p. (mimeographed, limited distribution).

The vanadium deposits at the Rifle and Garfield mines, northeast of Rifle, Garfield County, Colo., are in the Entrada sandstone of Upper Jurassic age. The rocks in the area dip southward at moderately low angles, but this dip is locally disrupted by small folds and faults. Exposed formations include the Triassic "Red Beds," the Entrada sandstone and Morrison formation of Jurassic age, and the Dakota(?) sandstone and Mancos shale of Cretaceous age.

The ore is light-colored crossbedded fine-grained sandstone impregnated with vanadium minerals, the most important of which is a fine-grained micaceous mineral of uncertain composition. Fossil carbonaceous material has not been observed. The deposits occur in three layers which range in thickness from a feather-edge to a maximum of 30 feet and average about 5 feet. Generally the ore layers are nearly conformable to formation contacts; they normally cross inclined bedding. At the Rifle mine, the lower ore layer forms an elongate deposit that has been mined horizontally for nearly 5,000 feet. An altered zone at the top of the "Red Beds" is locally vanadiferous; the thicker parts of the altered zone are spatially related to vanadium deposits in the overlying Entrada sandstone.

88 Fix, Philip, 1956, Geochemical prospecting for uranium by sampling ground and surface waters: Geology of uranium and thorium,

United Nations, v. 6, p. 788-791; see also, Hydrogeochemical exploration for uranium: U. S. Geol. Survey Prof. Paper 300, p. 667-671.

Ground water and surface water take uranium into solution in amounts determined by the pH and chemical composition of the water and the composition and permeability of the geologic material with which the water is in contact If due regard is accorded these variables, the uranium content of the water will serve as a rough index of the uranium concentration in the geologic materials near the place where the sample was obtained.

The background concentration of uranium in large streams in the United States is commonly about 0.1 part per billion but may be higher or lower depending on the character of the geologic terrane traversed. Geological and chemical factors determine what point between 3 and 10 times the background shall be considered the threshold of significance. In most uraniferous areas the surface waters commonly contain from 1 to 10 parts per billion.

Analysis of water is a quick way of indexing the uranium possibilities in unexplored areas if the sampling of surface waters has been carefully planned. The analysis of water samples is also useful in guiding both physical exploration and detailed geologic work in known mineralized districts and active mines. Data from more than 700 analyzed samples have established the validity of this method, and comparisons with geologic and geophysical methods of prospecting show excellent agreement.

89 Fleck, Herman, and Haldane, W. G., 1907, A study of the uranium and vanadium belts of southern Colorado: Rept. of the Colo. State Bur. of Mines, 1905-1906, p. 47-115.

The geology of the uranium and vanadium deposits in southwestern Colorado, the metallurgy of the ores, and the uses of the metals are discussed. Little is known of the geology of the deposits. They are in sandstone beds in a series of sandstone, shale, and conglomerate above the La Plata formation (Entrada sandstone) of Jurassic age and were formed subsequent to the deposition of the sandstone beds. Some writers (Hillebrand and Ransome, 1900) have suggested that the deposits were recently formed near the present surface as local concentrations of material already in the sandstone. Fleck and Haldane suggest that the deposits may be much older. A number of mines and prospects in the region are described.

90 Freeman, H. D., 1935, Vanadium and uranium deposits in the Triassic and Jurassic sandstones of the Plateau area of southwestern Colorado and southeastern Utah: Unpub. thesis, Princeton Univ.

Some of the vanadium and uranium deposits on the Colorado Plateau are described. The vanadium deposits at Placerville occur in the La Plata sandstone (Entrada) of Jurassic age at about the same stratigraphic horizon throughout the district. Roscoelite, the principal vanadium mineral, occurs in thin but rich (as much as 8.3 percent V_2O_5) horizontal seams with sparsely disseminated mineral in the sandstone above and below. The deposits range from less than 1 foot to 10 feet in thickness and may extend for several hundred feet along the outcrop. Deposits of chromium occur in the same area, but not in association with the vanadium deposits.

The description of the uranium deposits in the Shinarump conglomerate of Triassic age at Temple Mountain, Utah, is taken from Hess, 1922 (see ref. 130).

Most of the uranium deposits in the Paradox Valley area are small bodies of carnotite-impregnated sandstone about 300 feet above the base of the Morrison formation of Jurassic age. The host bed, from 40 to 70 feet thick, is a crossbedded sandstone that contains mudstone lenses, numerous clay galls, and abundant organic debris.

The author reviews previous theories of origin, proposes that the deposits are syngenetic, and suggests that the metals were introduced with bits of clay or deposited by biochemical processes.

91 Friedel, Charles, and Cumenge, E., 1899, Sur un nouveau minerai d'urane, la carnotite: Soc. franc. mineralogie Bull., v. 22, p. 26-29, (In French); Bull. Soc. Chim. de Paris (3), v. 21, p. 328 (In French); Acad. des Sciences, Paris, Comptes Rendus, v. 128, p. 532 (In French); Chemical News, v. 80, p. 16.

A powdery yellow substance from Montrose County, Colo., was received by the authors and found to be a new mineral species. The mineral, a hydrous potassium uranyl vanadate, was named carnotite in honor of M. Adolphe Carnot.

92 Gabelman, J. W., 1956, Uranium deposits in limestone: U. S. Geol. Survey Prof. Paper 300, p. 387-404; Geology of uranium and thorium, United Nations, v. 6, p. 338-345.

The Todilto limestone of Middle Jurassic age is present in northern New Mexico in an area which roughly coincides with the San Juan Basin. Throughout the basin the limestone is deformed by intraformational folds ranging in width from less than 1 inch to about 35 feet. Folding may have begun contemporaneously with deposition, but it continued after lithification. Fold axes have two major directions and form a reticulate pattern which commonly coincides with the joint pattern.

The mineralized areas occupy the troughs of wide, shallow synclines which plunge down the northeast flank of the Zuni uplift. Ore deposits are confined to the crests of the small anticlines within the synclines and are, therefore, long and narrow. Ore trends coincide with the reticulate joint and fold pattern directions; the deposits occur close to the larger faults.

Uranium in considerably smaller quantities occurs in the Kaibab limestone of Permian age in Arizona, in the San Andres equivalent of that limestone in New Mexico, in calcareous parts of the Bidahochi formation of Miocene age in the Hopi Buttes area of Arizona, and in algal limestone in the Browns Park formation of Miocene age in Wyoming.

93 Gabelman, J. W., 1956, Uranium deposits in paludal black shales, Dakota formation, San Juan Basin, N. Mex.: U. S. Geol. Survey Prof. Paper 300, p. 303-319; Geology of uranium and thorium, United Nations, v. 6, p. 422-429.

Uranium deposits are present in black shale at the base of the

Dakota sandstone of Cretaceous age in the San Juan Basin, northwestern New Mexico. The shales are of paludal and littoral origin and are richly carbonaceous. The shale beds are discontinuous lenses which interfinger with, and are enclosed by, discontinuous channel-sand lenses formed by ancient streams. Interbedded sandstone beds and lenses are gray, medium- to coarse-grained, and highly contaminated with carbonaceous trash.

Uranium is most common in the carbonaceous sandstone lenses which have the greatest lithologic variability. Yellow uranium minerals impregnate the most carbonaceous parts of the sandstone. Less commonly, beds of pure black carbonaceous shale or peat overlying ancient stream channel sands are mineralized rather than the neighboring sands. No uranium minerals are recognizable in the shales and the uranium is presumably absorbed by the carbon.

In the Gallup area, the Diamond No. 2 and Becenti deposits are in carbonaceous sandstone beds, and the Hogback No. 4 deposit is in black carbonaceous shale.

In the Grants area, the Silver Spur, Small Stake, and Dakota deposits are in the carbonaceous basal part of the Dakota sandstone which is enclosed by shale.

In the Nacimiento uplift, the Butler deposit is in a thin peat lens in the basal zone of interbedded black shales and sandstones in the Dakota formation. The Diamond No. 2, Hogback No. 4, and Butler deposits are described briefly.

94 Gale, H. S., 1906, Carnotite in Rio Blanco County, Colo.: U. S. Geol. Survey Bull. 315-C, p. 110-117.

Carnotite deposits about 15 miles northeast of Meeker in Rio Blanco County are in sandstone of the Dakota sandstone of Cretaceous age. The carnotite coats fractures in the sandstone and is associated with fossil wood. The deposits are probably superficial.

95 Gale, H. S., 1908, Carnotite and associated minerals in western Routt County, Colo.: U. S. Geol. Survey Bull. 340, p. 257-262.

The carnotite deposits near Skull Creek in western Routt County occur in a white massive crossbedded coarse-grained sandstone of Jurassic age. Uranium, vanadium, copper, selenium, and chromium minerals impregnate the sandstone and coat fractures along a shear zone. The rock is heavily stained with limonite.

96 Garrels, R. M., 1953, Some thermodynamic relations among the vanadium oxides, and their relations to the oxidation state of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 38, no. 11-12, p. 1251-1265; [abs.] Geol. Soc. America Bull., v. 64, no. 12, p. 1426.

Fields of stability of several vanadium oxides in water solution at 25° C have been calculated as functions of pH and oxidation potential. The bivalent V_2O_2 is not expected under natural conditions; it should occur only at oxidation potentials below the breakdown potential of water. The oxide corresponding to the mineral montroseite $V_2O_3\,H_2O$ or VOOH, is predicted to coexist with common metal sulfides and to oxidize to V_2O_4 at about the same potential at which sulfide ion oxidized to sulfate. Owing to difficulties entailed by the complex chemistry of vanadium, V^{+5}, no attempt was made to calculate a boundary between V_2O_4 and a higher oxide. Diagrams showing the fields of stability of the various oxides have been constructed, and contours showing the activities of the various vanadium ions have been superimposed. The stability fields of the vanadium oxides should be useful in deducing the environment of formation of the carnotite ores and the "blue-black" ores of the Colorado Plateaus. — *Author's abstract*

97 Garrels, R. M., 1954, Thermodynamic relations among the uranium oxides, and their relation to the oxidation states of the uranium ores of the Colorado Plateaus [abs.]: Geol. Soc. America Bull., v. 65, no. 12, p. 1254-1255.

Fields of stability of uranyl hydroxide and uranous hydroxide in water solution at 25° C and 1 atmosphere pressure have been calculated as functions of Eh and pH. Equilibrium values of the activity of uranyl ion and of uranous ion also have been calculated and are shown as contours on the stability fields. Thermodynamic relations among the uranyl hydroxides, oxides, and hydrated oxides indicate that the free-energy differences among the various species are small. The data are interpreted to mean that a variety of such uranium (VI) compounds may form and even co-exist. Similar studies of the uranium (IV) hydroxide indicate that it is unstable relative to the oxide and might well be expected to invert to the oxide at a finite rate. Uranium (V) compounds probably have a transitory existence because of the instability of the UO_2+ ion; uranium (III) oxides and hydroxides would not be expected to occur naturally because the uranium (III) ion would decompose water. A comparison of the behavior of the low-valence vanadium hydroxides (III and IV) with uranium (IV) and (VI) hydroxides indicates that vanadium (III) hydroxide should oxidize to the vanadium (IV) hydroxide at a slightly lower potential than that required for the uranous to uranyl hydroxide pair. A speculative diagram showing probable fields of stability of many of the major minerals of the Colorado Plateaus is presented, and it is suggested that a consistent picture results if one assumes that the ores represent the superimposition of a weathering environment on a mineral assemblage formed in a primary reducing environment. — *Author's abstract*

98 Garrels, R. M., 1955, Weathering of uranium deposits: Min. Cong. Jour., v. 41, no. 5, p. 58-60.

The vanadium-uranium and copper-uranium ores of the "sandstone-type" deposits of the Colorado Plateau exhibit an extremely complex and varied mineralogy. The ores occur predominantly in sandstones of continental origin. The ore minerals characteristically are interstitial to or replacements of the sandstone particles. Before 1950, the metals contained in the ores mined were of a high-valent type, but since then low-valent ores from deeper mines have contributed significantly to the total production.

A consistent picture of the genesis and alteration of the minerals is obtained if it is assumed that the deposits originally consisted entirely of minerals containing uranium, vanadium, copper, and iron in their lower valence states, and that the present ores exhibit, from place to place, every possible degree and range of oxidation of this primary assemblage. The sequence of minerals formed during the process of oxidation and weathering is illustrated and explained.

99 Gilkey, A. K., 1953, Fracture pattern of the Zuni uplift—Final report: U. S. Atomic Energy Comm. RME-3050, 34 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The objectives of this study have been to determine the nature of the major fracture pattern of the Zuni uplift; to analyze this pattern for evidence of the mode of origin of the uplift; and to compare the fracturing in the ore areas with that elsewhere on the uplift to see whether diagnostic features exist that might make it possible to indicate other favorable areas.—*Author's abstract*

The dominant set of fractures is roughly parallel to the long axis of the Zuni uplift, and a subordinate set is about normal to the long axis. These sets of joints and faults are present in both crystalline and sedimentary rocks. Gilkey concludes that the Zuni uplift was produced by up-warping of the crystalline core by large regional tectonic elements. The general area in which most of the uranium ore has been found is a prominently faulted part of the uplift with joints especially common near the faults. Some ore bodies show well-defined elongations in the directions of the principal fracturing; this suggests that the ore is related to fracturing.

100 Gill, J. R., 1953, Uranium minerals in Cedar Canyon, Harding County, S. Dak.; *in* Search for and geology of radioactive deposits, Semiannual progress report, December 1, 1952 to May 31, 1953: U. S. Geol. Survey TEI-330, p. 124-125, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A small deposit of a yellow uranium mineral, possibly carnotite, occurs in a channel sandstone at the top of the White River formation of Oligocene age in Cedar Canyon near the south end of the Slim Buttes. The mineral is most abundant in the sandstone near the base of the channel and is concentrated near fossil roots or stems and on the surfaces of fractures.

101 Gilluly, James, and Reeside, J. B., Jr., 1928, Sedimentary rocks of the San Rafael Swell and some adjacent areas in eastern Utah: U. S. Geol. Survey Prof. Paper 150-D, p. 61-110.

The sedimentary formations of the San Rafael Swell area range in age from Permian to Late Cretaceous. Triassic and Jurassic formations are most widely exposed and are mostly of continental origin. Formations older than Late Cretaceous are predominantly sandstone. A few igneous dikes and sills are present in the southwestern part of the San Rafael Swell. The formations are described and a number of measured sections are presented.

102 Gilluly, James, 1928, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U. S. Geol. Survey Bull. 806-C, p. 69-130.

Sedimentary formations in this area of Emery County range in age from Permian to Late Cretaceous. A number of igneous sills and dikes are present in the southwestern part of the San Rafael Swell which is a huge asymmetric elongate dome. The dips on the north and west flank are gentle, but the south and southeast flanks are steeply dipping. Many minor folds are superimposed on the main structure, and small faults are present in many places. The report includes a geologic and structural map of the area at a scale of 1 : 126,720.

Vanadium-uranium ores have been mined at several places along the east flank of the swell, and carnotite stains were seen at several places on the west flank.

103 Gott, G. B., and Erickson, R. L., 1952, Reconnaissance of uranium and copper deposits in parts of New Mexico, Colorado, Utah, Idaho, and Wyoming: U. S. Geol. Survey Circ. 219, 16 p.

Copper and uranium are associated in several minable uranium deposits on the Colorado Plateau. Because of this association, a reconnaissance was made of several known deposits of copper disseminated in sandstone to determine whether they might be a source of uranium. Commercial-grade uranium is not associated with the copper deposits that were examined.

Uraniferous asphaltite deposits in the Shinarump conglomerate of Triassic age in the San Rafael Swell were also examined. These deposits may be economic sources of uranium. The uraniferous asphaltite deposits contain a suite of trace metals similar to that contained in crude oil and other bituminous materials. The metals in the asphaltite may have been concentrated from petroleum.

104 Gott, G. B., Jones, R. S., Post, E. V., and Braddock, W. A., 1954, Black Hills, S. Dak.; *in* Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953, to May 31, 1954: U. S. Geol. Survey TEI-440, p. 64-72, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The repeated occurrence in the Edgemont district of vanadium-uranium deposits in host rocks possessing particular characteristics was observed by the authors. These characteristics may be guides in predicting the occurrence of ore. The most favorable host rock appears to be the thickest sandstone in the lower part of the Lakota formation of Cretaceous age. The deposits generally occur where the sandstone contains numerous mudstone "splits." Many of the carnotite deposits occur on structural terraces. A characteristic purplish-pink iron oxide stain impregnates the sandstones adjacent to many of the deposits; this color appears to be one of the more useful guides to ore. Silica and carbonate cement are associated with the deposits in some places, but also are present in areas where ore is not known to exist.

105 Gray, J. R., and Tennissen, A. C., 1953, Uranium investigations near Aladdin, Crook County, Wyo.: U. S. Atomic Energy Comm. RME-4016, 13 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits occur in the Cretaceous Inyan Kara group in

Crook County, Wyo. Carnotite-type minerals and possibly autunite and torbernite occur in sandstone as interstitial fillings and as coatings along bedding planes in four ore zones. Many areas of anomalous radioactivity are known. The radioactivity anomalies and mineralized areas are on the west flank of an anticline plunging north from the main part of the Black Hills uplift.

106 Gregg, C. C., 1952, Reconnaissance and investigational drilling on Hoskinninni and Nokai Mesas, San Juan County, Utah, and Navajo County, Ariz.: U. S. Atomic Energy Comm. RMO-987, 10 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Diamond-drilling programs on Hoskinninni and Nokai Mesas demonstrated that these areas do not contain sufficient mineralized ground to justify further work by the Federal Government. The gross geology is similar to uranium-producing areas in Monument Valley. Sediments of the Shinarump conglomerate of Triassic age fill channels cut into the underlying Moenkopi formation, also of Triassic age. Copper and uranium minerals appear at places in sandstone and siltstone in these channels, but the size and grade do not satisfy the minimum requirements for ore.

107 Gregory, H. E., 1913, The Shinarump conglomerate: Amer. Jour. Sci., Ser. 4, v. 35, no. 208, p. 424-438.

The Shinarump conglomerate is a gray to white siliceous sediment of continental origin. It consists of cross beds and lenses of pebble conglomerate, coarse sandstone, and fine sandstone. The structure and texture vary both vertically and laterally from place to place. The formation is resistant to erosion and forms cliffs, benches, and tables. Silicified fossil wood is found throughout the Shinarump. Though the formation has great areal extent, it is usually less than 100 feet thick. The Shinarump conglomerate, probably of Late Triassic age, apparently is conformably overlain by the Chinle formation of Late Triassic age. In most places it rests unconformably on the Moenkopi formation of Permian age (now considered Triassic).

108 Gregory, H. E., 1917, Geology of the Navajo country — a reconnaissance of parts of Arizona, New Mexico, and Utah: U. S. Geol. Survey Prof. Paper 93, 161 p.

The geology of the Navajo country, an area in northeastern Arizona and adjacent parts of Utah, Colorado, and New Mexico, is described. Exposed consolidated sedimentary rocks in the region are mostly of Triassic, Jurassic, and Cretaceous age, but rocks of Precambrian, Pennsylvanian, and Eocene age also are present. Relatively large areas in the Carrizo Mountains and in the Hopi Buttes area are underlain by igneous rocks. Smaller bodies of igneous rocks are widely distributed. The sedimentary rocks in the region are horizontal or tilted at low angles except where they have been sharply folded into monoclines. Two major structural basins (now called San Juan basin and Black Mesa basin) and three major uplifts (now called Zuni uplift, Defiance uplift, and Monument uplift) are present in the region. The report includes a geologic map of the Navajo country at a scale of 1:500,000.

In Monument Valley a uranium-vanadium mineral, probably carnotite, was found among the pebbles of the Shinarump conglomerate and in association with petrified wood of the Chinle formation.

109 Gregory, H. E., 1938, The San Juan country, a geographic and geologic reconnaissance of southeastern Utah: U. S. Geol. Survey Prof. Paper 188, 123 p.

Exposed sedimentary formations in this region range in age from Pennsylvanian to Late Cretaceous. The formations are described, and a number of measured sections are presented. Relatively large masses of intrusive igneous rocks are present in the Abajo Mountains. The main structural features in the area are the Sage Plain downwarp, the Monument upwarp, and the intervening Comb Ridge monocline. Smaller folds locally modify these structures. The report includes a reconnaissance geologic map of the region at a scale of about 1:500,000.

110 Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona: U. S. Geol. Survey Prof. Paper 164, 161 p.

The sedimentary rocks of the Kaiparowits region are chiefly of Triassic, Jurassic, and Cretaceous age, but Eocene rocks cap the highest plateaus, and Permian sandstones and limestones are present in the upwarps. Extrusive igneous rocks of Tertiary age blanket an area in the northwest part of the region. The Waterpocket monocline and the East Kaibab monocline are the major flexures of the region. The Circle Cliffs upwarp, the Kaibab upwarp, and the Kaiparowits downwarp cover large areas and are modified by small folds. The Paunsaugunt fault in the northwest part of the region has a displacement of 1,500 feet. The report includes a geologic map of the region at a scale of 1:250,000.

111 Grier, A. W., (ed.), 1954, Geology of portions of the High Plateaus and adjacent Canyon lands, central and south-central Utah: Intermountain Assoc. of Petroleum Geologists, 5th Ann. Field Conference [Guidebook], Salt Lake City, Utah, 130 p.

This publication includes papers on the geomorphology, structural history, stratigraphic correlations, and the stratigraphy of the Carboniferous, Permian, Triassic, Jurassic, and Cretaceous and Tertiary rocks. Each of the formations is described. The stratigraphy and structure of the Capitol Reef area, the Kaiparowits region, and the Paunsaugunt Plateau region are described. The guidebook also contains papers on the oil and gas fields of the region and the uranium deposits at Temple Mountain. A number of geologic and structural maps and sections at various scales are included.

112 Griggs, R. L., 1953, A reconnaissance for uranium in New Mexico: U. S. Geol. Survey Circ. 354, 9 p.

A reconnaissance for uranium in New Mexico was made in the Datil area in Catron and Socorro Counties, the Cerrillos and the Glorieta mining districts in Santa Fe County, the Las Vegas area and the Tecolote mining district in San Miguel County, and in an area in Colfax County. Significant uranium deposits were found only in the Datil area, where one sample contained 0.056 percent U_3O_8. In this area, yellow uranium minerals associated with carbonaceous material and limonite occur in the Mesaverde formation of Cretaceous age at the base of sandstone beds which overlie shale.

113 Griggs, R. L., 1954, Datil Mountain area, New Mexico; *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 129-130, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits occur in the Mesaverde formation of Cretaceous age and in the Baca formation of Tertiary age in this area. The uranium is concentrated at the contact of porous sandstones with underlying impermeable shale beds and shale stringers. At one locality the uranium is in the thin edge of a lenticular sandstone in the Baca formation. Yellow uranium minerals are visible in some prospects but the uranium, in an unidentified form, is associated mainly with ferruginous and carbonaceous material in sandstone.

114 Gruner, J. W., 1951, Annual report for July 1, 1950 to June 30, 1951; part 2, Origin of the uranium deposits in the Shinarump formation — A preliminary study: U. S. Atomic Energy Comm. RMO-837, 27 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Features common to many or all of the uranium deposits in the Shinarump conglomerate of Triassic age are reviewed. Most of the deposits are associated with fossil carbonaceous material and are near the base of channels cut into the underlying rocks, which in most places are part of the Moenkopi formation, and are filled with irregular lenses and beds of conglomerate, sandstone, and clay. Commonly there is a thin bleached zone directly under the contact. The unoxidized parts of the deposits bear no relation to present-day topography. The uranium may be associated with vanadium or copper or neither, but pyrite is almost always present in the unoxidized ore.

Hypotheses that might explain the origin of uranium deposits in the Shinarump conglomerate are the hydrothermal, the concentration from the surface water that deposited the Shinarump conglomerate in Triassic time, and the concentration from circulating meteoric water since the deposition of the Shinarump conglomerate. Gruner favors the hypothesis that the surface waters that deposited the Shinarump conglomerate also deposited the uranium at the same time. Organic matter is thought to have been the precipitating agent.

115 Gruner, J. W., 1954, The origin of the uranium deposits of the Colorado Plateau and adjacent regions: Mines Mag., v. 44, no. 3, p. 53-56.

The uranium deposits on the Colorado Plateau are in essentially flat-lying sedimentary rocks that range in age from Permian to Tertiary, but most are in Triassic and Jurassic rocks. The uranium is associated with plant remains. The normally red rocks are bleached to gray near the uranium deposits, presumably by the same solutions which concentrated the uranium.

The rocks containing the ores are flood-plain deposits. Interstratified with them are thick volcanic ash beds, now mudstones and silts. The volcanic ash presumably contained a small amount of uranium which was easily leached by ground-water. During the Laramide revolution, tilting and doming of strata caused important changes in ground-water flow. At this stage much of the uranium was precipitated by the plant and hydrocarbon materials. The oxidation that changed the color of the ores from black to yellow is related to the present surface.

116 Gruner, J. W., 1956, A comparison of black uranium ores in Utah, New Mexico, and Wyoming: U. S. Geol. Survey Prof. Paper 300, p. 203-205; Geology of uranium and thorium, United Nations, v. 6, p. 530-532.

Unoxidized uranium deposits in four widely separated areas (Lisbon Valley, Utah; Temple Mountain, Utah; Poison Canyon, N. Mex.; and Gas Hills, Wyo.) are compared. The host rocks range in age from Triassic to Eocene, and all are poorly sorted arkosic sandstones which contain much organic carbon. Vanadium is not present in the deposits in Eocene rocks. The identified dark uranium-bearing minerals are uraninite and coffinite. The paragenetic sequence of minerals at all four deposits are very similar; the deposits were produced by nearly the same geologic processes. The "black ores" were deposited in a reducing environment, and they are primary in the sense that oxidized yellow ores are derived from them.

117 Gruner, J. W., Gardiner, Lynn, and Smith, D. K., Jr., 1953, Annual report for July 1, 1952 to March 31, 1953: U. S. Atomic Energy Comm. RME-3044, 58 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

This report is divided into six independent parts.

In Part 1 preliminary results of field work in the White Canyon and San Rafael Swell areas of Utah are reported. The "flop-over" at Temple Mountain, Utah, is described, and the structure is interpreted as collapse due to an unknown cause.

In Part 2 four categories of uranium-bearing carbonaceous materials are discussed. They are: lignitic plant material, asphaltite, gilsonite, and liquid hydrocarbons. Uraniferous asphaltite is common in the Temple Mountain mines, where it occurs interstitial to sand grains and as globules.

Part 3 deals with the synthesis of certain uranium minerals.

In Part 4 the changes in color from red to green of the silts and shales associated with uranium deposits and uraniferous horizons are discussed. The color change is due to the destruction of the red coloring matter, hematite, either by reduction of the iron or by chemical reaction of the hematite with hydromicas.

Part 5 is a discussion of the quantity of disseminated uranium present in the sedimentary rocks of the Colorado Plateau, and how it could have been concentrated into ore bodies.

Part 6 is a discussion of the syngenetic and hydrothermal hypotheses of the origin of the uranium deposits of the Colorado Plateau. Gruner believes that the ore minerals probably were precipitated from acidic sulfate ground-water solutions. The uranium may have been derived from a magmatic source or, as Gruner believes, from a sedimentary source. A number of observed facts that may be pertinent to the problem are presented.

118 Gruner, J. W., Gardiner, Lynn, and Smith, D. K., Jr., 1954, Mineral associations in the uranium deposits of the Colorado Plateau and adjacent regions — Interim report: U. S. Atomic Energy Comm. RME-3092, 48 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The mineral associations and paragenetic sequence of the uranium ore minerals of the Colorado Plateau are similar in most of the deposits, notwithstanding the preponderance of vanadium-bearing minerals in some deposits and sulfides in others. "Black ores" containing uraninite and coffinite are unoxidized and are not necessarily of hydrothermal origin.

119 Gruner, J. W., Rosenzweig, Abraham, and Smith, D. K., Jr., 1954, The mineralogy of the "Mi Vida" uranium ore deposit of the Utex Exploration Company in the Indian Wash area, Utah; *in* Annual Report for April 1, 1953 to March 31, 1954: U. S. Atomic Energy Comm. RME-3094, p. 15-27, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The "Mi Vida" vanadium-uranium ore deposit is in calcareous sandstone and mudstone lenses in the Chinle formation of Triassic age. The area is on the southwest flank of the Lisbon Valley anticline, and the rocks strike 15° - 30° NW and dip about 10° SW. The ore body is covered with impervious shale and siltstone. The mineralogy of the host rock and ore minerals is described, and the origin of the deposit is discussed. Uraninite is the major uranium mineral, but tyuyamunite and metatyuyamunite also are recognized. Montroseite, doloresite, and unidentified vanadium minerals are present. The ore minerals are associated with abundant carbonaceous material.

120 Gruner, J. W., Towle, C. C., and Gardiner, Lynn, 1951, Uranium mineralization in Todilto limestone near Grants, McKinley County, N. Mex. [abs.]: Econ. Geology, v. 46, no. 7, p. 802; Geol. Soc. America Bull., v. 62, no. 12, p. 1445.

Uranium ores have been found in Todilto limestone near Grants, N. Mex., about 75 miles west of Albuquerque. The rocks are a part of the southern rim of the San Juan Basin and dip gently northward. The Todilto is practically conformably underlain by Entrada sandstone. The Summerville formation overlies it. The limestone in the area under discussion varies from 3 to 20 feet in thickness. Usually, the upper part shows considerable recrystallization. It is in this portion that most of the mineralization is found. Here, the minerals carnotite, tyuyamunite, uranophane, and some amorphous, ill-defined uranium-vanadium compounds partly replace the calcite. Fluorite has been found in two places replacing calcite. Pitchblende in minute blebs has been identified. The lower, thinly bedded limestone contains uranium only along joints and fractures. Very minor amounts of uranium minerals have been discovered in the basal few feet of the overlying Summerville. It may be stated tentatively that the uranium content is probably of syngenetic origin. Diagenesis caused recrystallization of the upper Todilto and some concentrations of the ore. Circulating ground water caused much later solution and reprecipitation in the ores. — *Authors' abstract*

121 Grutt, E. W., Jr., 1955, Geologic notes on some Wyoming uranium districts: Mines Mag., v. 45, no. 3, p. 106-108.

Uranium in Wyoming occurs in veins in Precambrian rocks, in sedimentary rocks of Paleozoic and Mesozoic age, and in sedimentary rocks of Tertiary age. The deposits in sedimentary rocks of Tertiary age are most important.

In the Owl Creek Mountains, in the Pedro Mountains, and in the Laramie Mountains, uraninite occurs in hydrothermal veins in Precambrian rocks.

Carnotite deposits occur in sandstones of the Inyan Kara group of Early Cretaceous age on the northwest flank of the Black Hills.

Uranium deposits in the Powder River Basin occur in the Wasatch formation of Eocene age in two broad areas. In the Pumpkin Buttes area, there are two types of deposits: disseminated and concretionary. Both occur in coarse-grained arkosic sandstone but are not usually found together. The deposits in Converse County are mostly of the disseminated type.

The uranium deposits near Lance Creek, on the southeast margin of the Powder River Basin are mostly in arkosic sandstone in the White River formation of Oligocene age.

In the Gas Hills area, the majority of the deposits occur in gently dipping coarse-grained arkosic sandstone of the Wind River formation of Eocene age. A number of uranium minerals are disseminated in the host rock. In the Owl Creek Mountains, meta-autunite is disseminated along seams or bedding in tuffaceous sediments of the Wind River formation.

In the Crooks Gap area in the Green Mountains, uranophane and other uranium minerals are disseminated in very coarse-grained sandstone and conglomerate in the lower part of the Wasatch formation of Eocene age.

Near Baggs, Wyo., and Maybell, Colo., uranium minerals are irregularly disseminated in sandstone of the Browns Park formation of Miocene age.

122 Grutt, E. W., Jr., 1956, Uranium deposits in Tertiary clastics in Wyoming and northern Colorado: Geology of uranium and thorium, United Nations, v. 6, p. 392-402; see also, Uranium deposits in Tertiary sedimentary rocks in Wyoming and northern Colorado: U. S. Geol. Survey Prof. Paper 300, p. 361-370.

Uranium deposits in the Wyoming sedimentary basins are in medium- to coarse-grained and conglomeratic sandstones of Eocene, Oligocene, and Miocene age. Torrential crossbedding is common; the sandstones have calcareous, ferruginous, or phosphatic cement and often contain carbonaceous material.

The important uranium minerals in deposits of the Powder River Basin are vanadates; the deposits in the Wind River Basin contain mostly phosphates and arsenates; and the principal uranium-bearing minerals in deposits of the Green Mountains, Great Divide basin, and Washakie basin are silicates and sulphates. Uraninite has been identified in deposits in the Wind River, Powder River, and

Washakie basins.

Stratigraphic and lithologic guides to uranium deposits in the important districts are suggested. Structure plays an important but obscure role, and the size and shape of the deposits range within wide limits. The most promising deposits are those which contain uranium minerals disseminated in sandstone strata as grain coatings and interstitial fillings. The largest ore body of this type probably contains more than 50,000 tons of ore.

Representative deposits from the various areas are described and compared with other deposits in similar environments.

123 Gustafson, J. K., 1949, Uranium resources: Nucleonics, v. 4, no. 5, p. 23-28.

The occurrence of uranium in nature, the potential supply of uranium, and the uranium procurement policy of the U. S. Atomic Energy Commission are discussed. Uranium deposits are divided into four main types: in igneous rocks, in veins of hydrothermal origin, in sedimentary rocks, and deposits of doubtful and perhaps complex origin. Within the fourth group are the carnotite-type uranium deposits of the Colorado Plateau. Tabular or lenticular bodies of carnotite-impregnated sandstone are found in certain parts of the Morrison and Entrada formations of Jurassic age and in the Shinarump conglomerate of Triassic age. The carnotite is commonly associated with other vanadium minerals and fossil plant material.

124 Hall, R. B., 1955, Recent uranium developments in the Black Hills: Mines Mag., v. 45, no. 3, p. 60, 122-123.

The Black Hills is a relatively flat, domal uplift, elliptical in shape, and trends northwesterly. Crystalline Precambrian rocks are exposed in the core, and sedimentary rocks of Cambrian to Cretaceous age form a series of cuestas and hogbacks around the core. In the Edgemont district, Fall River County, S. Dak., the regional dip is to the southwest; the regional dip is interrupted by two large south-plunging anticlines and some minor structural features.

Uranium deposits in the Edgemont district, first discovered in 1951, are mainly confined to the Inyan Kara group of Early Cretaceous age. The Inyan Kara group, in descending order, includes the Fall River, Fuson, and Lakota formations. Most of the deposits and all of the large producing mines are in areas where the rocks dip less than 5°, and generally where there is a sharp change in dip. The Gould ore body, the largest mine in the Black Hills, is in the basal part of the Fall River sandstone. Near the Gould mine, the ore-bearing rock is a buff to brown coarse- to very coarse-grained sandstone. The principal ore mineral, carnotite, occurs as interstitial fillings. Another large ore body was discovered during exploratory drilling done to test the validity of the concept of structural control. It is thought that lithologic controls combined with structural controls were instrumental in localizing the ore bodies.

An electrical resistivity survey in the drilling area demonstrated that a resistivity anomaly exists over the ore body. Resistivity techniques may be successful in delimiting favorable ground.

125 Hatfield, K. G., and Maise, C. R., 1954, Geologic reconnaissance of the Defiance uplift, Apache County, Ariz: U. S. Atomic Energy Comm. RME-71, 14 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

A search for uranium deposits in the Defiance uplift was concentrated on the Chinle formation of Triassic age. No large deposits were found. A number of mineralized localities in the Chinle are associated with small concretions and carbonized logs. The deposits are surrounded by a zone in which the normal blue or purple color has been altered to gray or brownish-orange. Small uranium deposits may occur in formations other than the Chinle. Formations that range in age from Precambrian to Tertiary are exposed in the broad structural feature known as the Defiance uplift.

126 Hess, F. L., 1913, Carnotite near Green River, Utah: U. S. Geol. Survey Bull. 530-K, p. 161-164.

The carnotite deposits near Green River occur in coarse-grained crossbedded sandstone of the Flaming Gorge formation (redefined in part as the Morrison formation) of Jurassic age. The carnotite impregnates the sandstone, coats fractures, and fills small irregular cavities. The mineral is associated with iron oxide stains and abundant fossil plant material.

127 Hess, F. L., 1913, Notes on the vanadium deposits near Placerville, Colo.: U. S. Geol. Survey Bull. 530-K, p. 142-156.

The vanadium mineral roscoelite occurs in a dark fine-grained sandstone in the La Plata formation (redefined in part as the Entrada sandstone) of Jurassic age. The mineral impregnates the sandstone in a few places at about the same stratigraphic horizon along several miles of outcrop. The individual deposits are tabular and have an outcrop length of as much as 700 feet. Carnotite, which is less plentiful than roscoelite, occurs locally along joints in the vanadium deposits. Mariposite, a green chromium mineral, is disseminated in sandstone and nearly envelopes the vanadium deposits. Inconclusive evidence suggests that the deposits were formed from hot water solutions of magmatic origin.

128 Hess, F. L., 1913, Uranium and vanadium: U. S. Geol. Survey, Mineral Resources, 1912, Pt. 1, p. 1003-1007.

This report is a brief study of the uranium and vanadium industry of the world in 1912 and a survey of the geology of deposits of uranium and vanadium. The deposits discussed are in southwestern Colorado, in Gilpin County, Colo., in several less important localities in the United States; and in Central Europe, England, Australia, Sweden, Norway, Portugal, France, Russia, East Africa, and Madagascar.

The uranium and vanadium minerals in the deposits in southwestern Colorado occur as interstitial fillings in sandstone. There are two types of deposits: carnotite and roscoelite. The roscoelite deposits contain a negligible amount of uranium.

129 Hess, F. L., 1914, A hypothesis for the origin of the carnotites of Colorado and Utah: Econ. Geology, v. 9, no. 7, p. 675-688.

The composition and areal occurrence of carnotite are described, and hypotheses of the origin of the carnotite deposits are reviewed. The carnotite deposits on the Colorado Plateau occur in nearly white, crossbedded medium-grained sandstone and are closely associated with carbonaceous fossil material. The carnotite impregnates the sandstone in aureoles around carbonaceous material and replaces plant debris and that part of fossil logs which evidently was most decayed at the time of burial.

Hess advances the hypothesis that the metals were weathered from veins and carried in solution to a shallow sea where they were absorbed by or precipitated by decaying organic matter. Upon the lifting, draining, and aerating of the rocks the minerals were oxidized to form carnotite and other minerals. During and after oxidation the carnotite moved slightly outward to form aureoles around the carbonaceous matter.

130 Hess, F. L., 1922, Uranium-bearing asphaltite sediments of Utah: Eng. Min. Jour., v. 114, no. 7, p. 272-276.

Uranium and vanadium minerals occur in and associated with asphaltite in the Shinarump conglomerate of Triassic age at Temple Mountain, Emery County, Utah, on the southeast flank of the San Rafael Swell. Fossil plant material is abundant. The asphaltite grains are detrital and are deformed around other sand grains. The metal-bearing asphaltite is notably harder and blacker than is asphaltite that contains no metals. Brightly colored uranium and vanadium minerals are conspicuous on the outcrop; they become markedly rarer a few feet from the surface. Ore shoots have an irregular ellipsoidal form that is probably due to weathering. The feature on part of Temple Mountain called the "flop-over" may be due to the action of sulfurous hot springs. Normally red or brown sediments are bleached to white; the structure is jumbled, and asphaltite is absent. Small masses of uranium ore occur in the "flop-over" in the Wingate sandstone of Jurassic age. The metals were probably leached from the asphaltite and redeposited; the volatile products were lost.

Hess suggests that the uranium and vanadium were picked up by the asphaltite grains before or during deposition of the surrounding sediments. The position, size, and shape of the ore shoots, although modified by weathering, are thought to be fortuitous. The possibility also exists that the metals were derived from the hot springs.

131 Hess, F. L., 1933, Uranium, vanadium, radium, gold, silver, and molybdenum sedimentary deposits; *in* Ore deposits of the Western States (Lindgren volume), p. 450-481, Am. Inst. Min. Met. Eng., New York.

Uranium and vanadium deposits are widely distributed on the Colorado Plateau in rocks of Triassic and Jurassic age. The vanadium may occur without visible plant fossils, but the uranium is nowhere found without either fossiliferous or petroliferous carbonaceous material in association.

The uraniferous asphaltite deposits at Temple Mountain, Utah, are in the Shinarump conglomerate of Triassic age. The asphaltite was deposited with the sand as rolled grains—some of which were hard enough to hold their shape. The beds contain abundant fossil plants. The uranium ore lies in distinct shoots that have an irregular ellipsoidal shape which may be due to weathering. Brightly colored uranium and vanadium minerals are also present, mostly near the surface. The asphaltite and its contained metals were locally corroded and redeposited or removed by hot sulfurous waters flowing upward along minor structures.

Large deposits of vanadium ore occur in very fine grained sandstone of the La Plata (Entrada) sandstone of Jurassic age near Placerville, Colo. The vanadium mineral, roscoelite, impregnates the sandstone to form broad thinly lenticular ore bodies. The edges are enclosed in a halo of sandstone in which is disseminated a chromium mineral, mariposite. Carnotite stains joints in the sandstone, particularly where the vanadium content is high.

The carnotite deposits in the Morrison formation of Jurassic age are in crossbedded sandstones in the lower part of the formation. Many deposits are confined to replaced logs and the halos around them. In some places carnotite forms tiny veinlets in fractures, and in others the mineralized rock stops abruptly at fractures. Locally, the ore bodies are bounded by smooth rounded "rolls" that cut across bedding planes.

The author suggests that the metals were removed from dilute solutions directly or indirectly by decaying carbonaceous matter at the time of deposition of the sediments.

132 Hewett, D. F., 1923, Carnotite in southern Nevada: Eng. Min. Jour., v. 115, no. 5, p. 232-235.

Small noncommercial carnotite deposits have been found in three areas in Clark County, Nev., southwest of Las Vegas. Near Sloan the carnotite occurs in vertical joints in a Tertiary rhyolite flow. The occurrences near Sutor are in a sandstone bed that immediately underlies the lowest Permian limestone bed, and those near Goodsprings are in a sandstone bed that overlies the lowest Permian limestone bed. The deposits probably were emplaced in relatively recent time by surface waters.

133 Hewett, D. F., 1925, Carnotite near Aguila, Ariz.: Eng. Min. Jour., v. 120, no. 1, p. 19.

Small noncommercial carnotite deposits occur in a lacustrine bentonitic tuff bed that is faulted, tilted, and intruded by dikes. The tuff beds overlie Precambrian granite and are overlain by basalt flows. The carnotite replaces clay blebs near poorly defined fractures in the tuffs. The deposits were probably formed recently by circulating ground water.

134 Hewett, D. F., 1925, Central Arizona holds deposits of carnotite: Ariz. Min. Jour., v. 9, no. 7, p. 49-50.

Carnotite occurs as small patches along minor crosscutting fractures in drab thin-bedded Tertiary tuffs near Aguila in Maricopa County, Ariz. The tuffs are now largely bentonitic clays that total more than 200 feet in thickness. They are overlain by several hundred feet of vesicular basalt. The rocks are faulted and dip 10° - 25° S. The carnotite probably has been deposited recently by circulating ground water.

135 Hillebrand, W. F., and Ransome, F. L., 1900, On carnotite and associated vanadiferous minerals in western Colorado: Am. Jour. Sci., 4th ser., v. 10, no. 56, p. 120-144; 1905, U. S. Geol. Survey Bull. 262, p. 9-31.

The first part of this report describes some of the vanadium-uranium deposits in western Colorado, and the second part describes chemical analyses of the ores. The deposits were discovered only a few years before the report was published and little exploration and development had been done.

Vanadium deposits with minor amounts of uranium occur in the La Plata sandstone (Entrada sandstone) of Jurassic age near Placerville, Colo. Roscoelite impregnates fine-grained sandstone and may replace calcite cement. The vanadiferous material is fairly continuous over about 2,000 feet of outcrop but has no constant thickness; it locally splits into two or more layers. A thin discontinuous seam of sandstone impregnated with carnotite occurs near the base of the vanadiferous material.

The deposits at La Sal Creek are in massive nearly white sandstone in the McElmo formation (Morrison formation) of Jurassic age. Carnotite impregnates the sandstone along bedding planes and minor fractures. The deposits are small, discontinuous, and superficial. At the Roc Creek deposit carnotite impregnates sandstone and fills small openings along the hanging wall of a fault. At several other deposits in the region carnotite also impregnates the sandstone host rock.

The deposits of carnotite and roscoelite were formed subsequent to the deposition of the host rocks. The origin of the roscoelite deposits is not clear, but the carnotite deposits are thought to have been formed at the present surface of the ground by evaporation of uraniferous ground water. The metals were originally disseminated in the mass of the host formations.

136 Hilpert, L. S., and Freeman, V. L., 1956, Guides to uranium deposits in the Gallup-Laguna area, New Mexico: Geology of uranium and thorium, United Nations, v. 6, p. 346-349; see also, Guides to uranium deposits in the Morrison formation, Gallup-Laguna area, New Mexico: U. S. Geol. Survey Prof. Paper 300, p. 299-302.

Significant quantities of uranium ore have been produced in New Mexico; most of the total has come from the Gallup-Laguna area of McKinley and Valencia Counties where the ore occurs mostly in the Todilto limestone and the Morrison formation, both of Jurassic age. A large part of the reserves in New Mexico are in the Brushy Basin member of the Morrison formation in the Gallup-Laguna area.

The Brushy Basin member consists mostly of claystone with subordinate amounts of sandstone, conglomerate, and limestone; it ranges in thickness from a knife-edge to about 375 feet. The larger deposits in the Brushy Basin member generally occur in the thicker parts of relatively coarse grained sandstone units. Preliminary ore guides and methods of prospecting have been developed for two of these sandstones—the so-called Poison Canyon and Jackpile sandstone units.

137 Hinckley, D. N., and Volgamore, J. H., 1953, Reconnaissance of Little Wild Horse Mesa, Green River Desert, Emery County, Utah: U. S. Atomic Energy Comm. RME-43, 14 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium occurrences on Little Wild Horse Mesa are in medium- to coarse-grained crossbedded sandstone near the middle of the Salt Wash member of the Morrison formation of Jurassic age. Two of the three mineralized localities may have some economic importance.

138 Huff, L. C., 1955, Preliminary geochemical studies in the Capitol Reef area, Wayne County, Utah: U. S. Geol. Survey Bull. 1015-H, p. 247-256.

A bleached zone at the base of the Chinle formation near the Oyler mine, Wayne County, Utah, was studied to establish whether there was a chemical relationship between bleaching in the Chinle and uranium mineralization in the Shinarump conglomerate. The preliminary results suggest that the bleaching was accompanied by a slightly reducing acid solution which deposited zinc and copper but no uranium in the bleached zone. A field test for heavy metals which has been devised for geochemical prospecting appears to be satisfactory for detecting and tracing such mineralization effects. It is hypothesized that the solution which bleached the Chinle also deposited uranium in the Shinarump, but more work is needed to clarify this relationship. — *Author's abstract*

139 Huleatt, W. P., Hazen, S. W., Jr., and Traver, W. M., Jr., 1946, Exploration of vanadium region of Western Colorado and Eastern Utah: U. S. Bur. Mines. Rept. Inv. 3930, 30 p.

Core-drilling on the Colorado Plateau from May to December 1943 was done by the Bureau of Mines to stimulate wartime production of vanadium ore. Eight hundred ninety-five core-drill holes having an aggregate depth of 38,510 feet were distributed among 46 areas. Small maps, short descriptions of each area and assay data are included in the report.

The deposits explored are carnotite ore bodies in the Morrison formation of Jurassic age. The ore bodies are tabular, irregular in shape, and generally conform to the bedding. The uranium and vanadium minerals impregnate the sandstone and may locally replace fossil wood.

140 Hunt, C. B., 1953, Geology and geography of the Henry Mountains region, Utah: U. S. Geol. Survey Prof. Paper 228, 234 p.

The Henry Mountains are situated in a structural basin; exposed sedimentary rocks aggregate about 8,000 feet in thickness and include rocks of Permian, Triassic, Jurassic, Late Cretaceous, and Quaternary age. More than 80 percent of the pre-Cretaceous rocks are of continental origin; most of the Upper Cretaceous rocks are marine. Faults are generally uncommon. Each of the Henry Mountains is a structural dome produced by the injection of stocks and laccolithic masses. The report includes geologic and structural maps of the region at a scale of about 1:125,000, and geologic maps of Mount Hillers, of Mount Holmes and Mount Ellsworth, and of Mount Ellen and Mount Pennell, all at the scale of 1:31,680.

Vanadium- and uranium-bearing minerals locally impregnate the sandstone and replace fossil plant remains in the lower part of the Morrison formation of Jurassic age on the east side of the Henry Mountains. Similar deposits, some of which contain copper, occur in the Shinarump conglomerate of Triassic age in areas adjacent to this region.

141 Huttl, J. B., 1954, New Mexico uranium: Eng. Min. Jour., v. 155, no. 8, p. 96-99.

This report deals mainly with the uranium mining and milling operations of the Anaconda Copper Mining Company in the Grants district, New Mexico. The Anaconda's Section 9 mine near Grants is in the Todilto limestone of Jurassic age, and the Jackpile mine, also an Anaconda property, is in the Westwater Canyon member of the Morrison formation of Jurassic age. The carnotite ore body at the Jackpile mine is cut by a diabase sill.

142 Isachsen, Y. W., 1954, Ore deposits of the Big Indian Wash-Lisbon Valley area; *in* Uranium deposits and general geology of southeastern Utah: Utah Geol. Society, Guidebook to the geology of Utah, no. 9, p. 95-105, Salt Lake City, Utah.

Uranium deposits in the Big Indian Wash-Lisbon Valley area are mostly in the Chinle formation of Triassic age, but small deposits occur in the Cutler formation of Permian age. The uranium-producing area is on the southwest flank of the faulted northwest-trending Lisbon Valley anticline, which is probably a salt structure.

In the deposits in the Chinle formation, uraninite and montroseite replace calcite cement, and uraninite also replaces coalified logs and carbonaceous debris. Pyrite is fairly abundant. The deposits, all of which are in the lower part of the formation, are sometimes directly on the underlying Cutler formation. Ore does not follow the host rock uniformly, nor does it follow primary textures in detail The host rock includes siltstone, fine- to coarse-grained arkosic sandstone, and conglomerate. The most favorable host rock is gray-green fine- to coarse-grained arkosic sandstone cemented with calcite.

The deposits in the Cutler formation consist of carnotite and becquerelite disseminated in streaks, pods, and patches in fluvial arkose lenses.

143 Isachsen, Y. W., 1954, Uranium deposits, Big Indian Wash-Lisbon Valley area, San Juan County, Utah [abs.]: Econ. Geology, v. 49, no. 7, p. 804; Geol. Soc. America Bull., v. 65, no. 12, p. 1267-1268.

Extensive bedded uranium deposits have been discovered... along the southwest limb of the Lisbon Valley salt anticline. The major ore bodies are confined to the lower portion of the Triassic Chinle formation which unconformably overlies the Permian Cutler formation. Arkosic, gray to black sandstone with intercalated lenses of gray-green mudstone and mudstone pebble conglomerate contain uraninite which has replaced carbonaceous material and calcite cement. Locally, solid masses of pure uraninite result from replacement of organic material. Montroseite occurs with uraninite in the major deposits discovered to date. Tyuyamunite frequently forms surface coatings along fractures. Thickness of ore in the area is generally sufficient to permit mining with little or no waste rock.

In several areas known to contain ore bodies, the gray-green color of the lower Chinle formation extends upwards into the overlying red Chinle mudstones in the manner of an alteration halo. About 100 feet beneath the Chinle ore horizon are arkosic lenses in the Cutler formation which contain, in some instances, low grade uranium mineralization. The ore minerals, carnotite and becquerelite, are disseminated in the arkose with greatest concentration adjacent to fractures. The oxidized state of these minerals coupled with the concentration near fractures suggests that the Cutler mineralization is due to leaching from uraninite ore bodies in the Chinle formation. — *Author's abstract*

144 Isachsen, Y. W., 1956, Geology of uranium deposits of the Shinarump and Chinle formations on the Colorado Plateau: Geology of uranium and thorium, United Nations, v. 6, p. 350-367; see also, Isachsen, Y. W., and Evensen, C. G., 1956, Geology of uranium deposits of the Shinarump and Chinle formations on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 263-280.

Large uranium deposits are present in the Shinarump conglomerate of Triassic age in Monument Valley, Ariz., and White Canyon, Utah; and in the Chinle formation, also of Triassic age, near Cameron, Ariz., and in the Big Indian Wash-Lisbon Valley and Temple Mountain areas in Utah.

Both formations are of continental origin. The Shinarump conglomerate consists dominantly of light-gray sandstone with lenses of grit and conglomerate, and smaller quantities of interbedded mudstone. The base of the Shinarump conglomerate fills ancient stream channels cut into the underlying Moenkopi formation, also of Triassic age. Carbonaceous plant debris is common in the channel-fills. The Chinle formation is predominantly a fluvial sequence of red to brown siltstone and mudstone interbedded with sandstone and conglomerate. Carbonaceous plant remains are widely distributed in the formation; asphaltite occurs locally.

Copper, copper-uranium, and vanadium-uranium deposits have been found in both formations. Oxidized and unoxidized ore minerals frequently occur together; however, the principal uranium mineral in most deposits is uraninite. The ore minerals are disseminated in sandstone, siltstone, and conglomerate, and locally replace carbonaceous plant material and calcite cement.

Uranium deposits in the Shinarump conglomerate are restricted to ancient stream channels and are usually low on the flanks or in the bottom of the channels. The deposits in the Chinle formation are not restricted to channels nor to any one stratigraphic unit in the formation, but most large deposits occur in sandstone or coarser clastic rocks in the lower half of the formation. The principal ore controls in the larger deposits of the Chinle formation appear to be structural rather than sedimentary. Bleaching or other discoloration of red beds above and below the deposits in the Chinle formation may be used as an exploration guide.

Age determinations indicate that the uranium deposits are epigenetic, but the source of the metals is not known. Localization of ore in channel fills and other permeable clastic units which contain carbonaceous plant material suggests that transmissibility is an important local ore control and that carbonaceous material is the main precipitant.

145 Isachsen, Y. W., Mitcham, T. W., and Wood, H. B., 1955, Age and sedimentary environments of uranium host rocks, Colorado Plateau: Econ. Geology, v. 50, no. 2, p. 127-134.

Uranium deposits have been found on the Colorado Plateau in a Tertiary monzonite porphyry and in 32 sedimentary units that range in age from Pennsylvanian to Tertiary. At least one example in each formation is briefly described. Ore has been produced from 22 of these units. Host rocks represent all of the principal sedimentary environments except the glacial. The wide variation in age and depositional environments of the host rocks suggests an epigenetic origin for uranium ore on the Colorado Plateau.

146 Jobin, D. A., 1956, Regional transmissivity of the exposed sediments of the Colorado Plateau as related to distribution of uranium deposits: U. S. Geol. Survey Prof. Paper 300, p. 207-211; Geology of uranium and thorium, United Nations, v. 6, p. 317-320.

A study of regional transmissivity of the sedimentary rocks of the Colorado Plateau has been made to relate variations in transmissivity to the position of known ore deposits. Transmissivity is defined as the capacity of a sedimentary rock as a whole to transmit fluids. The coefficient of transmissivity of sedimentary rock at a given locality is equal to the product of its thickness and mean permeability.

The sedimentary rocks on the Colorado Plateau may be divided into two groups on the basis of their transmissivity. Shales, mudstones, evaporites, and limestones are in effect nontransmissive because of their very low permeability. Conglomerates, sandstones, and siltstones are permeable and, therefore, the transmissive groups. The transmissive rocks may be separated into two groups: eolian sandstones of relatively uniform permeability and thickness, and fluvial sandstone, siltstone, and conglomerate which have a great range of permeability and thickness. The second group contains most of the uranium deposits in the Colorado Plateau. There is, however, no apparent correlation between position of ore deposits within a particular host rock and its regional permeability or transmissivity.

147 Jones, D. J., 1954, Sedimentary features and mineralization of the Salt Wash sandstone at Cove Mesa, Carrizo Mountains, Apache County, Ariz.: U. S. Atomic Energy Comm. RME-3093 (pt. 2), 40 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits at Cove Mesa are in sandstone beds in the Salt Wash member of the Morrison formation of Jurassic age. Mineralized areas flank the curving trends of areas which have a high sandstone:shale ratio. The Salt Wash stream channels changed direction from northwesterly to northeasterly in the Cove Mesa area. Areas marginal to Salt Wash channels, particularly where the channels changed direction, are apparently most favorable for the occurrence of uranium deposits. Cyclic repetition of rock types was observed in the Salt Wash member. The sequence includes a massive friable sandstone, capped by a thinner and strongly cross-bedded sandstone, and is normally repeated three times. The uranium deposits are largely confined to the massive friable type of sandstone.

148 Joubin, F. R., 1955, Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau — a discussion: Econ. Geology, v. 50, no. 2, p. 233-234.

This paper is a short comment on the paper of the same name by Rosenzweig, Gruner, and Gardiner (Ref. no. 215). Joubin observes that uranium is associated with hydrocarbons (thucolite) in a number of localities in the Precambrian rocks of Canada, but is absent from adjacent graphitic rocks. He suggests that the agent active in the precipitation of uranium is not elemental carbon but rather the hydrocarbon fraction (resin) that was once present.

149 Kaiser, E. P., 1951, Uraniferous quartzite, Red Bulff prospect, Gila County, Ariz.: U. S. Geol. Survey Circ. 137, 10 p.

Radioactivity is present in two zones in the silty upper part of the Dripping Spring quartzite of Precambrian age at the Red Bluff prospect in Gila County, Ariz. An unidentified uranium mineral, possibly pitchblende, is rather evenly disseminated through most of the rock in the deposits, but black streaks and fractures within the deposits contain a greater amount of uranium. Stratigraphic control of the radioactive zones is indicated by the restriction of the zones to two layers, each about 20 feet thick. The rock in the radioactive zones has been bleached and partly recrystallized. The uranium deposits are epigenetic and probably of hydrothermal origin.

150 Kelley, D. R., 1954, Drilling in the North Point No. 6 and Horn Channels, White Canyon, San Juan County, Utah: U. S. Atomic Energy Comm. RME-63, 33 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Shinarump conglomerate of Triassic age in the North Point No. 6 and Horn channels was explored by drilling. Two of the 52 diamond-drill holes penetrated ore-grade material. However, no ore bodies were found. Uranium silicates and secondary copper minerals are locally present in the channels. It is thought that the sediments contain too little carbonaceous material and that the sandstone is too fine-grained to be a suitable host rock.

151 Kelley, V. C., 1956, Influence of regional structure and tectonic history upon the origin and distribution of uranium on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 171-178; Geology of uranium and thorium, United Nations, v. 6, p. 299-306.

Although primary sedimentary structures are important factors in the localization of uranium in the rocks of the Colorado Plateau, the regional structure strongly influences the distribution and perhaps the origin of the uranium deposits.

Aspects of the regional structure are discussed in three parts. In the first of these, the structural elements are described and a tectonic subdivision of the Colorado Plateau made. In the second part, the geologic and tectonic history of the Colorado Plateau is interpreted from sedimentary thicknesses, the lithologic character of the rock, and unconformities. The third part is a discussion of tectonic influences on origin and distribution of uranium.

Geologic factors which may have been affected by tectonic events and which may have affected the distribution of ore include the geologic environments, paleohydrology, igneous activity, and erosional history.

152 Kelley, V. C., 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: Univ. of N. Mex. publications in geology, no. 5, Univ. of N. Mex. Press, Albuquerque, 120 p.

The relationship between regional structure and regional concentration of uranium deposits was studied. The report of this study consists of three principal parts: (1) a description and analysis of the regional tectonics, (2) a geologic history, and (3) a discussion of the tectonic influence on distribution and origin of uranium.

In the first part the structural elements are described and tectonic subdivisions of the Colorado Plateau are made. Within the principal tectonic subdivisions are a host of minor structures such as folds, faults, joints, and intrusive centers which are described and discussed from a regional point of view.

In the second part the sedimentational and tectonic histories of the Colorado Plateau are outlined as interpreted from sedimentary thicknesses, the nature of the rocks and unconformities.

In the third part, which deals with the relation between regional structure and uranium distribution on the Colorado Plateau, the conclusion is reached that little if any direct relation exists. However, tectonic events have had an important bearing on other geologic features that may have contributed directly to the origin and distribution of uranium. These factors are included in a discussion of provenances and environments, paleohydrology, igneous activity, and erosional history.

153 Kentro, D. M., 1954, Processing uranium ores: Min. Cong. Jour., v. 40, no. 12, p. 58-60, 71.

The two basic methods of processing uranium ores from the Colorado Plateau are the acid leach and the carbonate leach. These hydrometallurgical processes are modified, when necessary, to fit the different types of ore. The details of many of the different steps are not revealed, and improvements on the processes are being made continually.

In the acid leach, the crushed ore may first be roasted to destroy carbonaceous material, thus reducing acid consumption. If both uranium and vanadium are to be recovered, salt is added to the roaster feed to convert the vanadium to a water-soluble compound; when the conversion is complete, the vanadium is removed by a water leach. The residue goes to the sulfuric acid tanks where leaching for from 1 to 24 hours at temperatures of 30° - 40° C is normally sufficient to dissolve the uranium. Separation of the leach solution from the solids is difficult, but baking the ores before leaching and adding certain chemicals usually improves filtering and settling rates sufficiently. The uranium may be separated from the leach solution by several methods.

The carbonate leach process is particularly useful on ores that have a high content of lime. A solution containing 5 to 10 percent sodium carbonate and 1 to 5 percent sodium bicarbonate is used. Leaching times of 4 to 24 hours at temperatures of 70° - 115° C are normally sufficient for good recoveries. The addition of an oxidizing agent is usually necessary. If sufficient vanadium is present in the ore, the metals can be precipitated from the leach solution by lowering the pH, and if not, caustic soda is added to precipitate the uranium. The uranium-bearing product from both processes may be shipped as yellow cake, or it may be fused and shipped as black oxide of uranium.

154 Keys, W. S., 1956, Deep drilling in the Temple Mountain collapse, San Rafael Swell, Utah: Geology of uranium and thorium, United Nations, v. 6, p. 371-378; see also, Keys, W. S., and White, R. L., 1956, Investigation of the Temple Mountain collapse and associated features, San Rafael Swell, Emery County, Utah: U. S. Geol. Survey Prof. Paper 300, p. 285-298.

The collapse area at Temple Mountain is about 500 feet wide and 1,500 feet long; the maximum vertical displacement is about 300 feet. The core obtained from deep drilling (500-900 feet) shows that the rock has undergone flowage, fracturing, and alteration. Minerals present include pyrite, galena, arsenopyrite, realgar, pitchblende, unidentified uranium and vanadium minerals, and abundant asphalt.

The Sinbad and Kaibab limestones are missing in the six holes completed to date. Absence of the limestones suggests that the solution of carbonate rocks was in part responsible for the collapse of overlying sediments.

A new ore layer has been found at the top of the Coconino sandstone in a conglomerate of chert geodes and nodules cemented by asphaltic sandstone. This conglomerate occupies the stratigraphic position of the Kaibab limestone and probably represents insoluble remnants of the Kaibab. Weakly mineralized layers, associated with hard asphalt, were noted at various depths within the collapsed area.

155 Kimball, Gordon, 1904, Discovery of carnotite: Eng. Min. Jour., v. 77, no. 24, p. 956.

In May, 1898, the author shipped 10 tons of carnotite ore containing 21.5 percent U_3O_8 and more than 15 percent V_2O_5 from claims on Roc Creek, Montrose County, Colo., to Denver, Colo., where it was sold for $2,600. The yellow ore occurs in white sandstone as disseminated grains, bedded veins, seams, occasional pockets, and vug fillings.

156 King, J. W., 1951, Geology and ore deposits of Mesa V, Lukachukai district, Arizona: U. S. Atomic Energy Comm. RMO-754, 17 p.,

issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Vanadium-uranium deposits on Mesa V are in the lower part of a fine-grained sandstone unit in the Salt Wash member of the Morrison formation of Jurassic age. The unit is from 65 to 95 feet above the base of the formation. The light-tan limonite-stained sandstone is from 15 to 25 feet thick and contains thin mudstone beds which are bleached to gray near the ore deposits. The ore minerals, principally carnotite and vanoxite, impregnate the sandstone and coat the sand grains. Fossil carbonaceous material is locally abundant and at places is mineralized. The ore bodies on Mesa V are small but numerous; the deposits on Mesa Four-and-a-half are generally similar but are more numerous and of higher grade.

157 King, J. W., 1951, Reconnaissance of Red Rock district, Cove Mesa, and Kinusta (Tree) Mesa, Ariz.: U. S. Atomic Energy Comm. RMO-755, 11 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

All known vanadium-uranium ore deposits in the Red Rock district and the Cove Mesa and Kinusta Mesa areas are in the lower part of the Salt Wash member of the Morrison formation of Jurassic age. The Salt Wash member is about 200 feet thick and is composed of gray to brown fine-grained quartzose sandstone interbedded with red or green mudstone lenses a maximum of 5 feet thick. The small ore bodies are as much as 3 feet thick. Carnotite is the principal uranium mineral.

158 King, J. W., and Ellsworth, P. C., 1951, Geology and ore deposits of Mesa VII, Lukachukai district, Arizona: U. S. Atomic Energy Comm. RMO-803, 8 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Carnotite and vanoxite impregnate a light-tan sandstone at one place on the rim of Mesa VII. The sandstone bed is in the Salt Wash member of the Morrison formation of Jurassic age and is about 40 feet above the base of the formation. The ore exposure is less than 1 foot thick and is underlain by a green mudstone bed. The Salt Wash member on Mesa VII is composed of predominantly pink fine- to coarse-grained quartzose sandstone and interbedded red mudstone.

159 Klemic, Harry, and Baker, R. C., 1954, Occurrences of uranium in Carbon County, Pa.: U. S. Geol. Survey Circ. 350, 8 p.

Uranium vanadates, carbonates, and silicates occur in coarse graywacke conglomerate near the base of the Pottsville formation, of Pennsylvanian age, on the north limb of the Panther Valley syncline; and on the south limb, autunite and uranium silicates occur in graywacke sandstones near the top of the Catskill formation of Devonian age. Uraniferous graywacke sandstone occurs in the upper part of the Catskill formation near Butcher Hollow and near Penn Haven Junction in minor anticlines of the Broad Mountain anticline. Small amounts of kasolite and galena occur in the vicinity of Penn Haven Junction. — *Authors' Abstract*

The three uranium deposits in the Catskill formation appear to be at about the same stratigraphic horizon. The uranium minerals coat

fractures and are disseminated in the rock in lenses in discontinuously radioactive zones. The occurrences are all in gray or greenish-gray rock that contains finely divided carbonaceous material rather than in the red parts of the formations.

160 Knoerr, A. W., and Lutjen, G. P., editors, 1954, U_3O_8 — Formula for profits: Eng. Min. Jour., v. 155, no. 9, p. 87-118.

This article is a collection of several papers by several authors and deals mainly with the economic aspects of the uranium industry on the Colorado Plateau. Exploration and development, mining, and milling of ore are covered. Diagrams illustrating various ore controls and ore guides are included in a generalized discussion of the geology of the ore deposits.

161 Koeberlin, F. R., 1938, Sedimentary copper, vanadium-uranium, and silver in southwestern United States: Econ. Geology, v. 33, no. 4, p. 458-461.

This short communication was prompted by R. P. Fischer's paper of similar title published in 1937 in Economic Geology. Koeberlin suggests that the metals may have been derived from pyroclastic material. As explained by W. H. Emmons, mineral-bearing fluids expelled from cooling magmas may collect in domes and cupolas near the roofs. If the magmatic extract enters fractures and permeable zones, veins are formed. However, if the roof is not strong enough to confine the magma, the material may be ejected into the atmosphere as volcanic ash. The metallic content of the ash beds would be easily available to surface- or ground-water solutions because of the minute size of the metal-bearing particles.

162 Laverty, R. A., and Gross, E. B., 1956, Paragenetic studies of uranium deposits of the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 195-201; Geology of uranium and thorium, United Nations, v. 6, p. 533-539.

Detailed paragenetic studies have been made of several uranium deposits in Utah, Arizona, and New Mexico, and less detailed studies have been made of many other uranium deposits on the Colorado Plateau.

The composite paragenetic sequence is that expected in uranium ores deposited near the surface by juvenile water.

Paragenesis of these deposits is similar in that:

The uranium minerals occur as cement.

The earliest uranium minerals are always the lower valence oxides.

The uranium minerals are usually associated temporally and spatially with base metal sulfides.

Oxidized uranium minerals are found only in the youngest part of the sequence.

Similarities of the composite paragenetic sequence to that of the deposits of hydrothermal origin at Marysvale, Utah, are:

Early silicification and fluoritization.

Close association of uranium and sulfide minerals in both time and space.

Early U^{+4} minerals and late U^{+6} minerals.

163 Lindgren, Waldemar, 1933, Vanadium and uranium ores in sandstone; *in* Mineral deposits: 4th ed., New York and London, McGraw-Hill Book Company, Inc., p. 409-415.

Vanadium with some uranium and a trace of radium is common in gently inclined white crossbedded sandstones of the McElmo formation (Morrison formation) and La Plata sandstone (Entrada sandstone), both of Jurassic age, in western Colorado and eastern Utah. The three most important minerals are carnotite, vanoxite, and roscoelite. The carnotite ores are always associated with fossil wood. Lindgren suggests that the uranium and vanadium were concentrated by possibly tepid meteoric waters which leached the metals from terrigenous sediments derived from the disintegration of Precambrian igneous rocks and pegmatites.

164 Love, J. D., 1952, Preliminary report on uranium deposits in the Pumpkin Buttes area, Powder River Basin, Wyo.: U. S. Geol. Survey Circ. 176, 37 p.

Elongate concretionary bodies of uranium ore occur in sandstone beds in the Wasatch formation of Eocene age near the Pumpkin Buttes in northeastern Wyoming. Yellow and black uranium minerals are present but have not been specifically identified. Selected samples have contained more than 15 percent uranium. The host rocks are soft porous pink or tan medium- or coarse-grained crossbedded sandstones at several stratigraphic horizons and are persistent over a considerable area. The Pumpkin Buttes lie near the center of the Powder River Basin, a topographic and structural feature. The sedimentary rocks at Pumpkin Buttes are about 16,000 feet thick. Several deposits are described in some detail. The author suggests that the uranium was leached from overlying tuffaceous sedimentary rocks (now largely removed by erosion) and redeposited in the present location by ground water.

165 Love, J. D., 1953, Preliminary report on uranium deposits in the Miller Hill area, Carbon County, Wyo.: U. S. Geol. Survey Circ. 278, 10 p.

Most of the erratically distributed uranium deposits in the Miller Hill area of southern Wyoming occur in an algal limestone marker bed in the Browns Park formation of Miocene(?) age. The Browns Park formation is more than 1,000 feet thick, and consists of basal conglomerate, tuffs, tuffaceous limy sandstones, and thin persistent radioactive algal limestone beds. The formation unconformably overlies Precambrian crystalline rocks and slightly tilted and truncated rocks of Paleozoic, Mesozoic, and Cenozoic age. The disseminated uranium in the limestone marker bed is thought to be partly syngenetic. No uranium minerals were noted. The highest analysis showed 0.15 percent uranium, but most samples contained much less. The geologic column and the sampled localities are described.

166 Love, J. D., 1954, McComb area, Wyoming; *in* Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953 to May 31, 1954: U. S. Geol. Survey TEI-440, p. 175-178, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The McComb area is in the northern part of the Wind River

Basin near the Owl Creek Mountains in Fremont County, Wyo. Most of the uranium deposits in the area are in the Tepee Trail(?) formation of late Eocene(?) age. Autunite, schroeckingerite, and other uranium minerals occur in bentonitic claystone, bentonitic sandstone, arkosic sandstone, and boulder conglomerate. The adjoining Precambrian granite is locally radioactive.

167 Love, J. D., 1954, Preliminary report on uranium in the Gas Hills area, Fremont and Natrona Counties, Wyo.: U. S. Geol. Survey Circ. 352, 11 p.

Uranium deposits occur in the Thermopolis shale of Cretaceous age, in the Wind River formation of early Eocene age, and in rocks of middle Eocene age in the Gas Hills area of central Wyoming. The Cretaceous and older rocks are folded; the Tertiary rocks are almost horizontal. The Wind River formation was deposited on an irregular erosion surface developed on the Cretaceous and older rocks.

The uranium deposit in the Thermopolis shale is near the contact with the Wind River formation. The uranium was probably deposited in the shale from ground water solutions ponded by the erosion surface. The deposit is not of ore grade.

In most of the uranium ore deposits in the Wind River formation the uranium minerals meta-autunite(?), uranospinite(?), and an unidentified uranium mineral are disseminated in medium- to coarse-grained or conglomeratic sandstone, but some small low-grade deposits have been found in carbonaceous shale. Some of the deposits are in clayey sandstone, and some are associated with ferruginous concretions or beds. Samples selected from the deposits have contained as much as 10 percent uranium.

The uranium occurrence in the middle Eocene rocks is near the base of the sequence in a ferruginous coarse-grained conglomeratic sandstone. It does not contain ore-grade material.

The author suggests that uranium was leached from younger tuffaceous Tertiary rocks by ground water and transported downward and laterally to environments favorable for deposition.

168 Love, J. D., 1954, Uranium in the Mayoworth area, Johnson County, Wyo. — A preliminary report: U. S. Geol. Survey Circ. 358, 7 p.

The uranium mineral tyuyamunite occurs in a hard gray oolitic marine limestone at the base of the Sundance formation of Jurassic age in the Mayoworth area, Wyoming. This limestone bed is about 20 feet thick in the area, but it thins and disappears to the north and south. The rest of the Sundance formation is composed of marine sandstone and shale. The Sundance in this area is underlain by the Chugwater formation of Triassic age and is overlain by the Morrison formation of Jurassic age. The area is on the east flank of the Bighorn Mountains, and the rocks dip 10° - 15° NE. Metatyuyamunite coats fractures in the limestone and replaces the oolites. Selected samples contain as much as 0.71 percent uranium. Radioactivity is evident along some ferruginous brown clayey partings in the limestone. Dinosaur bones in the Morrison formation were radioactive wherever tested, but no significant amount of radioactivity was noted in the surrounding rocks. The uranium was apparently deposited in the limestone from ground water solutions. The author suggests that the uranium was derived from the White River formation of Oligocene age which truncates the older rocks about 2,500 feet higher, structurally, than the uranium deposits.

169 Lovering, T. G., 1954, Radioactive deposits of Nevada: U. S. Geol. Survey Bull. 1009-C, p. 63-106.

Uranium deposits in Nevada that were known before 1952 are described. Those which can be classed as sandstone-type deposits are included in this annotation. All known occurrences of this type are of low grade, and all are thought to have been deposited by ground waters.

Carnotite, associated with calcite and manganese oxide, forms fracture coatings and small veinlets in a rhyolite porphyry a few miles south of Sloan. Near Sutor and Goodsprings, carnotite associated with manganese oxide, calcite, and celestite forms joint and fracture coatings in sandstone of Permian age. Secondary uranium minerals occur as caliche in alluvium of Quaternary age between Erie and Arden. These four occurrences are in Clark County southwest of Las Vegas.

Discontinuous layers of uraniferous opal occur in vitric tuff and ash beds in the Virgin Valley opal district in northwestern Nevada. Carnotite occurs locally as fine coatings on parting planes and fractures in the opal.

170 Lovering, T. G., 1955, Progress in radioactive iron oxides investigations: Econ. Geology, v. 50, no. 2, p. 186-195.

Many uranium and thorium deposits in the western United States are closely associated with zones of radioactive secondary iron minerals. As a result of a study of these radioactive "limonites," it was concluded that uranium minerals in an oxidizing sulfide environment go into solution in acid sulfate waters as uranyl sulfate in the presence of ferric sulfate. When these acid waters are neutralized, ferric sulfate hydrolyzes to form a colloidal ferric oxide hydrate which absorbs the uranyl ion and thus removes most of the uranium from solution. As the colloidal ferric oxide hydrate ages, it crystallizes to form goethite and in this process most of the uranium is expelled to form particles of secondary uranium minerals. Most thorium minerals are resistant to weathering and are still present in their original form in the thorian limonites (goethite).

171 Lovering, T. S., Lakin, H. W., Ward, F. N., and Canney, F. C., 1956, The use of geochemical techniques and methods in prospecting for uranium: U. S. Geol. Survey Prof. Paper 300, p. 659-665; Geology of uranium and thorium, United Nations, v. 6, p. 782-787.

The art of successfully applying the fundamental principles of geochemical dispersion of the elements to the practical problem of finding hidden ore bodies depends on establishing diagnostic patterns of dispersed metals near ore deposits. The techniques of using variations in trace amounts of metals to delineate such patterns or anomalies is being used in the search for uranium and thorium.

The anomalies most commonly investigated in geochemical prospecting are those formed at the earth's surface by agents of weathering, erosion, or surficial transportation. Analysis of soil derived from the direct weathering of rock in place gives the most reliable and consistent indication of ore lying just beneath the soil. Attention also is being given to primary anomalies found in bedrock, and several studies have indicated the presence of dispersion halos adjoining and overlying some blind ore bodies — dispersions that are apparently related to the ore-depositing process.

Owing to the varying mobilities of different elements, some of these diagnostic halos, both primary and secondary, extend over a large area and form broad targets which are useful in general reconnaissance; others, which are restricted to the vicinity of the ore body itself, are more useful for detailed studies.

172 Lowell, J. D., 1953, Applications of cross stratification studies to problems of uranium exploration: U. S. Atomic Energy Comm. RME-44, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.; 1955, Econ. Geology, v. 50, no. 2, p. 177-185.

Uranium ore bodies in the lower part of the Morrison formation of Jurassic age in the Chuska Mountains area in northeastern Arizona are elongated in the direction of ancient stream channels. Intersections of ancient stream systems appear to be favorable loci for the deposition of uranium ore. These stream directions and intersections can be reconstructed and projected by mapping and analysis of cross stratification. Mineral-bearing solutions appear to have followed networks of filled channels and scours, moving through them along the path of greatest permeability. Where the velocity of the moving solutions was reduced by especially permeable rocks, uranium was deposited if a suitable geochemical environment existed.

173 Luedke, R. G., and Shoemaker, E. M., 1953, Tectonic map of the Colorado Plateau: U. S. Geol. Survey TEM-301, open-file report.

The structure of the Colorado Plateau is characterized by broad uplifts and basins, monoclinal folds, and salt anticlines. These structures are locally modified by large and small faults and by intrusive igneous rocks. Extensive areas of extrusive igneous rocks occur near the margins of the Colorado Plateau. Each of these features is discussed in the text. The map shows structural contours and fault lines and indicates the areas of salt structures and intrusive and extrusive igneous rocks.

174 McKay, E. J., 1955, Geology of the Atkinson Creek quadrangle, Colorado: U. S. Geol. Survey Map GQ 57 (with text).

The Atkinson Creek quadrangle is one of eighteen 7½ minute quadrangles in the carnotite-producing area of southwestern Colorado that are being mapped as part of a study of the carnotite deposits. Three other quadrangles (see Cater, F. W.) have been completed. The regional geology and the stratigraphy, structure, and mineral deposits of the area are described.

Rocks exposed in the eighteen quadrangles mapped consist of crystalline Precambrian rocks and sedimentary rocks that range from Late Paleozoic to Quaternary. Crystalline rocks crop out only in the northeastern part of the area along the flanks of the Uncompahgre Plateau; the rest of the area is underlain by sedimentary rocks. Over most of the region the sedimentary beds are flat lying, but in places they are disrupted by high-angle faults or are folded into northwest-trending monoclines, shallow synclines, and strongly developed anticlines.

The uranium-vanadium deposits are mostly restricted to the upper layer of sandstone lenses in the Salt Wash member of the Morrison formation of Jurassic age. The ore consists mainly of sandstone impregnated with uranium- and vanadium-bearing minerals, but rich concentrations are also associated with thin mudstone partings, beds of mudstone pebbles, and carbonized fossil plant material. The ore bodies range from small irregular masses that contain a few tons of ore to large tabular masses containing many thousands of tons; most ore bodies are relatively small and contain only a few hundred tons. Margins of ore bodies may be vaguely or sharply defined. Layers of ore lie essentially parallel to the bedding; most of the deposits occur in the thicker parts of the sandstone lenses, and commonly near the base of the lenses. The trend of the long direction of the deposits and the trend of the rolls in the sandstones are roughly parallel to the trend of the fossil logs in the sandstone and to the average resultant dip of the crossbedding in the sandstone.

175 McKee, E. D., Evenson, C. G., and Grundy, W. D., 1953, Studies in sedimentology of the Shinarump conglomerate of northeastern Arizona: U. S. Atomic Energy Comm. RME-3089, 48 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Studies of sedimentary features of the Shinarump conglomerate in northeastern Arizona . . . include analyses of composition, texture, and cross-stratification, examination of small-scale primary structures and of features of the basal contact, and the accumulation of data on stratigraphic relations and the controls of mineralization. — *Authors' abstract*

Much of the detrital sediment included in the Shinarump conglomerate was transported by streams from the south and southwest. The formation developed as a regressive sandstone, forming a blanket deposit across a surface of small hills, valleys, and stream channels. The types of deposition were rigidly controlled by water level.

Field relations indicate that lateral and downward moving solutions, following the paths taken by ground water today, introduced the mineral matter. Channels cut into the underlying Moenkopi formation appear to have determined the main directions of movement of the solutions; local sedimentary traps of several types within these channels have been responsible for ore accumulation. Carbonaceous matter and some varieties of clay deposits are associated with mineralization in many sedimentary traps.

176 McKelvey, V. E., 1955, Search for uranium in the United States: U. S. Geol. Survey Bull. 1030-A, p. 1-64.

The search for uranium in the United States is the most intensive ever made for any metal during our history. The largest part of this search has been concentrated in the Western States. No vein deposit of major importance by world standards has been discovered, but the search has led to the discovery of important minable deposits in sandstones in the Colorado Plateau, Wyoming, and South Dakota and in coals in South Dakota; of large low-grade deposits of uranium in phosphates in both western and Florida fields, in black shales in Tennessee, and in coals in the Dakotas, Wyoming, Idaho, and New Mexico; and of some promising occurrences of uranium in vein deposits.

The Colorado Plateau deposits contain carnotite and other oxidized minerals near the surface, but pitchblende and other dark uranium and vanadium minerals occur below the zone of oxidation. These minerals, along with hydromica, pyrite, and other sulfides, fill pore spaces in tuffaceous, arkosic, and quartzose sandstones and conglomerates and also replace clay galls, logs, and other wood fragments. Some of the deposits contain uraniferous asphaltic pellets and lenses. The ore deposits are tabular masses, generally elongated in the direction of the long axes of the sandstone or conglomerate lenses in which they occur. Near the ore, associated mudstone lenses are generally green or gray instead of the red generally found. Ore has been produced from about 20 formations on the Plateau, but the principle sources have been the Shinarump and Chinle formations of Triassic age, and the Entrada, Todilto, and Morrison formations of Jurassic age.

The report includes an extensive bibliography of uranium and a number of small maps of the United States showing the distribution of the different types of uranium deposits.

177 McKelvey, V. E., Everhart, D. L., and Garrels, R. M., 1956, Summary of hypotheses of genesis of uranium deposits: U. S. Geol. Survey Prof. Paper 300, p. 41-53; Geology of uranium and thorium, United Nations, v. 6, p. 551-561.

The origin and distribution of uranium in several geologic environments are discussed. The uranium deposits in sandstones on the Colorado Plateau are probably epigenetic. Certain studies have shown that the uranium probably came from a source deep in the earth, but it is possible that the uranium was derived from volcanic ash or other dispersed sources within the sedimentary pile and transported to the site of deposition by circulating waters or petroleum. Whatever the source, the path the ore solutions followed in the sandstones was determined mainly by sedimentary structures. The precipitation of uranium is probably caused by reduction due, perhaps, to decaying organic matter.

178 McKnight, E. T., 1940, Geology of area between Green and Colorado Rivers, Grand and San Juan Counties, Utah: U. S. Geol. Survey Bull. 908, 147 p.

Exposed sedimentary formations in this area range in age from Pennsylvania to Late Cretaceous. Most of the Permian, Triassic, and Jurassic formations are of continental origin; the Pennsylvanian and Upper Cretaceous formations are mostly marine. The dominant structure of the area is a gentle regional dip to the north. Superposed on the regional dip are several folds, some of which may be due to the intrusion of salt. The report includes a geologic map and structural geologic map of the area, both at the scale of 1:62,500.

179 Masters, J. A., 1951, Uranium deposits on southwest rim of Lukachukai Mountains, northeast Arizona: U. S. Atomic Energy Comm. RMO-911, 10 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Vanadium-uranium deposits on the southwest rim of the Lukachukai Mountains are in the Salt Wash member of the Morrison formation of Jurassic age. The Salt Wash member is composed of red and gray fine-grained quartzose sandstones interbedded with red and gray shales and siltstones. Carnotite and vanoxite are associated with carbonaceous material and impregnate crossbedded channel sandstone from 45 to 100 feet above the base of the Salt Wash sandstone. The host rock is light to dark gray; the rocks in other units are commonly red. However, not all gray sandstone is mineralized. The deposits extend from Dry Bone Mesa to Camp Mesa on the opposite side of the Lukachukai Mountains from the mineralized belt on the northeast rim.

180 Masters, J. A., 1953, Geology of the uranium deposits of the Lukachukai Mountains area, northeastern Arizona: U. S. Atomic Energy Comm. RME-27, 23 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.; 1955, Econ. Geology, v. 50, no. 2, p. 111-126.

A concentration of vanadium-uranium ore bodies occurs in fine-grained to very fine grained sandstone of the Salt Wash member of the Morrison formation of Jurassic age in a north-south belt across the Lukachukai Mountains. The belt extends from Mesa I to Mesa V on the north side, and from Two Prong Mesa to Step Mesa on the south side of the mountains. The ore belt conforms to a lenticular sandstone and mudstone facies and is bounded on the west by a massive sandstone facies and on the east by a mudstone facies containing some sandstone.

Changes in permeability influenced the movement of mineral-bearing solutions by causing their diversion, damming, and concentration. Permeability is greatest near ancient stream channels. The ore bodies, which lie in and are elongated parallel to these channels, tend to occur in clusters along the flanks. The presence of carbonaceous material and possibly of mudstone caused precipitation of uranium from solution. Ore most commonly occurs in gray and limonitic-brown sandstone; and, in the vicinity of ore, the associated mudstone is usually gray. The favorable color zones follow the ancient stream channels. The ore solutions presumably bleached the rocks from red to gray or brown. The ore bodies in the Lukachukai Mountains are generally smaller than, but otherwise similar to, those of the Uravan mineral belt. Carnotite and vanoxite impregnate sandstone and "trash piles," and replace fossil logs. Some ore bodies are rolls. The ore bodies in the Lukachukai Mountains and in the Uravan mineral belt are associated with bleached sandstone and mudstone.

The Lukachukai Mountains lie on the east flank of the Defiance uplift, and the rocks dip 1° - 2° NE. The Lukachukai anticline, a northwest-plunging sharply asymmetric flexure, reverses this dip by 10 to 30°. The axis of the attendant syncline lies along the northeast edge of the Lukachukai Mountains.

181 Merritt, P. L., 1950, Uranium exploration in the United States: Rocks and Minerals, v. 25, no. 7-8, p. 363-370; Canadian Min. and Met. Bull., v. 43, no. 460, p. 438-443; Mines Mag., v. 40, no. 6, p. 36, 51-52.

The exploration program of the U. S. Atomic Energy Commission and the methods used by the Commission to stimulate private exploration are outlined. Generalized geologic descriptions are given of the types of environments in which uranium has been found in the United States. The uranium deposits on the Colorado Plateau are mostly in continental sandstone formations of Triassic and Jurassic age. The most important producing formation is the Salt Wash member of the Morrison formation of Jurassic age. The deposits are roughly tabular, irregnlar in outline, and in general conform to the bedding, although in detail they may cross the bedding. The most important mineral is carnotite; it is usually associated with fossil organic material. Also described are pitchblende deposits in the Colorado Front Range; in the Coeur d'Alene district in Idaho; at Marysvale, Utah; in upper Michigan; and uraniferous phosphorite and black shale deposits in the United States.

182 Miller, L. J., 1952, Drilling in the Happy Jack mine area, White Canyon, San Juan County, Utah: U. S. Atomic Energy Comm. RME-4039, 14 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Diamond drilling in the Happy Jack mine area was done to locate copper-uranium deposits in the Shinarump conglomerate of Triassic age and to outline channels cut into the underlying Moenkopi formation of Triassic age. Eleven of the 26 holes penetrated ore, and the Sunrise, Gonaway, and Happy Jack channels were outlined. The ore occurs in the Shinarump conglomerate at or near the base of the channels and is characteristically in porous coarse-grained sandstone which rests on dense mudstone. The principal uranium mineral, pitchblende, is associated with carbonaceous material and in places replaces woody material. The host rock is erratically cemented with gypsum, calcite, and silica.

183 Miller, L. J., 1953, Ore textures of uraninite and associated minerals from the Colorado Plateau uranium deposits [abs.]: Geol. Soc. America Bull., v. 64, no. 12, p. 1453-1454.

Uraninite in the ore deposits of the Colorado Plateau is present as a replacement mineral. It replaces the clay cement of the quartz grains, the quartz overgrowths, asphaltite, organic matter, and in some cases sulfide minerals. The exsolution texture of chalcopyrite and bornite indicates deposition at a high temperature. A comparison of the large amount of alteration at the Marysvale (Utah) uranium deposit and the low amount of alteration of the Plateau deposits suggests a low-temperature deposition for the Plateau deposits. — *Author's abstract*

184 Miller, L. J., 1953, Uranium ore controls of the Happy Jack deposit, White Canyon, San Juan County, Utah: U. S. Atomic Energy Comm. RME-33, 34 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.; 1955, Econ. Geology, v. 50, no. 2, p. 156-169.

Miller, L. J., 1952, Uranium ore controls in the Happy Jack mine and vicinity, White Canyon, Utah [abs.]: Econ. Geology, v. 47, no. 7, p. 774; Geol. Soc. America Bull., v. 63, no. 12, p. 1280.

The copper-uranium deposit at the Happy Jack mine is in an ancient stream channel which contains sediments of the Shinarump conglomerate of Triassic age. The host rock is a coarse-grained to conglomeratic quartzose sandstone which contains abundant carbonaceous material. This unit is present only in the channels; it is overlain by an intrachannel mudstone unit of the Shinarump and is underlain mainly by dense mudstones of the Moenkopi formation of Triassic age. The ore is associated with organic material and sedimentary structures and is generally in deep areas within the channel. Lithologic controls include bedding planes, petrologic traps, scours within the Shinarump, and basal Shinarump mudstone. Uraninite and copper sulfides impregnate the sandstone and replace carbonaceous material and secondary overgrowths on quartz grains. The ore minerals are nearly contemporaneous. Secondary uranium and copper minerals are minor. The normally red sediments near the ore deposit have been bleached to green, but there is no other evidence of alteration within the deposit.

Channels within the Shinarump formation of Triassic age are thought to be the principal uranium ore control in White Canyon, southeastern Utah. Intrachannel controls include carbonaceous matter, lithologic changes, and bedding planes.

185 Miller, R. D., 1954, Reconnaissance for uranium in the Hualapai Indian Reservation area, Mohave and Coconino Counties, Ariz.: U. S. Atomic Energy Comm. RME-2007, 18 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The only known occurrence of uranium in the Hualapai Indian Reservation is at the Ridenour mine. The workings are in bleached fine-grained sandstone members of the normally red Supai formation of Permian age. Copper minerals occur in a vein and breccia zone with pyrite and limonite. Vein quartz is absent, and uranium and vanadium are minor. Consolidated sedimentary rocks in the area range in age from Cambrian to Permian. Precambrian crystalline rocks are exposed in the deeper canyons. Large faults are prominent. The sedimentary rocks are either horizontal or gently dipping. The Supai formation and the Hermit shale, both of Permian age, appear to be the most favorable host rocks in the area for uranium deposits localized by stratigraphic control.

186 Mirsky, Arthur, 1953, Preliminary report on uranium mineralization in the Dakota sandstone, Zuni uplift, New Mexico: U. S. Atomic Energy Comm. RME-47, 21 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits occur in sandstone and carbonaceous shale of the Dakota sandstone of Cretaceous age along the north and

northeast flank of the Zuni uplift. The Dakota sandstone regionally truncates older rocks. The sandstone units are buff to gray, fine- to medium-grained, crossbedded, plane-bedded or massive, and are interbedded with blue or gray mudstone and carbonaceous shale. Most beds are lenticular; the formation is about 50 feet thick. The uranium mineral metatyuyamunite(?) is closely associated with carbonaceous material and iron oxides. The deposits are in or marginal to ancient stream channels. Joints may partially control the location of the deposits. Except for one deposit in carbonaceous shale, all are in sandstone.

187 Mitcham, T. W., and Evenson, C. G., 1955, Uranium ore guides, Monument Valley district, Arizona: Econ. Geology, v. 50, no. 2, p. 170-176.

The contact between the Shinarump conglomerate and the Moenkopi formation, both of Triassic age, is a marked erosional unconformity. Basal Shinarump sediments fill ancient stream channels incised into the underlying Moenkopi. *** Uranium ore deposits are commonly found in these stream channels. Paleostream channels are the prime guide to ore in the Shinarump. Twenty-seven others of varying degrees of usefulness are summarized.—*Authors' abstract*

188 Moore, G. W., and Levish, Murray, 1955, Uranium-bearing sandstone in the White River Badlands, Pennington County, S. Dak.: U. S. Geol. Survey Circ. 359, 7 p.

Uranocircite is locally disseminated in the lower 2 feet of a channel sandstone in the Chadron formation of Oligocene age in the White River Badlands. The sandstone is yellowish gray and coarse-grained; it is directly underlain by an impermeable bed of bentonitic claystone.

Metatyuyamunite(?) was found at one place in a bed of fresh-water limestone in the Chadron formation. At several places carnotite forms very thin coatings on the outer surfaces of chalcedony veins in the overlying Brule formation of Oligocene age.

The uranium was probably leached from the overlying volcanic ash beds by descending meteoric waters and carried by these waters to an environment favorable for deposition.

189 Moore, R. B., and Kithil, K. L., 1913, A preliminary report on uranium, radium, and vanadium: U. S. Bur. Mines Bull. 70, 101 p.

Topics discussed in this report are the carnotite deposits of Colorado and Utah, the pitchblende deposits of the world, the vanadium deposits in the United States and Peru, methods of analysis of ore, methods of ore treatment, and uses of the metals. Carnotite deposits in the Green River and Thompsons districts in Utah, and at Skull Creek, Coal Creek, and in the Paradox Valley region of Colorado are described. The deposits are commonly associated with carbonaceous material in sandstone beds. Some vanadium minerals may be present. The deposits in the Paradox Valley region are in a light-colored sandstone of the McElmo formation (Morrison formation) of Jurassic age. The most typical ore is sandstone impregnated with carnotite and which contains small brown masses of vanadium-rich sandy clay. The deposits are invariably in pockets and are associated with gypsum, carbonaceous material, and red, brown, blue, and black vanadium minerals. Some of the mine workings are described as they appeared in 1912.

The authors suggest that the uranium was disseminated in the sandstone country rock and has been concentrated in ore bodies by the action of water.

190 Muilenburg, G. A., 1949, Notes on uranium: Mo. Div. Geol. Survey and Water Res. Inf. Circ. 5, 18 p.

This circular briefly describes uranium minerals and methods of identifying them, different types of uranium deposits, and uranium occurrences in Missouri. Only specimen quantities of uranium minerals have been found in Missouri. Meta-torbernite has been found in a fire-clay in Franklin County, and carnotite has been found on a joint surface in limestone at a quarry near Ste. Genevieve. Several other localities are known.

191 Muilenburg, G. A., and Keller, W. D., 1950, Carnotite and radioactive shale in Missouri: Am. Mineralogist, v. 35, no. 3-4, p. 323-324.

Carnotite and possibly other radioactive minerals have been found in a quarry in the Spergen limestone of Mississippian age about 5 miles north of Ste. Genevieve, Ste. Genevieve County, Mo. The carnotite forms a thin film along a joint in the limestone. A thin parting of highly radioactive black shale overlies the occurrence; the carnotite is thought to have been derived from this shale parting.

192 Mullens, T. E., and Freeman, V. L., 1952, Lithofacies study of the Salt Wash sandstone member of the Morrison formation [abs.]: Geol. Soc. America Bull., v. 63, no. 12, p. 1340.

The Salt Wash sandstone, the lower member of the Upper Jurassic Morrison formation in a large part of the Colorado Plateau, is the product of an aggrading fluvial system and consists of lenticular beds of light-colored cross-laminated sandstone and conglomeratic sandstone irregularly interbedded with mudstone, claystone, and horizontally laminated sandstone.

The fluvial deposits are divided into stream and flood-plain deposits: the stream deposits include all sediments interpreted as deposited from moving water; the flood-plain deposits include all deposits interpreted as deposited from slack water.

The lithofacies of the Salt Wash member is the total aspect of the thickness, relative proportions, and continuity of the two types of deposits. Areal variations in the Salt Wash lithofacies are shown by isopach and isolith maps.

Interpretations of the areal variations in Salt Wash lithofacies indicate piedmont-type deposition by a distributary drainage system from one principal source area. The distributary drainage radiated outward from south-central Utah and spread sediments to the north and east in a fan-shaped pattern. The total thickness of the deposits and relative proportion of stream deposits decrease rather uniformly away from the apex of the fan. In the Four-Corners area, where the Salt Wash member interfingers with the Bluff sandstone member of the Morrison, the development of the fan shape was interrupted as the distributary streams encroached on the sand dunes of the Bluff sandstone member. — *Author's abstract*

193 Nininger, R. D., 1954, Minerals for atomic energy: New York, D. Van Nostrand Company, Inc., 367 p.

This book, written by the Deputy Assistant Director for Exploration of the Atomic Energy Commission, is a guide to exploration for uranium, thorium, and beryllium minerals. Part 1 describes the minerals and mineral deposits that are the sources and potential sources of these metals. Representative uranium deposits on the Colorado Plateau and in other areas are reviewed. Part 2 is a discussion of possibilities for new deposits in various areas of the world, and particularly in the United States. Part 3 covers prospecting equipment and techniques, the use of the Geiger and scintillation counters, evaluation of deposits, and details of prices, markets, and governmental controls. Appendixes include mineral identification tables, classifications of ore deposits, testing and analysis procedures, and other pertinent information.

194 Notestein, F. B., 1918, Some chemical experiments bearing on the origin of certain uranium-vanadium ores: Econ. Geology, v. 13, no. 1, p. 50-64.

The carnotite deposits of the Colorado Plateau occur as small lenticular bodies of mineralized light-colored sandstone within hard ledge-forming crossbedded sandstones of the McElmo formation (Morrison formation) of Jurassic age. The deposits generally conform to the bedding. Nearly all of the ore-bearing beds are rich in fossil carbonaceous material, and most also contain calcite and gypsum.

The three hypotheses of origin that have been advocated are summarized as follows:

1. Widely disseminated uranium and vanadium minerals have been dissolved from overlying rocks and transported by ground water; the metals were reprecipitated at the position where now found through some agency such as calcite or organic material or through oxidation near outcrops. Recency is implied. (Hillebrand and Ransome, 1905, see ref. 135).

2. The minerals carry vanadium and uranium were concentrated by ordinary processes of sedimentation at or near the present position, and the carnotite is an oxidation product of such minerals. (Fleck and Haldane, 1907, see ref. 89; Wherry, 1915, see ref. 276).

3. The uranium and vanadium were precipitated from sea water by the reducing action of decaying vegetable matter; carnotite is an oxidation product, nearly in place, of such precipitated salts. (Hess, 1914, see ref. 129).

The author ascertained through laboratory experiments that carnotite is readily soluble in sulfate ground water, and that calcite will precipitate uranium and vanadium from sulfate solution. This precipitate is soluble in calcium bicarbonate solution but will be reprecipitated by loss of carbon dioxide.

The author suggests that descending sulfate waters took the disseminated uranium and vanadium minerals into solution. The metals precipitated when a calcitic bed was reached, and gypsum and carbon dioxide formed. The carbon dioxide reached with calcite to form calcium bicarbonate which redissolved the uranium and part of the vanadium; the dissolved salts were then transported to an outcrop or some other suitable place where the loss of carbon dioxide caused reprecipitation of the metals.

195 Page, L. R., 1950, Interim report of geologic investigation, Lost Creek schroeckingerite deposits, Sweetwater County, Wyo.: U. S. Geol. Survey TEM-183A, 3 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Schroeckingerite occurs principally as rounded aggregates as much as 1 inch in diameter in green, brown, or purple clay, and also as tiny flakes disseminated in sand or sandy clay. The clays are early Eocene or younger in age and are interbedded with arkosic sands and grits. These beds are overlain by Pleistocene and Recent sands and gravels which conceal the ore-bearing material. The ore beds are relatively continuous along the strike, but the nature of schroeckingerite (an efflorescent mineral) indicates that the deposit does not extend to any great depth. The schroeckingerite deposits appear to be associated with the Cyclone Rim fault which is believed to have been the channel for the uranium-bearing solutions. Suggestions for prospecting are included.

196 Page, L. R., 1956, Geologic prospecting for uranium and thorium: U. S. Geol. Survey Prof. Paper 300, p. 627-631; Geology of uranium and thorium, United Nations, v. 6, p. 688-691.

The search for uranium and thorium in the United States has emphasized the value of geologic guides in prospecting. The application of the guides discussed in this report in conjunction with radiometric, geochemical, botanical, panning, and geophysical techniques has greatly increased the rate of discovery. Prospecting for new districts is based on very general criteria; prospecting for individual ore deposits in new or old districts requires specific guides. Geologic guides to ore deposits vary for each of the principal uranium and thorium districts.

197 Page, L. R., and Redden, J. A., 1952, The carnotite prospects of the Craven Canyon area, Fall River County, S. Dak.: U. S. Geol. Survey Circ. 175, 18 p.

Carnotite deposits occur in the Lakota sandstone of Early Cretaceous age in Craven Canyon, Fall River County, S. Dak. The area lies on the southwest flank of the Black Hills uplift and the rocks dip gently to the southwest. The Lakota sandstone is a white to buff massive to thin-bedded sandstone containing many thin white to purplish-red shale beds. Throughout the area studied a dense black bed of carbonaceous shale from 1 to 3 feet thick is exposed and used as a marker bed. The carnotite occurs as impregnations of sandstone and as joint coatings and fillings; it is commonly associated with iron oxides and fossil carbonaceous material. The deposits are generally parallel to the bedding, but in detail they may cut across the bedding. Because there are few exposures little is known about the outline of the deposits, but they are probably tabular and quite small. The average thickness is about 2 feet. Eleven prospects are described, and suggestions for prospecting are included.

198 Phair, George, and Levine, Henry, 1952, Notes on the differential leaching of uranium, radium, and lead from pitchblende in H_2SO_4 solutions: U. S. Geol. Survey TEI-262, 23 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.; 1953, Econ. Geology, v. 48, no. 5, p. 358-369.

It has been noted that the radium: uranium ratios in weathered pyritic pitchblende ores are abnormally high. The complex solutions involved in the leaching of pitchblende in pyritic mines and dumps are characterized by a relatively high concentration of sulfuric acid. Laboratory experiments show that in an oxidizing and highly acid environment uranium is rapidly leached, and radium and lead tend to be residually concentrated. Further, UO_3 is preferentially leached with respect to UO_2.

199 Phoenix, D. A., 1956, Relation of carnotite deposits to permeable rocks in the Morrison formation, Mesa County, Colo.: U. S. Geol. Survey Prof. Paper 300, p. 213-219; Geology of uranium and thorium, United Nations, v. 6, p. 321-325.

The uppermost, almost continuous, sandstone layer in the Salt Wash member of the Morrison formation of Jurassic age contains most of the carnotite deposits in southwestern Colorado and southeastern Utah. It is composed of broadly lenticular strata of sandstone separated by fine-grained laminated sediments collectively called mudstone. Carnotite deposits are localized where the sandstone strata thicken and rest one upon another; they are not found where the sandstone strata are thin and the layer is mostly mudstone.

The permeability of sediments in the uppermost layer is influenced by the character of the original sediment and by the later effects of diagenesis. Laminated mudstone and siltstone are least permeable and bedded sandstone is most permeable except in places where the original porosity has been reduced by the interstitial clay, quartz overgrowths, and calcite and iron oxide cement. The sedimentary rocks are less permeable across bedding than parallel to bedding.

The coefficient of transmissivity, which is equal to the product of the thickness and mean permeability, was determined for samples from drill holes in Mesa County, Colo. Maps showing transmissivity indicate that carnotite deposits are localized where the rocks in the uppermost layer are most transmissive; they are uncommon where rocks in the uppermost layer are least transmissive.

200 Poehlmann, E. J., and King, E. N., 1953, Report on wagon drilling for uranium in the Silver Reef (Harrisburg) district, Washington County, Utah: U. S. Atomic Energy Comm. RME-2004, 24 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

An exploratory wagon-drilling program revealed two new uranium ore bodies in the Silver Reef district. The uranium deposits in the Silver Reef district are near the faulted north-plunging nose of the Virgin anticline. Silver, uranium, vanadium, and copper minerals occur in 5 carbonaceous, sandy shale zones of the Leeds and Tecumseh members of the Chinle formation of Triassic age. The most important uraniferous zone is a carbonaceous crossbedded sandy shale which lies in the upper part of the Leeds sandstone. Mineralization has favored areas where relatively close-spaced normal faults of very small displacement cut the favorable beds.

201 Poole, F. G., and Williams, G. A., 1956, Direction of transportation of the sediment constituting the Triassic and associated formations of the Colorado Plateau: Geology of uranium and thorium, United Nations, v. 6, p. 326-330; see also, Direction of sediment transport in the Triassic and associated formations of the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 227-231.

Clastic sediments develop characteristic features in certain depositional environments and these features reflect the direction in which the transporting medium was moving. These characteristic features are called sedimentary, primary, or original structures. Sedimentary structures that possess directional characteristics include channels, cross-strata, current lineation, and ripple marks. From these primary structures the direction of transportation can be determined and the direction of source can be inferred.

Studies of sedimentary structures have been made of rocks of the Colorado Plateau that range in age from Permian to Jurassic, and directions of sediment transportation of several formations have been determined. This information is useful in the exploration for uranium and vanadium deposits because the ore bodies, which are localized in channel-filling sandstones, generally are elongate in the direction of transportation of the sediments.

202 Proctor, P. D., 1953, Geology of the Silver Reef (Harrisburg) mining district, Washington County, Utah: Utah Geol. and Mineralog. Survey Bull. 44, 169 p.

The Silver Reef mining area in southwestern Utah contains the only known occurrence in the United States of commercial bodies of silver ore in sandstone. Minor amounts of copper, uranium, and vanadium minerals also are present in the ore. The ore bodies are restricted to the Silver Reef sandstone member of the Chinle formation of Triassic age, and they occur on the limbs and nose of the northeast-trending and plunging Virgin anticline and a subsidiary anticline and syncline. A north-trending normal fault and a thrust fault with a minimum eastward displacement of 1,500 feet repeat the ore horizon three times. No constant relation exists between mineralized ground and the folds or faults.

The deposits are associated with carbonaceous material in lenses of light-colored quartzose sandstone and may be localized in channels in the Silver Reef sandstone.

The author concludes that the metals in the Silver Reef deposits were derived from volcanic tuffs by ground or surface waters and precipitated in proximity to carbonaceous material in the Silver Reef sandstone. The silver was further concentrated by enrichment.

203 Proctor, P. D., Hyatt, E. P., and Bullock, K. C., 1954, Uranium: where it is and how to find it: Salt Lake City, Eagle Rock Publishers, 85 p.

This publication is a nontechnical guide to prospecting for uranium. Included is information on uranium minerals and deposits, areas of known deposits, equipment, and other topics of interest to a uranium prospector.

204 Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago, Univ. Chicago Press, 912 p., see p. 632-639.

The geochemistry of uranium is discussed. Uranium is a member of the actinide series of rare-earth elements, has a large ionic radius, and is radioactive. The most important uranium mineral is the oxide, UO_2, found as uraninite and pitchblende. Other uranium minerals include hydroxides, phosphates, arsenates, vanadates, uranates, carbonates, silicates, and sulfates; these minerals are usually derived from the alteration or decomposition of uraninite and pitchblende. Uranium never occurs in the natural state and never forms sulfides, arsenides, or tellurides.

Uranium does not enter the crystal lattices of the rock-forming minerals during the crystallization of a magma because its ionic radius is too large; it is therefore enriched in residual solutions. It may crystallize in pegmatites or it may enter pneumatolytic and hydrothermal veins. Uranium is also concentrated, notably in the presence of vanadium, in minerals precipitated from ground waters; such uranium deposits are sometimes found in sandstones.

The cycle of uranium and the biogeochemistry of uranium are also discussed. Uranium is absorbed by biological substances. Some petroleum and associated brines contain uranium, and marine carbonaceous shales have a definitely higher uranium content than most other sedimentary rocks. Some coals also have a high uranium content.

The largest and most important uranium deposits are near Great Bear Lake in Canada, at Katanga in the Belgian Congo in West Africa, and in Czechoslovakia. They are all associated with hydrothermal veins. Important deposits also occur in continental sandstones in the western United States.

205 Rapaport, Irving, 1952, Interim report on the ore deposits of the Grants district, New Mexico: U. S. Atomic Energy Comm. RMO-1031, 19 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium deposits in the Grants district occur in the Todilto limestone and in the Morrison formation, both of Jurassic age. The deposits are on the northeast flank of the Zuni uplift and on the Lucero uplift. Unexposed deposits may exist in the intervening McCarty syncline. Exposed rocks range from Precambrian to Tertiary in age.

The deposits in the Todilto limestone are in the upper coarse, crenulated, recrystallized part of the formation. Pitchblende is associated with calcite, pyrite, barite, and fluorite. Uranium vanadates, uranium silicates, and hematite are found in the oxidized parts of the deposits. Some of the deposits are associated with minor semicylindrical bulges or anticlines that have no intervening synclines. The deposits seem to be in a zone between the silty limestone facies to the south and the gypsiferous limestone facies to the north. Joints and faults also may have had an influence on the movement and emplacement of ore.

The uranium minerals in the Morrison deposits, mainly carnotite with some schroeckingerite, are associated with carbonaceous material and limonite. Carnotite impregnates sandstone, coats fractures, and replaces fossil logs. Ancient stream channels, diastems, intricate facies changes, and the presence of organic material seem to localize the ore.

The uranium, iron, sulfur, barium, and flourine probably were transported in solution in hydrothermal waters to the place of deposition. The ore-bearing solutions moved laterally and undoubtedly were mixed with ground water.

206 Rapaport, Irving, Hadfield, J. P., and Olson, R. H., 1952, Jurassic rocks of the Zuni uplift, New Mexico: U. S. Atomic Energy Comm. RMO-642, 45 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Zuni uplift is an asymmetrical elliptical dome in the southeastern corner of the San Juan Basin. It is about 65 miles long by 40 miles wide and is elongated in a northwesterly direction. Precambrian crystalline and metamorphic rocks are exposed in the central part of the uplift. About 1,000 feet of Paleozoic and more than 3,000 feet of Mesozoic sedimentary rocks overlie the Precambrian rocks. Tertiary and Quaternary lava flows cover areas of moderate size.

Jurassic sedimentary rocks of this region, in ascending order, are the Glen Canyon group, the San Rafael group, and the Morrison formation. The Wingate formation is the only member of the Glen Canyon group. The San Rafael group consists of, in ascending order, the Carmel, the Entrada, the Todilto, the Summerville, and the Bluff formations. The Morrison formation is divided into the Recapture Creek, the Westwater Canyon, and the Brushy Basin members. Rock types include shale, siltstone, sandstone, and limestone. All Jurassic formations, except perhaps the Carmel, are of continental origin.

The regional stress responsible for the Zuni dome appears to have been mainly one of vertical uplift that occurred probably in early or middle Tertiary time. Structural relief is more than 6,600 feet. The joints and faults seem to be tensional and normal to the direction of most bending and to the bedding.

207 Rasor, C. A., 1952, Uraninite from Gray Dawn mine, San Juan County, Utah: Science, v. 116, no. 3004, p. 89-90.

Massive chunks of primary uraninite have been found intimately associated with carnotite-bearing ores from the Grey Dawn mine which is on a small tributary of La Sal Creek near the southeast flank of the La Sal Mountains, San Juan County, Utah. The host rock is a gently dipping sandstone bed in the Salt Wash member of the Morrison formation of Jurassic age. This is the first discovery of uraninite in the Salt Wash sandstone. The deposit is otherwise similar to other carnotite deposits in the Salt Wash sandstone. This occurrence of uraninite may make it necessary to modify the present concept of the origin of these ores.

208 Redmond, R. L., and Kellogg, J. P., 1954, Drilling at Polar Mesa, Grand County, Utah, and review of favorability criteria used: U. S. Atomic Energy Comm. RME-22 (pt. 1), 30 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Vanadium-uranium deposits on Polar Mesa occur in a sandstone unit of the Salt Wash member of the Morrison formation of Jurassic age. This unit, called the "payoff sand," is a massive crossbedded medium- to fine-grained yellow-brown sandstone that ranges from 10 to 70 feet in thickness. The base of the ore-bearing zone is about 270 feet above the contact of the Entrada and Summerville. Carnotite and roscoelite are associated with fossil trees and carbonaceous trash. The ore bodies are generally tabular, of irregular shape, and contain as much as 10,000 tons.

A drilling program was conducted near the northeast rim of the mesa. The "payoff sand" was correlated between holes on the basis of regional dip. A favorability map of this area was constructed to guide further drilling. Factors considered favorable for uranium ore are the presence of either equal amounts of sandstone and mudstone or more sandstone than mudstone; of more yellow-brown than grey sandstone; and of blue-green mudstone.

209 Reinhardt, E. V., 1951, Reconnaissance of Henry Mountains area, Wayne and Garfield Counties, Utah: U. S. Atomic Energy Comm. RMO-753, 7 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Uranium ore deposits occur in sandstone of the Salt Wash member of the Morrison formation of Jurassic age in a strip about 3 miles wide along the east flank of the Henry Mountains. Tertiary laccolithic intrusive rocks in a structural basin form the core of the Henry Mountains. The uranium deposits are found from north to south, in the North Wash, the Trachyte, and the Little Rockies districts. The deposits are of good grade and apparently extensive, but many are thin. Development and production have been limited mostly by the cost of transportation to distant shipping points and buying stations.

210 Reinhardt, E. V., 1952, Practical guides to uranium ores on the Colorado Plateau: U. S. Atomic Energy Comm. RMO-1027, 13 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

This report presents and discusses a list of guides to uranium ore. Items 1 through 4 are syngenetic features, and items 5 through 11 are epigenetic. The order of listing does not reflect importance.

1. Presence of ancient stream channels.
2. Thickening of sandstone lenses.
3. Interfingering of mudstone and sandstone lenses.
4. Presence of carbonaceous material.
5. Proximity of ore.
6. Relation to mountain masses and large folds.
7. Bleaching of sandstone.
8. Bleaching of mudstone adjacent to sandstone lenses.
9. Presence of yellow iron-oxide stains.
10. Presence of bleached mudstone pebbles in the sandstone lenses.
11. Etched and corroded sand grains.

211 Reinhardt, E. V., 1952, Uranium-copper deposits near Copper Canyon, Navajo Indian Reservation, Ariz.: U. S. Atomic Energy Comm. RMO-902, 13 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Copper-uranium deposits in the Copper Canyon area of the Monument Valley district in Utah and Arizona occur in the Shinarump

conglomerate of Triassic age near the base of channels cut into the underlying Moenkopi formation of Triassic age. The deposits, which are relatively small, are all less than 20 feet above the base of the channels and the best concentrations are in the lower 5 feet. The ore contains as much as 0.68 percent U_3O_8. Carnotite, the principal uranium mineral, impregnates sandstone and replaces fossil carbonaceous material. The copper minerals occur similarly but also are found higher in the section. There is no constant ratio between the copper and uranium content of the deposits. Exposed consolidated sedimentary rocks range in age from Permian to Jurassic and dip 1°-2° NW.

212 Reyner, M. L., 1950, Preliminary report on some uranium deposits along the west side of the San Rafael Swell, Emery County, Utah: U. S. Atomic Energy Comm. RMO-673, 31 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Twelve uranium deposits along the western flank of the San Rafael Swell were examined. The deposits are lenticular or tabular bodies of mineralized sandstone, conglomerate, or shale, and all are near the base of the Shinarump conglomerate of Triassic age. The uranium is intimately associated with blebs, seams of asphalt, and small bits of carbonized wood. Brightly colored secondary uranium minerals are present at the outcrop. The author describes the Lone Tree, Hard Pan, Dalton, Dexter, Wickiup, Dolly, South Fork, Pay Day, Green Vein, Brown Throne, and Dirty Devil groups of claims, and the Clifford Smith, Hertz No. 1, and Gardell Snow claims.

213 Robeck, R. C., 1954, Uranium deposits of Temple Mountain; *in* Geology of portions of the High Plateaus and adjacent Canyon Lands, central and south-central Utah: Intermountain Assoc. of Petroleum Geologists, 5th Ann. Field Conference (Guidebook), Salt Lake City, Utah, p. 110-111.

The uranium deposits at Temple Mountain, Utah, are in the so-called Mossback sandstone unit of the Chinle formation of Triassic age. The area is on the southeast flank of the San Rafael Swell. The uranium is associated with wood fragments and petroleum residue (asphalt) in the lower part of a 100-foot thick cliff-forming sandstone bed.

214 Rogers, K. J., 1954, Reconnaissance of the lower Chinle along the Colorado River between the Moab and Dewey bridges, Grand County, Utah: U. S. Atomic Energy Comm. RME-70, 17 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

One small radioactivity anomaly was noted during a reconnaissance for uranium deposits in the lower part of the Chinle formation of Triassic age in an area north of Moab along the Colorado River. The lower Chinle in this area is apparently unfavorable for the occurrence of uranium deposits.

215 Rosenzweig, Abraham, Gruner, J. W., and Gardiner, Lynn, 1954, Widespread occurrence and character of uraninite in the Triassic and Jurassic sediments of the Colorado Plateau: Econ. Geology, v. 49, no. 4, p. 351-361.

Uraninite has been found in many uranium deposits in the sedimentary rocks of the Colorado Plateau. Although this mineral is not restricted to any one formation, most of the occurrences are in the Shinarump conglomerate and Chinle formation of Triassic age. The two principal modes of occurrence are with copper sulfides or in asphaltic bodies. Association with fossil plants is common. Uraninite replaces the cell walls of fossil plants and copper sulfides fill the cells.

216 Schlottman, J. D., and Smith, L. E., 1954, Preliminary report on uranium mineralization in the Troublesome formation, Middle Park, Grand County, Colo.: U. S. Atomic Energy Comm. RME-1042, 14 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The uranium minerals carnotite, autunite, and schroeckingerite occur in conglomerates, sands, and clays of the Troublesome formation of Oligocene to Miocene age in Middle Park, Colo. Middle Park is a structural and topographic basin partly filled with nearly a thousand feet of fluvial and lacustrine sediments of the Troublesome formation. Underlying rocks range in age from Precambrian to Tertiary. The uranium deposits, distributed throughout several square miles, are limited stratigraphically to the lower 160 feet of the formation. They are lenticular and are controlled by facies changes in the clays, sands, and conglomerates. Carbonized plant material, jarosite, and brown and green vanadium minerals are common in many of the deposits. The deposits are small and most are not in radioactive equilibrium.

217 Schnabel, R. W., 1955, The uranium deposits of the United States: U. S. Geol. Survey Min. Inv. Res. Appraisals Map MR 2 (with text)

This map shows the location of the more important uranium deposits in the United States. The deposits are classed according to their geologic environment. These classes include the deposits in sandstone which are mainly on the Colorado Plateau but also in South Dakota, Wyoming, and other States; deposits in phosphorite in Florida, South Carolina, and in the Northwest; deposits in lignite which are mainly in South Dakota, North Dakota, and Wyoming; uraniferous black shale deposits which are mainly in Tennessee, Kentucky, Alabama, and Georgia; placer deposits of monazite in southeastern United States and in Idaho; and deposits in igneous rocks, pegmatites, veins, and limestone. The geology of each class of occurrence is briefly summarized.

218 Sharp, W. N., McKay, E. J., and McKeown, F. A., 1954, Powder River Basin, Wyo.; *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 117-119, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The uranium deposits in the Pumpkin Buttes area of the Powder River Basin are associated with a zone of interbedded, dominantly red sandstone lenses and claystone strata near the middle of the Wasatch formation of Eocene age. The red color boundary locally transects primary sedimentary features. Iron-manganese-uranium concretions are scattered erratically in the red sandstone at most places, although in some places they are associated with primary sedimentary features. Disseminated uranium ore with some iron, manganese, and concentrations of carbonate is associated with a sharp color change from primarily buff and gray sandstone to red sandstone.

219 Sharp, W. N., McKeown, F. A., McKay, E. J., and White, A. M., 1956, Geology and uranium mineral deposits of the Pumpkin Buttes area, Powder River Basin, Wyo.: U. S. Geol. Survey Prof. Paper 300, p. 371-374; Geology of uranium and thorium, United Nations, v. 6, p. 403-406.

The Pumpkin Buttes are in the Powder River Basin which is an asymmetrical syncline trending north-northwest. The Wasatch formation of Eocene age crops out over most of the basin. Older rocks are exposed along the perimeter of the basin and remnants of the White River formation of Oligocene age cap the Pumpkin Buttes. The regional dip in the Pumpkin Buttes area ranges from 30 to 100 feet per mile to the northwest.

The uranium deposits in the Pumpkin Buttes area are spatially related to a zone of predominantly red sandstone within the normally buff or gray Wasatch formation. The contacts between red and buff or gray parts transect all sedimentary structures and rock types within a sandstone unit. Tyuyamunite and carnotite are disseminated in buff or gray sandstone near and at the contact with red sandstone. Calcite is abundant at the contact. Uranophane occurs chiefly in the cores of, and peripheral to, manganese-iron oxide concretions; these deposits are small but high grade.

It is suggested that the deposits of oxidized uranium minerals were derived from initial deposits which were formed under reducing and mildly alkaline conditions.

220 Shawe, D. R., 1956, Significance of roll ore bodies in genesis of uranium-vanadium deposits on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 239-241; Geology of uranium and thorium, United Nations, v. 6, p. 335-337.

Similarities between "roll" ore bodies and the more prevalent tabular ore bodies in sedimentary rocks on the Colorado Plateau suggest a common origin for the two types. Analysis and interpretation of details of roll ore bodies may clarify genesis of the vanadium-uranium ore deposits on the Colorado Plateau. Roll ore bodies are found principally in sandstone lenses and layers in the upper part of the Salt Wash sandstone member of the Morrison formation of Jurassic age — commonly near the base of thick sandstone units where many thin well-defined mudstone layers are interbedded with thin sandstone layers. Roll ore bodies are generally layered deposits that crosscut sandstone bedding in sharply curving forms. The long axes of rolls generally coincide with primary sedimentary features and may extend for hundreds of feet. Rolls commonly terminate against an upper and lower mudstone layer and may be split into two distinct rolls by a third thin mudstone layer. The details of roll ore bodies suggest that they were formed by precipitation of minerals at an interface between solutions of different composition and density, and that flow of the ore-bearing or active solution as it passed through connate waters in the sediments was influenced strongly by local sedimentary features.

221 Shoemaker, E. M., 1954, Structural features of southeastern Utah and adjacent parts of Colorado, New Mexico, and Arizona; *in* Uranium deposits and general geology of southeastern Utah: Utah Geol. Soc., Guidebook to the geology of Utah, no. 9, Salt Lake City, p. 48-69.

Structural features of southeastern Utah are considered in three main categories: major uplifts and basins; salt plugs and salt anticlines; and domes, laccoliths, dikes, and diatremes.

The principal uplifts of southeastern Utah are the San Rafael Swell, Circle Cliffs uplift, the Uncompahgre uplift, and the Monument uplift; the largest basins are the Kaiparowits basin, the Henry Mountains basin, and the Uinta Basin. Each of the uplifts and basins is an asymmetric fold bounded on one side by a large monocline.

Five series of salt structures, some of which have collapsed crests, occur mainly in a northwest-trending belt in Colorado and Utah. The structures resulted from the intrusion of plastic masses of salt and gypsum.

The laccolithic mountain groups in Utah — the Henry, La Sal, and Abajo Mountains — consist of stocks of igneous rocks from which radiate tongue-shaped masses. Sills, dikes, small laccoliths, and diatremes are distributed irregularly in parts of southeastern Utah.

The tectonic history of the region is reviewed. The regional pattern was established before Cambrian time. Slight folding during the Permian period probably initiated the intrusion of salt which continued until late in Jurassic time. During the Late Cretaceous, the area was inundated by the sea and covered with about 5,000 feet of sediments. Probably by the end of Cretaceous time most of the larger structures had assumed their present form and the laccolithic mountain groups had been intruded. The entire area was uplifted during the late Tertiary.

222 Smith, J. F., Jr., Hinrichs, E. N., and Luedke, R. G., 1952, Progress report on geologic studies in the Capitol Reef area, Wayne County, Utah: U. S. Geol. Survey TEI-203, 29 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Small deposits of uranium occur principally in a thin clay bed at the base of the Shinarump conglomerate of Triassic age in the Capitol Reef area. The uranium minerals zippeite and metatorbernite are associated with copper minerals, carbonaceous material, a thick bleached zone at the top of the underlying Moenkopi formation, and channels or scours in the top of the Moenkopi. Consolidated sedimentary rocks in the Capitol Reef area range in age from Permian to Jurassic and have an aggregate thickness of more than 3,000 feet. The stratigraphy is described in considerable detail. The area is on the northeast and east flanks of a topographic and structural dome.

223 Staatz, M. H., and Bauer, H. L., Jr., 1951, Virgin Valley opal district, Humboldt County, Nev.: U. S. Geol. Survey Circ. 142, 7 p.

Carnotite and uraniferous opal occur in a gently dipping series of vitric tuff and ash beds in the Virgin Valley opal district. The carnotite occurs as fracture coatings and fine layers in the opal. The opal layers, some of which are uraniferous, are discontinuous and irregular in extent and thickness; they parallel the bedding of the ash and tuff beds. One sample contained 0.12 percent U_3O_8; others contained less than 0.05 percent U_3O_8.

224 Steen, C. A., Dix, G. P., Jr., Hazen, S. W., Jr., and McLellan, R. R., 1953, Uranium-mining operations of the Utex Exploration Co. in the Big Indian district, San Juan County, Utah: U. S. Bur. of Mines Inf. Circ. 7669, 13 p.; 1954, Mines Mag., v. 44, no. 4, p. 16-28.

A large uranium-vanadium ore deposit was discovered in July 1952 by C. A. Steen on the Mi Vida claim in the Big Indian mining district, San Juan County, Utah. The district lies on the southwest flank of the faulted northwest-trending Lisbon Valley anticline; near the Mi Vida mine the rocks dip about 15° SW. The deposit is in the Chinle formation of Triassic age which is underlain by the Cutler formation of Permian age and overlain by the Wingate sandstone of Jurassic age. The rocks of the Chinle formation consist of variegated mudstones and siltstones, intraformational conglomerates, and fine- to medium-grained crossbedded sandstones. The ore-bearing unit in the lower part of the Chinle formation is characteristically gray; the upper part of the formation is red. The ore body is irregularly tabular in shape and ranges from 10 to 23 feet in thickness. The deposit lies in a channel scoured in the Cutler formation to a depth of about 50 feet; the channel axis trends about N 30° W. Abundant carbonaceous trash in the channel is replaced by pyrite or uraninite or preserved as carbon. The highly variable lithologic character of the channel material provides a favorable host rock.

Steen believes that the deposit was emplaced by hydrothermal solutions derived from Late Cretaceous or early Tertiary intrusive igneous rocks such as are exposed in the La Sal Mountains, but there is a possibility that the solutions could have been ground water or a mixture of ground water and hydrothermal solutions. The position of the deposits may have been controlled by the Lisbon Valley anticline.

Exploration, development, the surface and underground plants, the mining methods, and production are described.

225 Stephens, J. G., 1954, Crooks Gap area, Fremont County, Wyo.; *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 120-122, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

In the Crooks Gap area, uranium occurs mainly along a thrust-fault zone in both the arkosic sandstones of the Wasatch(?) formation of Eocene age and in ferruginous limestone and shale of Cambrian age. No ore-grade deposits have been discovered in the Cam-

brian rocks. The Wasatch(?) formation consists of iron-stained coarse arkose that contains thin lenses of carbonaceous sandy shale and mudstone and interbeds of giant-boulder conglomerate. The uranium deposits are in the lower part of the formation and are associated with fine-grained carbonaceous beds and with red and brownish-yellow iron stained sandstone. Uranophane is the principal uranium mineral.

226 Stewart, J. H., and Williams, G. A., 1954, Stratigraphic relations of the Triassic Shinarump conglomerate and a prominent sandstone unit of the Chinle formation in southeastern Utah [abs.]: Geol. Soc. America Bull., v. 65, no. 12, p. 1387.

Recent field work in southern Utah indicates that the Shinarump conglomerate is not so extensive as was formerly thought, and that rocks called Shinarump conglomerate in east-central and central Utah are actually a separate unit. Field relations indicate that the Shinarump conglomerate extends from the type section in northwestern Arizona to a northwest-trending line passing about 10 miles north of White Canyon, in southeastern Utah, where it pinches out. The Shinarump conglomerate is generally less than 100 feet thick and consists of light-colored coarse- to very coarse-grained cross-stratified conglomeratic sandstone.

A prominent sandstone in the Chinle formation lying 200 feet above the top of the Shinarump conglomerate in White Canyon correlates with the unit called Shinarump in central and east-central Utah. A new name for this unit will be proposed at a later date. The prominent sandstone averages about 50 feet in thickness and is composed of light-colored fine- to medium-grained cross-stratified conglomeratic sandstone. Northward from White Canyon this prominent sandstone overlaps the underlying part of the Chinle. The known distribution of this sandstone indicates that it was deposited as a mass about 60 miles wide and 150 miles long extending northwestward from southwestern Colorado to central Utah.

The Shinarump conglomerate and the prominent sandstone are both interpreted to be stream deposits formed by northwest-flowing streams. —*Authors' abstract*

227 Stieff, L. R., and Stern, T. W., 1952, Identification and lead-uranium ages of massive uraninites from the Shinarump conglomerate, Utah: Science, v. 115, no. 3000, p. 706-708.

Age determinations were made on massive uraninites from the Happy Jack mine in White Canyon, San Juan County, Utah, and from the Shinarump No. 1 claim in Seven Mile Canyon, Grand County, Utah. Both are in the Shinarump conglomerate of Triassic age. The ages, as determined from the Pb^{206}/U^{238} and the Pb^{207}/U^{235} ratios, range from 65 to 75 million years.

If the ages calculated are close to the true ages of these ores, then these minerals were probably formed in late Mesozoic or early Tertiary time. This interpretation differs from an earlier belief that the ore bodies were formed during or soon after deposition of the host rocks in Late Triassic time.

228 Stieff, L. R., and Stern, T. W., 1956, The interpretation of the $Pb^{206}/U^{238} < Pb^{207}/U^{235} < Pb^{207}/Pb^{206}$ age sequence of uranium ores: Geology of uranium and thorium, United Nations, v. 6, p. 540-546; see also, Interpretation of the discordant age sequence of uranium ores: U. S. Geol. Survey Prof. Paper 300, p. 549-555.

The age of many uranium ore minerals calculated from the Pb^{206}/U^{238}, Pb^{207}/U^{235}, and Pb^{207}/Pb^{206} ratios do not agree. The Pb^{206}/U^{238} age is less than the Pb^{207}/U^{235} age which is much less than the Pb^{207}/Pb^{206} age. Various investigators have selected one of these ages as "the true age" in preference to the other two and have interpreted the age sequence as a result of loss of radon, loss of lead, failure to correct for original radiogenic lead, or variations in the U^{235}/U^{238} ratio. The geologic consequences of this selection, which may be very significant in terms of the search for and the origin of uranium ores, are discussed.

229 Stieff, L. R., Stern, T. W., and Milkey, R. G., 1953, A preliminary determination of the age of some uranium ores of the Colorado Plateaus by the lead-uranium method: U. S. Geol. Survey Circ. 271, 19 p.

Age determinations by lead:uranium methods were made of 41 samples of uranium ore from the Colorado Plateau. The average age as determined by the Pb^{206}/U method is about 71 million years, and the average age as determined by the Pb^{207}/U^{235} method is about 82 million years. If these ages are close to the true ages of the ores, the uranium was introduced into the sediments during Late Cretaceous or early Tertiary time — 55 to 80 million years ago. This interpretation differs markedly from the previous belief that the present uranium deposits were formed in the Late Triassic and Late Jurassic sediments during or soon after deposition of the sediments between 152 million and 127 million years ago. The methods and difficulties of making determinations are discussed.

230 Stieff, L. R., Stern, T. W., and Sherwood, A. M., 1955, Preliminary description of coffinite — a new uranium mineral: Science, v. 121, no. 3147, p. 608-609.

A new radioactive black mineral has been discovered in several mines on the Colorado Plateau, and in Wyoming, Colorado, Arizona, and several foreign countries. The mineral, a uranous silicate with some hydroxyl substitution, has been named coffinite in honor of Reuben Clare Coffin.

231 Stokes, W. L., 1944, Morrison formation and related deposits in and adjacent to the Colorado Plateau: Geol. Soc. of America Bull., v. 55, no. 8, p. 951-992.

The Morrison formation in and adjacent to the Colorado Plateau is discussed. The Salt Wash, Brushy Basin, Recapture Creek, and Westwater Canyon members are considered equivalent to the type Morrison and are almost certainly of Jurassic age. The San Rafael group of Jurassic age and beds tentatively classed as Lower Cretaceous are also considered. Lithologic character, distribution, and paleogeography of all units are discussed, and changes in nomenclature and correlation are recommended.

232 Stokes, W. L., 1948, Geology of the Utah-Colorado salt dome region with emphasis on Gypsum Valley, Colorado: Utah Geol. Soc. Guidebook 3, 50 p.

The geology and origin of salt anticlines and related structures in the Paradox salt basin in Utah and Colorado are discussed.

Sedimentary rocks ranging in age from Pennsylvanian to Recent are exposed in the area and Precambrian rocks are exposed to the northwest in the Uncompahgre Plateau. The evaporite deposits of the Paradox formation of Pennsylvanian age are overlain by nearly 6,000 feet of younger rocks. The primary structural trend, northwest-southeast, was established before deposition of the Pennsylvanian evaporites. Intrusion and solution of the salt has produced long, narrow, collapsed anticlines. Salt flowage has been intermittent since Permian time.

233 Stokes, W. L., 1951, Carnotite deposits in the Carrizo Mountains area, Navajo Indian Reservation, Apache County, Ariz., and San Juan County, N. Mex.: U. S. Geol. Survey Circ. 111, 5 p.

Carnotite deposits occur in the Salt Wash member of the Morrison formation of Jurassic age in the area surrounding the Carrizo Mountains in northeastern Arizona and northwestern New Mexico. Tertiary intrusive igneous rocks form the core of the mountain mass, and Mesozoic sedimentary rocks surround the mountains. The Salt Wash member in this area is a light-colored fine-grained cross-bedded lenticular sandstone interbedded with shale and is from 60 to 220 feet thick. Carnotite may occur at any stratigraphic level within it. The ore bodies are irregular tabular masses a maximum of 15 feet thick and a few hundred feet wide, and are nearly parallel to the principal bedding of the sandstone. The ore bodies are generally clustered in ill-defined areas a few thousand feet across. The origin of the deposits is not clearly understood, but they are thought to have been formed from ground water solutions shortly after the sands accumulated.

234 Stokes, W. L., 1952, Uranium-vanadium deposits of the Thompsons area, Grand County, Utah, with emphasis on the origin of carnotite: Utah Geol. and Mineralog. Survey Bull. 46, 51 p.

The Thompsons area of about 200 square miles occupies most of the northeast flank of the Salt Valley anticline in north-central Grand County, Utah. The area has been a contributor of uranium and vanadium ores since about 1911. Exposed sedimentary rocks include the Navajo, Carmel, Entrada, Summerville, Morrison, Cedar Mountain, Dakota, and Mancos formations. The Morrison formation, which contains the ore deposits, consists of a lower unit, the Salt Wash sandstone member and an upper unit, the Brushy Basin shale member. Paleontology, paleogeography, and lithologic features of the Morrison formation indicate a fluvial origin on an aggrading flood plain.

The ore bodies consist of a concentration of various uranium and vanadium minerals in sand lenses. Most of the ore minerals occupy pore spaces in the sandstone. The largest and richest ore bodies are elongate and crudely semicylindrical "rolls" that occur in groups in the sand lenses. Studies of cross-bedding in the area show that the long axes of rolls are parallel to the direction of flow of the water that deposited the enclosing sandstone. The ore is nearly always accompanied by organic material of some kind, by limonite staining in associated sandstones, and by blue-green color alterations in the mudstones below the deposits.

It is assumed that the ore minerals were deposited from ground water in the vicinity of decaying organic materials shortly after the enclosing sandstones accumulated. As organic material seems to be essential to ore formation, considerable attention has been given to factors that favor the accumulation of plant materials on flood plains.

It is concluded that the edges of thicker sand channels, especially along meander curves, are favorable sites for plant accumulation and hence for the formation of ore deposits.—*Author's abstract*

235 Stokes, W. L., 1953, Primary sedimentary trend indicators as applied to ore finding in the Carrizo Mountains, Arizona and New Mexico: U. S. Atomic Energy Comm. RME-3043(Pt. 1), 48 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Field studies in three areas in the Carrizo Mountains region indicate that uranium deposits in the Salt Wash member of the Morrison formation are more common in areas where there are well-marked shifts in fluvial trends within the Salt Wash. These changes in stream directions may have been due to ancient structures or to the confluence of ancient streams. The increased favorability of such areas is thought to be due to an increase in the amount of plant debris deposited along the bends of streams.

236 Stokes, W. L., 1953, Sedimentary patterns and uranium mineralization in the Morrison formation of the Colorado Plateau [abs.]: Geol. Soc. America Bull., v. 64, no. 12, p. 1516.

It is generally believed that the Salt Wash is a fluvial deposit made up of coarser fractions deposited in the channels and finer fractions deposited on the flood plains. The ore deposits occur in the sandstone lenses usually in association with fossil vegetation. Most ore bodies contain elongate masses of higher-grade material which are called "rolls"; fossil logs, when present, lie parallel with the associated rolls.

The current directions which prevailed during the deposition of the sandstones can be determined through mapping of cross-lamination and other primary features. Detailed study of the ore bodies made in certain districts show that the rolls lie mostly parallel with the direction of flow of the depositing streams as revealed by cross-lamination. This is thought to mean that the subsurface solutions which brought together the various constituents of the ore traveled through the sand lenses in essentially the same patterns and directions as the original surface streams. Other problems such as the ultimate source of the constituents of the ore and the time of mineralization may also be solved by aid of sedimentary studies. —*Author's abstract*

237 Stokes, W. L., 1954, Relation of sedimentary trends, tectonic features, and ore deposits in the Blanding district, San Juan County,

Utah: U. S. Atomic Energy Comm. RME-3093(Pt. I), 40 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Field studies of the Salt Wash member of the Morrison formation in the Blanding district indicate a relation between tectonic features, river courses, the accumulations of fossil plants, and the formation of ore bodies. It is thought that the Monument upwarp exerted some influence on stream directions in Salt Wash time, and that the carbonaceous material which localized the uranium deposits was preferentially deposited at the bends of streams.

238 Stokes, W. L., 1954, Some stratigraphic, sedimentary, and structural relations of uranium deposits in the Salt Wash sandstone, Final report — April 1, 1952 to June 30, 1954: U. S. Atomic Energy Comm. RME-3102, 50 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Investigations of the Salt Wash member of the Morrison formation of Jurassic age in Arizona and Utah included the study of (1) nature and origin of primary structures and their use in tracing zones that are favorable or unfavorable to mineralization; (2) relation of sedimentary properties of Salt Wash sandstones to primary structures and ore formation; (3) occurrence and meaning of the repetition of rock types in the Salt Wash; (4) relation of fossil plants or other organic material to sedimentary patterns and ore; and (5) relation of sedimentary patterns to mineralized areas and to ancient structural features.

Environments favorable for the deposition of uranium minerals probably were created by buried organic matter. Growth and burial of plants in Salt Wash time was not uniform but was concentrated along old river bends which are now shown by curving patterns of sediments. The areas of pronounced bends and greater than average amounts of organic matter are thought to occur in places where normal directions of flow were changed or where deflections of current took place due to tectonic features. Such areas can be located and followed by the observation and analysis of primary structures and of other sedimentary features.

239 Stokes, W. L., 1954, Stratigraphy of the southeastern Utah uranium region; *in* Uranium deposits and general geology of southeastern Utah; Utah Geol. Soc., Guidebook to the geology of Utah, no. 9, Salt Lake City, p. 16-47.

Exposed sedimentary formations in southeastern Utah are of every system from Mississippian to Tertiary. Older sedimentary rocks may be present but are not exposed. Each of the exposed formations is described.

Uranium ore has been produced from 21 formations on the Colorado Plateau; 7 formations contain uranium deposits that have yielded more than 1,000 tons. The bulk of the production in southeastern Utah has come from the Shinarump and Chinle formations of Triassic age and from the Morrison formation of Jurassic age. These three formations are discussed in greater detail than the others.

240 Stokes, W. L., (ed.), 1954, Uranium deposits and general geology of southeastern Utah: Utah Geol. Soc., Guidebook to the geology of Utah, no. 9, Salt Lake City, 115 p.

Two sections of this report are devoted to the history of the vanadium-uranium-radium industry on the Colorado Plateau. The uranium mineralogy of the region is described in another section that includes mineral tables. The stratigraphy and structure of the region are discussed separately (annotations of these reports in this bibliography are no. 239 and 221 respectively). The uranium deposits of the Thompson area in Grand County and the Big Indian Wash-Lisbon Valley area in San Juan County are also described separately (annotat5ons of these reports are no. 241 and 142 respectively).

241 Stokes, W. L., and Mobley, C. M., 1954, Geology and uranium deposits of the Thompson area, Grand County, Utah; *in* Uranium deposits and general geology of southeastern Utah: Utah Geol. Soc., Guidebook to the geology of Utah, no. 9, Salt Lake City, p. 78-94.

Uranium-vanadium deposits in the Thompson area occur in fluvial sandstones in the Salt Wash member of the Morrison formation of Jurassic age. Rocks in the area dip at low angles to the northeast away from the Salt Valley anticline. Carnotite and tyuyamunite replace fossil plant material and are disseminated in the surrounding sandstone. Corvusite and a micaceous vanadium mineral are disseminated in the sandstone also, but they do not always occur with the uranium minerals. The deposits may be tabular or lenticular, with their long axes parallel to the bedding, or they may be curved zones, called "rolls," of mineralized material that cross the bedding planes. The sandstone enclosing most of the ore bodies is dominantly light gray to white rather than the usual red, and the mudstone interbedded with the sandstone near the ore bodies is gray rather than the normal red-brown. The ore appears to be confined mainly to the thicker and more continuous sandstone lenses; the larger ore deposits are in the central part of the lenses.

242 Stokes, W. L., and Phoenix, D. A., 1948, Geology of the Egnar-Gypsum Valley area, San Miguel and Montrose Counties, Colo.: U. S. Geol. Survey Oil and Gas Inv. Prelim. Map 93 (with text).

The stratigraphy and structure of the area are described. Exposed sedimentary rocks range in age from Pennsylvanian to Quaternary; no igneous rocks are present. Most of the Permian, Triassic, and Jurassic rocks are of continental origin. The structural trend is northwest-southeast; the gentle regional folding dates in part to Paleozoic time. From south to north, the structures include the Dolores anticline, the Disappointment syncline, and the Gypsum Valley anticline. The Dolores anticline may be due to intrusive salt, and the Gypsum Valley anticline certainly is. The crest of the latter is extensively faulted and collapsed.

243 Stokes, W. L., Russell, R. T., Fischer, R. P., and Butler, A. P., Jr., 1945, Geologic map of the Gateway area, Mesa County, Colo., and the adjoining part of the Grand County, Utah: U. S. Geol.

Survey Strategic Minerals Inv. Prelim. Map 3-173 (with text).

The vanadium-uranium deposits in the Gateway area of Colorado are in a bench-forming sandstone unit in the lower part of the Morrison formation of Jurassic age. The sandstone in the deposits is partly or wholly impregnated with carnotite and other vanadium minerals, and some plant material is richly mineralized. The ore bodies are irregular in shape; the larger ones are tabular and lie generally parallel to the bedding but cut the bedding in detail. Some of the ore bodies, called rolls by the miners, have a roughly cylindrical shape. The rolls and the mineralized logs have a northeasterly orientation. A belt in which the ore bodies are relatively close-spaced trends northwestward through the area. The location of the deposits is shown on a map.

244 Stokes, W. L., and Sadlick, Walter, 1953, Sedimentary properties of Salt Wash sandstones as related to primary structures — part 2, Technical report for April 1, 1952 to March 31, 1953: U. S. Atomic Energy Comm. RME-3067, 26 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Field and laboratory studies of primary sedimentary structures of the Salt Wash member of the Morrison formation of Jurassic age in the Carrizo Mountains of Arizona indicate that uranium deposits are most prevalent between the flood plain and the more central parts of the channel sands because this environment was most favorable to the plant growth and burial needed to create an environment favorable to ore deposition. This zone can be identified by reference to primary structures and by sedimentary analysis.

245 Strobell, J. D., Jr., 1954, Stratigraphic relations in the Carrizo Mountains area, northeastern Arizona and northwestern New Mexico [abs.]: Geol. Soc. American Bull., v. 65, no. 12, p. 1310-1311.

Formations exposed in the Carrizo Mountains area range in age from Permian to Eocene(?). The De Chelly sandstone member of the Cutler formation (Permian) is underlain by Cutler red beds and unconformably overlain by Shinarump conglomerate (Late Triassic); the Moenkopi formation (Early and Middle(?) Triassic) is absent. The Chinle formation (Late Triassic) is restricted to Gregory's lower three divisions; red siltstone of Gregory's "A division" is now the lower member of a twofold Wingate sandstone that is assigned to the Triassic system on evidence gained by J. W. Harshbarger and associates elsewhere in the Navajo country. The Kayenta formation (Jurassic?) and Navajo sandstone (Jurassic) thin southward and disappear within the Carrizo Mountains area. The San Rafael group (Middle and Late Jurassic) comprises five formations: Carmel formation, Entrada sandstone, Todilto limestone, Summerville formation, and Bluff sandstone. Carmel is present only in the western half of the area, and Todilto only along the eastern edge. Where Carmel pinches out, Entrada rests unconformably without detected angularity upon Wingate.

The Morrison formation (Late Jurassic) comprises four members — Salt Wash, Recapture, Westwater Canyon, and Brushy Basin. Possible equivalents of the Burro Canyon formation (Early Cretaceous) are not differentiated from the Morrison. Dakota sandstone

(Late Cretaceous) unconformably overlies the Morrison and is conformably succeeded by marine Mancos shale. Nondeposition of Moenkopi, convergence of Kayenta, Navajo, Carmel, and Todilto, and thinning and lithologic change in other formations suggest intermittent uplift during Mesozoic time. These rocks were folded, truncated, and subsequently covered by Chuska sandstone (Eocene?). —*Author's abstract*

246 Stugard, Frederick, Jr., 1951, Uranium resources in the Silver Reef (Harrisburg) district, Washington County, Utah: U. S. Geol. Survey TEM-214, open-file report, 33 p.

Uranium deposits of the Silver Reef district near Leeds, Utah, occur in the Tecumseh sandstone member of the Chinle formation of Triassic age. The principal structural feature of the area is the northeast-trending and plunging Virgin anticline which has been thrust-faulted and breached by erosion. Hogbacks, or "reefs," dipping as much as 36° are developed on resistant sandstone beds. The ore occurs in thin-bedded and crossbedded fluvial lenses of shale and sandstone and is apparently associated with carbonized plant material. Vanadium-uranium ore has been shipped from the Chloride Chief and Silver Point claims. The ore contains several times as much vanadium as uranium, some copper, and traces of silver. The occurrences are similar to the silver deposits which were mined from 1875 to 1909. More than 150 claims have been staked in the area.

247 Stugard, Frederick, Jr., 1952, Two uranium deposits in sandstone, Washington and Kane Counties, Utah [abs.]: Geol. Soc. America Bull., v. 63, no. 12, p. 1373.

Uranium, vanadium, copper, and silver minerals occur as small lenticular deposits in sandstone of the Chinle formation of Triassic age at Silver Reef, Washington County, Utah. A mass of trachyte porphyry nearby is thought to be the source of the metal-bearing hydrothermal solutions that formed the deposits.

At the Bulloch properties in Kane County, disseminated autunite constitutes a blanket deposit in Jurassic sandstone just below the unconformity between the Jurassic and Cretaceous systems. The source of the uranium is not known.

248 Stugard, Frederick, Jr., 1953, Physical exploration for uranium during 1951 in the Silver Reef district, Washington County, Utah: U. S. Geol. Survey TEI-254, open-file report, 59 p.

The Silver Reef district in southwestern Utah lies on the northeastward trending and plunging Virgin anticline which has been breached by erosion. Thirteen diamond-drill holes, 10 of which were located around Pumpkin Point, were drilled in 1951; no ore-grade deposits were found. Carnotite and volborthite are present in surface exposures in mined areas. Small lenticular ore bodies have been mined in the Chinle formation, but no ore remains in sight. The chances of discovering significant uranium deposits in the Silver Reef district are poor because of highly variable lithology, closely faulted structure, and the obliteration of shallow uranium-bearing lenses during silver mining. The report includes descriptions of several mines and prospects in the area.

249 Tavelli, J. A., 1951, Review of airborne radioactivity survey techniques in the Colorado Plateau: U. S. Atomic Energy Comm. RMO-697, 12 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

An airborne technique for rapidly prospecting for surface exposures of uranium deposits is being developed. It has been found that uranium concentrations of commercial grade can be detected by simple instruments from low-flying fixed-wing aircraft. Flight elevations of 50 feet at air speeds of about 60 miles per hour have produced successful results with commercially available scintillation equipment. The technique is applicable only to exposed deposits and does not eliminate the need for ground prospecting.

250 Thomas, H. D., 1954, Uranium in Wyoming: Mines Mag., v. 44, no. 3, p. 81-82, 96.

Uranium deposits in Wyoming occur in sedimentary rocks that range in age from Cambrian to Recent. The deposits in the Black Hills are in the Lakota sandstone, Fuson shale, and Fall River sandstone, all of Cretaceous age. Carnotite fills small fractures and interstitial spaces in medium- to coarse-grained sandstone that contains abundant carbonaceous material.

Deposits of carnotite and uranophane occur in sandstone in the Wasatch formation of early Eocene age in the Pumpkin Buttes area. In the Miller Hill area a uraniferous limestone occurs in a series of several hundred feet of mildly radioactive tuffaceous rocks of Tertiary age. Most of the uranium deposits of the Gas Hills are in sandstone in the Wind River formation of early Eocene age. The uranium deposits in the McComb area are in rocks of middle or late Eocene age, those in the Saratoga area are in the North Park formation of Pliocene age, and deposits near Mayoworth are in limestone of the Sundance formation of Jurassic age. In the Red Desert area schroeckingerite occurs in the Wasatch formation and in younger alluvial material. The deposits near Baggs are in Tertiary sandstones.

251 Tourtelot, H. A., 1952, Reconnaissance for uraniferous rocks in northeastern Wind River Basin, Wyo.: U. S. Geol. Survey TEM-445, 14 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Most of the radioactivity anomalies detected by airborne instruments were in Precambrian rocks, but some were in Paleozoic and Cenozoic rocks. None contained more than 0.003 percent uranium.

252 Towle, C. C., and Rapaport, Irving, 1952, Uranium deposits of the Grants district, New Mexico: Min. Eng., v. 4, no. 11, p. 1037–1040 [abs.]: Econ. Geology, v. 47, no. 1, p. 128.

Uranium mineralization along the north flank of the Zuni Uplift in northwest New Mexico was discovered . . . in 1950. . . . Irregular blanket-type uranium deposits are in terrestrial Jurassic sediments. The principal ore-horizon is the upper recrystallized portion of the Todilto limestone. This limestone erodes as benches one-half to three miles wide, enabling relatively cheap exploration and open-pit mining. Ore deposits have also been discovered in the sand lenses of the Morrison formation, 500 to 800 feet stratigraphically above the Todilto. The Morrison erodes into steep cliffs, necessitating more expensive exploration and mining methods.

The uranium minerals in the Todilto are carnotite, tyuyamunite, and uranophane; finely disseminated pitchblende is found where the deposits are removed from the effects of superficial oxidation. Gangue minerals are pyrite, hematite, calcite, and traces of barite and fluorite. The sandstone ores in the Morrison contain carnotite and schroeckingerite, associated with limonite and organic material. The ore deposits are believed to have achieved their present form by the lateral percolation of slightly heated Tertiary waters. Uranium, however, may have originally been contributed during the Jurassic. — *authors' abstract*

253 Trites, A. E., Jr., Finnell, T. L., and Thaden, R. E., 1956, Uranium deposits in the White Canyon area, San Juan County, Utah: U. S. Geol. Survey Prof. Paper 300, p. 281-284; Geology of uranium and thorium, United Nations, v. 6, p. 379-382.

Uranium deposits in the White Canyon area occur in the Shinarump conglomerate of Triassic age in channels that have been cut into the Moenkopi formation, which is also of Triassic age. Most of the channels are within a band from 8 to 15 miles wide, and all of the known high-grade uranium deposits are in channels that are within 15,000 feet of the edge of the band of Shinarump conglomerate. The principal intrachannel control of uranium deposition appears to have been lithologic; the most favorable host rock is clayey sandstone which contains carbonized plant material and which overlies siltstone or mudstone.

254 Troyer, M. L., McKay, E. J., Soister, P. E., and Wallace, S. R., 1954, Summary of investigations of uranium deposits in the Pumpkin Buttes area, Johnson and Campbell Counties, Wyo.: U. S. Geol. Survey Circ. 338, 17 p.

Uranium occurrences in the Pumpkin Buttes area are predominantly in sandstones of the Wasatch formation of Eocene age. The Pumpkin Buttes area lies in the topographic and structural Powder River Basin. The Wasatch formation is about 1,500 feet thick, and is underlain by the Fort Union formation of Paleocene age and overlain by the White River formation of Oligocene age. Except for the thin capping of White River rocks on the high buttes, the rocks exposed in the area are of the Wasatch formation.

The uranium occurrences are in gray to buff sandstones that are closely associated with a red sandstone zone 450 to 900 feet above the base of the Wasatch formation. The sandstone in this zone is typically massive and crossbedded, medium- to coarse-grained, feldspathic, and friable to moderately well cemented; a few beds are tuffaceous.

The uranium occurrences are of two principal types: concretionary and disseminated. The concretionary deposits are small irregular masses in which the principal uranium mineral is uranophane. These also contain vanadium minerals and a large amount of iron and manganese oxides. The uranium content is locally as high as 15 percent. The deposits are as much as 10 feet in maximum dimension, but are usually smaller and may occur in clusters. The disseminated deposits occur as irregular zones in which metatyuyamunite irregularly impregnates the sandstone; little or no iron or manganese oxide is visible. In general, the sandstone in the concretionary deposits is cleaner than that in the disseminated deposits.

Two geologic maps of the area are included. One shows the locations of uranium occurrences and radioactivity anomalies; the other shows the distribution of favorable sandstones in the east-central part of the area.

255 Tschanz, C. M., 1953, Guadalupita, N. Mex.; *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1953: U. S. Geol. Survey TEI-390, p. 81-90, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The copper and uranium deposits near Guadalupita occur in lenticular shale, sandstone, arkose, and limestone beds in the lower 2,500 feet of the Sangre de Cristo formation of Pennsylvanian and Permian(?) age. Although the Sangre de Cristo is predominantly a "red bed" unit, all the known deposits in this area are in gray, green, dark-gray, or yellow-brown beds. Both copper and uranium are most abundant in the more carbonaceous sediments. The deposits are discontinuous.

256 Tschanz, C. M., 1954, Guadalupita, N. Mex.; *in* Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953 to May 31, 1954: U. S. Geol. Survey TEI-440, p. 72-73, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The copper-uranium deposits in the Guadalupita area are in the steeply dipping Sangre de Cristo formation of Pennsylvanian and Permian(?) age in a sandstone member near the middle of the formation. The deposits are localized by sedimentary structures in stream-laid sandstone beds that overlie the members that contain most of the larger copper deposits. Particularly favorable for uranium deposits are those parts characterized by local cut-and-fill structures, carbonized plant remains, chalcopyrite, gray or black clay galls, visible copper or vanadium minerals, and distinctive pink sandstone. Most of the uranium in sandstone is in a black ferric(?) oxide, but metatyuyamunite is locally abundant.

257 U. S. Atomic Energy Comm. and U. S. Geol. Survey, 1956, Techniques for prospecting for uranium and thorium: Geology of uranium and thorium, United Nations, v. 6, p. 752-755; see also, Foote, R. S., and Page, L. R., 1956, Techniques for prospecting for uranium and thorium — A summary: U. S. Geol. Survey Prof. Paper 300, p. 621-625.

Successful prospecting and physical exploration for uranium and thorium requires a thorough knowledge of geologic, geochemical, and geophysical techniques. The favorability of each distinct geological unit within any large unexplored area can be evaluated by the use of these techniques. Preliminary geophysical reconnaissance of the favorable areas is best made by gamma radiation detectors carried by the geologist-prospector on the ground or in a low-flying aircraft. These techniques locate only exposed or slightly buried deposits, but they commonly result in opening up new districts where concealed deposits are found by other methods.

Where ore minerals are not exposed, panning and the analysis of soil, rock, water, and plant samples are useful supplements to radiation and geologic criteria. Structural, lithologic, and mineralogic guides useful in the search for deeply buried deposits have been determined for most uranium districts in the United States. Some of these guides, such as the structurally and lithologically favorable host rocks, have been effectively delineated by geophysical techniques.

258 U. S. Geological Survey, 1951, Progress report: Wamsutter (Red Desert) area, Wyoming: U. S. Geol. Survey TEM-96A, 2 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

This report concerns the preliminary results of field work done during 1949 on the schroeckingerite deposits at Lost Creek near Wamsutter, Sweetwater County, Wyo. The schroeckingerite occurs as a caliche deposit along a fault zone. The uranium may have been derived from uraniferous lignite cut by the fault zone at a depth of about 500 feet. It is suggested that similar deposits may occur along other fault zones that cut uraniferous lignite.

259 U. S. Geological Survey, 1953, Search for and geology of radioactive deposits, Semiannual progress report, December 1, 1952 to May 31, 1953: U. S. Geol. Survey TEI-330, 302 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

260 U. S. Geological Survey, 1953, Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1953: U. S. Geol. Survey TEI-390, 280 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

261 U. S. Geological Survey, 1954, Geologic investigations of radioactive deposits, Semiannual progress report, December 1, 1953 to May 31, 1954: U. S. Geol. Survey TEI-440, 246 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

262 U. S. Geological Survey, 1954, Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, 299 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Geological Survey, under the sponsorship of the Atomic Energy Commission, has undertaken investigations of radioactive materials in the United States and Alaska. Each of these reports, which are statements of progress made during a period of 6 months, gives the principal unclassified information compiled during the particular period.

263 Vickers, R. C., 1954, Belle Fourche area, Northern Black Hills, S. Dak.; *in* Geologic investigations of radioactive deposits, Semiannual progress report, June 1 to November 30, 1954: U. S. Geol. Survey TEI-490, p. 209-210, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The uranium deposits of the Belle Fourche area are near the position of horizontal change in color from pink or red to gray or buff sandstone within the lower unit of the Fall River formation of Cretaceous age. In detail the pink to buff contact cuts across the minor structures, but in general it is parallel to the regional strike of the beds. The deposits also seem to be related to local structural features such as flattening or reversal of the dip.

264 Vine, J. D., and Prichard, G. E., 1954, Uranium in the Poison Basin area, Carbon County, Wyo.: U. S. Geol. Survey Circ. 344, 8 p.

Uranium deposits occur in sandstone in the Browns Park formation of Miocene(?) age in the Poison Basin west of Baggs, Wyo. The Browns Park formation overlies the slightly tilted Wasatch and Green River formations of Eocene age. The unit in which the deposits lie is a soft light-colored crossbedded quartzose fine- to medium-grained sandstone that contains small amounts of tuffaceous material. The uranium minerals, mostly uranophane and schroeckingerite, are associated with brown, green, gray, or yellow sandstone. The uranium minerals coat fractures and are disseminated in the sandstone. They were probably deposited by ground water solutions of unknown origin. The Browns Park formation in this area contains an exceptionly large amount of selenium.

265 Walker, G. W., 1953, Rosamond uranium prospect, Kern County, Calif.: Calif. Div. Mines, Spec. Rept. 37, 8 p.

Small quantities of autunite and of another radioactive mineral occur in tuffaceous sedimentary rocks of the Rosamond formation of Miocene age at the Rosamond prospect about 10 miles south of Mojave, Kern County, Calif. The autunite occurs principally as coatings on fracture and joint surfaces and, to a lesser extent, as disseminations in the tuffaceous rocks adjacent to faults. A waxy reddish-brown to black radioactive mineral associated with iron oxides and chlorite(?) is found in small quantities on slickensided fault surfaces.

266 Walthier, T. N., 1955, Uranium occurrences of the eastern United States: Min. Eng., v. 7, no. 6, p. 545-547.

Uranium occurrences in the eastern United States are in sandstone, arkose, black shale, coal, and crystalline rocks in several different geologic environments. In the Jim Thorp area of Carbon County, Pa., several small pods of uraniferous material have been found in fluvial sandstone and graywacke in the Catskill formation of Devonian age. Uranium occurs in the same area in siliceous conglomerate in the Pottsville formation of Pennsylvanian age. In Hunterdon County, N. J., and Bucks County, Pa., small amounts of uranium minerals have been found in arkosic redbeds of the Stockton formation of Triassic age, and in southwest Virginia, abnormal radioactivity has been found in the Price sandstone of Mississippian age.

267 Wantland, Dart, 1952, Geophysical investigations for United States Atomic Energy Commission in the Colorado Plateau area: U. S. Bur. Reclamation Geol. Rept. G-119, 151 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Geophysical field investigations were conducted at King Tutt Mesa in Apache County, Ariz., and at Bull Canyon in Montrose County, Colo. The resistivity method was used in both areas; the potential drop ratio method was unsuccessful in a part of the Bull Canyon area. Areas of high resistivity can be correlated with areas of ground favorable for the occurrence of uranium deposits. The field procedures are described and resistivity depth curves are plotted.

268 Wantland, Dart, and Casey, R. D., 1952, Field tests for the United States Atomic Energy Commission on the use of the seismic geophysical method for tracing "buried channels" in the Monument Valley area, Arizona: U. S. Bur. Reclamation Geol. Rept. G-123, 68 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Seismic methods were tested to determine whether they could be used in the mapping of buried channels in which uranium ore might occur. It was tentatively concluded that the seismic refraction method could be used to determine the outline of channels. The seismic reflection method proved unsuitable for this purpose.

269 Waters, A. C., and Granger, H. C., 1953, Volcanic debris in uraniferous sandstones, and its possible bearing on the origin and precipitation of uranium: U. S. Geol. Survey Circ. 224, 26 p.

The relationships between uranium-vanadium ore deposits on the Colorado Plateaus and volcanic material that, in part, make up the host rocks suggest that the uranium and vanadium have a complex origin and history, and that they were emplaced during the structural deformation and igneous intrusion of Tertiary time.

Volcanic debris, now altered to clay minerals, has been recognized in the Salt Wash sandstone and Brushy Basin shale members of the Morrison formation and in the Shinarump conglomerate and Chinle formation. Field studies and microscopic examination of the ores indicate a relationship between the ore minerals and montmorillonite clay formed by devitrification of volcanic glass. The vanadium hydromica formerly called "roscoelite" is believed to be derived from montmorillonite.

A paragenetic sequence of events, shown by examination of thin sections of the ore-bearing sandstones, begins with cementation of the sand by calcite, followed by secondary enlargement of quartz grains. The new silica deposited as overgrowths on the quartz grains was probably released by devitrification of the glassy volcanic material. At a later date the quartz grains were dissolved and vanadium hydromica and uranium-bearing minerals were formed. Deposition of the ore minerals was probably related to a change in ground-water conditions brought about by igneous intrusion.

During devitrification of volcanic ash, ground waters may have leached alkalis, uranium, vanadium, and other substances from the ash. The absence of blanket deposits of uranium and vanadium minerals however, implied either (1) reactivated circulation of metal-bearing ground water, or, more probably, (2) introduction of metal-bearing juvenile waters into the ground-water system. Several additional problems must be investigated before final conclusions can be reached. — *Authors' abstract*

270 Weeks, A. D., 1951, Red and gray clay underlying ore-bearing sandstone of the Morrison formation in western Colorado: U. S. Geol.

Survey TEM-251, 19 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

As a result of a preliminary study of the clays that underlie the ore-bearing sandstone of the Morrison formation of Jurassic age, the principal clay mineral has been tentatively identified as hydrous mica. Chemical analyses show that the red clay contains more iron than the gray clay, but that more of the iron in the gray clay is n the ferrous state. Spectrographic analyses of minor constituents show no significant difference between the red and gray clay except in iron content. Quartz and carbonate have a wide range in quantity that is not related to the color of the clay. Sufficient evidence is not available to indicate whether the gray color was produced by alteration of the red clay.

271 Weeks, A. D., 1953, Mineralogic study of some Jurassic and Cretaceous claystones and siltstones from western Colorado and eastern Utah: U. S. Geol. Survey TEI-285, 22 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The clay minerals and water-soluble minerals identified in 50 samples of siltstone and claystone from Jurassic and Cretaceous formations suggest some distinctive characteristics for these formations and some differences in source area or environment of deposition. Hydromica predominates in samples of the Summerville and Burro Canyon formations and of the Salt Wash member of the Morrison formation, but montmorillonite derived from volcanic ash is found in samples from the Brushy Basin member of the Morrison. Kaolinite in the Dakota sandstone is probably related to the regional unconformity at the base of the Dakota. Size analyses show that most of the samples are siltstones.

272 Weeks, A. D., and Thompson, M. E., 1954, Identification and occurrence of uranium and vanadium minerals from the Colorado Plateaus: U. S. Geol. Survey Bull. 1009-B, p. 13-62.

This report gives physical properties, X-ray data, and in some instances results of chemical and spectrographic analyses of 48 uranium and vanadium minerals Also included are lists of mines in which the minerals have been identified.

273 Weeks, A. D., Thompson, M. E., and Thompson, R. B., Jr., 1953, Mineral associations and types of uranium ores on the Colorado Plateaus [abs.]: Geol. Soc. America Bull., v. 64, no. 12, p. 1489-1490.

Uranium ores from the Colorado Plateaus are classified as (1) uranium with vanadium, and (2) uranium with copper and other metals. Each type is subdivided into highly oxidized ore and relatively unoxidized ore

The vanadium-to-uranium ratio of the vanadiferous ores ranges from about 30:1 at Placerville and Rifle, Colo., to about 1:1 at Temple Mountain in the San Rafael district of Utah. The chief uranium minerals of the highly oxidized ore are the uranyl vanadates: carnotite, tyuyamunite, and metatyuyamunite.

The black unoxidized vanadiferous ores contain a new black uranium mineral, and pitchblende, montroseite, and at least two other low-

valence vanadium oxides. They are associated with base-metal sulfides.

The oxidized nonvanadiferous ore is characterized by yellow, orange, or green uranium minerals and blue or green copper minerals.

The unoxidized nonvanadiferous ore is also black and contains pitchblende, base-metal sulfides, and the new uranium mineral mentioned above.

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

This report describes the geologic features that can be used to appraise the favorableness of ground in guiding diamond-drill exploration for carnotite deposits in the Upper Jurassic Morrison formation on the Colorado Plateau. It is based on a statistical study of the geologic logs of about 2,500 holes drilled by the Geological Survey. The most useful features consist of the thickness and color of the ore-bearing sandstone, the altered mudstone associated with the ore-bearing sandstone, and the abundance of carbonaceous material in the sandstone. Although each feature can be used alone to appraise the favorableness of the ground, an appraisal based on all of them together is more useful. A method of expressing this in numerical values is suggested.

The results obtained by the Geological Survey using these geologic guides appear to be at least twice as favorable as the drilling results obtained with little or no geologic guidance. — *Author's abstract*

275 Wherry, E. T., 1912, A new occurrence of carnotite: Am. Jour. Sci., 4th ser., v. 33, no. 198, p. 574-580.

Small scattered occurrences of carnotite have been found in a bed of conglomerate in the Pottsville formation of Pennsylvanian age near Mauch Chunk, Pa. The mineral occurs in scattered streaks and patches in the lower part of the bed, which is exposed for about 2,600 feet along a roadway. The author suggests that the uranium and vanadium minerals were originally deposited in black shale beds as detritus, and that the metals were extracted and redeposited by circulating meteoric waters.

276 Wherry, E. T., 1915, Carnotite near Mauch Chunk, Pa.: U. S. Geol. Survey Bull. 580-H, p. 147-151.

Carnotite occurs thoroughly but unevenly distributed throughout a 40-foot layer of coarse-grained conglomerate near the base of the Pottsville formation of Pennsylvanian age about a mile north of Mauch Chunk. The outcrop extends for about 2,000 feet along a road cut. The uranium and vanadium are thought to have been originally contained in detrital minerals of the host formation. Circulating ground waters since have dissolved and redistributed the uranium and vanadium.

277 Williams, F. J., and Barrett, D. C., 1953, Preliminary report of reconnaissance in the Cameron area, Arizona: U. S. Atomic Energy Comm. RME-4002, 10 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Ground and airborne reconnaissance for uranium was conducted in the Cameron area, Coconino County, Ariz. The largest and best deposits are in the Petrified Forest member of the Chinle formation of Triassic age, but uranium also occurs in association with fossil logs in the Shinarump conglomerate, also of Triassic age. The uranium deposits in the Petrified Forest member are in silty mudstone and clay which contain scattered sand and carbonaceous material. The normal gray of the rocks has been changed to light tan or yellowish brown near the deposits. Uraninite and secondary uranium minerals are associated with pyrite, smaltite, calcite, gypsum and carbonaceous material. The deposits contain negligible amounts of copper and vanadium.

278 Williams, G. O., 1925, Radium-bearing silts of southeastern Utah: Eng. Min. Jour., v. 119, no. 5, p. 201-202.

Radium-uranium deposits have been found in silt and clay beds of either Tertiary or Quaternary age on the floor of Montezuma Canyon in San Juan County, Utah. The author suggests that ancient carnotite deposits in an unknown host rock were eroded, washed downstream, and redeposited on the floor of the canyon.

279 Wilmarth, V. R., 1953, Garo, Colo.; *in* Search for and geology of radioactive deposits, Semiannual progress report, December 1, 1952, to May 31, 1953: U. S. Geol. Survey TEI-330, p. 109-110, issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

The Shirley May uranium-vanadium-copper deposit near Garo, Park County, is on the northeast flank of the Garo anticline in the Maroon formation of Permian age. The minerals, principally tyuyamunite, carnotite, volborthite, azurite, and malachite, occur in three separate medium- to coarse-grained sandstone beds as disseminations, cementing material, and fracture fillings. The gangue minerals are calcite, manganite, and hematite. The localization of ore is mainly controlled by faulting and the porosity of the sandstones adjacent to the faults.

280 Winterhalder, E. C., 1954, Preliminary reconnaissance for uranium in the Green River Basin and the Rock Springs uplift, Sweetwater and Fremont Counties, Wyo.: U. S. Atomic Energy Comm. RME-1045, 10 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Reconnaissance for uranium deposits in part of southwestern Wyoming disclosed two areas of anomalous radioactivity. One area is northwest of Oregon Buttes in the southwest corner of Fremont County. Anomalous radioactivity is present in some micaceous and arkosic sandstones of the Tipton tongue of the Green River formation and the Cathedral Bluffs tongue of the Wasatch formation, both of Eocene age. The other area, the Red Creek basin, is south of Rock Springs, Wyo., near the Utah-Wyoming border. Here, some shale, carbonaceous shale, coal, and limestone beds in the Tipton tongue of the Green River formation are anomalously radioactive.

281 Witkind, I. J., 1954, Localization of uranium minerals in channel sediments at the base of the Shinarump conglomerate, Monu-

ment Valley, Ariz. [abs.]: Econ. Geology, v. 49, no. 7, p. 804-805; Geol. Soc. America Bull., v. 65, no. 12, p. 1327.

Uranium ore bodies in the Monument Valley area are localized in the conglomeratic sandstone of the Shinarump conglomerate of Triassic age that fills channels scoured into the underlying Moenkopi formation which is also of Triassic age. These channels range from 15 feet wide and 10 feet deep to 2,300 feet wide and 70 feet deep. Fragments of trees were deposited with Shinarump sediments in the channels. Witkind suggests that when the Shinarump conglomerate was invaded by mineralizing solutions, the uranium minerals were deposited mainly in and adjacent to decomposing plant material. The author also suggests that short channels are more likely to contain ore than long channels.

282 Witkind, I. J., 1956, Channels and related swales at the base of the Shinarump conglomerate, Monument Valley, Ariz.: U. S. Geol. Survey Prof. Paper 300, p. 233-237; Geology of uranium and thorium, United Nations, v. 6, p. 368-370.

Vanadium-uranium ore deposits in Monument Valley are in channel sediments at the base of the Shinarump conglomerate of Triassic age. The channels range in width from 15 to 2,300 feet and are scoured a maximum of 75 feet into underlying strata. The relation between channels and uranium deposits has been demonstrated so repeatedly that prospecting in the area has evolved into searching for, and exploring, these channels.

In some places a channel coincides with the axis of a broad elongate swale. The swales are too large for visual observation but are apparent on isopach maps. The swales range in width from 1 to 3 miles, and have about 40 feet of relief. It may be possible to locate and outline concealed channels by exploration of the swales.

283 Wood, H. B., and Grundy, W. D., 1956, Techniques and guides for exploration of Shinarump channels on the Colorado Plateau: Geology of uranium and thorium, United Nations, v. 6, p. 701-703; see also, Techniques and guides in exploration for uranium in Shinarump channels on the Colorado Plateau: U. S. Geol. Survey Prof. Paper 300, p. 651-657.

This paper discusses geologic guides and drilling techniques employed in the search for uranium deposits in the Shinarump conglomerate of Late Triassic age in the Circle Cliffs and White Canyon regions of southeastern Utah, and the Monument Valley region of Utah and Arizona. The formations concerned are continental deposits of Permian and Triassic age. Uranium deposits of commercial quality occur in Shinarump sediments which fill ancient stream channels cut into the underlying rocks.

284 Wright, R. J., 1954, Prospecting with a counter: U. S. Atomic Energy Comm., 68 p., U. S. Government Printing Office, Washington, D. C.

This report is a summary of information on the operation and use of portable radiation detection equipment suitable for use in prospecting for uranium, such as Geiger counters and scintillation counters.

285 Wright, R. J., 1955, Ore controls in sandstone uranium deposits of the Colorado Plateau: Econ. Geology, v. 50, no. 2, p. 135-155.

Wright, R. J., 1953, Lithologic ore controls in sandstone type uranium deposits, Colorado Plateau [abs.] : Geol. Soc. America Bull., v. 64, no. 12, p. 1495.

Marked lithologic control characterizes most uranium deposits in sandstone formations of the Colorado Plateau. Deposits in rocks ranging in age from the Cutler formation of Permian age to the Wasatch formation of Eocene age are primarily in 1) fluvial sandstones which, 2) contain carbonized plant matter, 3) are light-colored or gray rather than red, and 4) contain feldspar or mica. In addition, 5) sandstones that are interbedded with or interfinger with shales or mudstones are particularly favorable. These features are also characteristic of most sedimentary copper deposits.

Most uranium deposits in sandstone formations show no immediate connection with tectonic features, but a general clustering of ore bodies around large positive structures is noted. The reason for this is not clear.

It is postulated that at least some of the uranium in the ores was derived from the same source as the host rocks. In this light the sandstone uranium deposits may be the continental analogue of uranium-rich marine black shales and phosphorites. Sedimentary copper deposits may have had a similar origin. Uranium moving seaward in streams, during erosion of a land mass, may be fixed on the continent in certain favorable fluvial environments. — *Author's abstract*

286 Wyant, D. G., 1952, Lost Creek (Wamsutter) schroeckingerite deposit, Sweetwater County, Wyo.: U. S. Geol. Survey TEM-10B, 3 p., issued by U. S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Schroeckingerite deposits occur at Lost Creek, Wyo., in clays and sands of Eocene or younger age. The yellow platy micaceous mineral occurs as rounded aggregates in the clay beds, and as fine disseminations in the sand and sandy clay beds. The uraniferous beds are discontinuous and their areal distribution is erratic. The beds strike northwest and dip 14° - 27° NE. The area is part of the Continental Divide Basin.

287 Wyant, D. G., Beroni, E. P., and Granger, H. C., 1952, Some uranium deposits in sandstones; *in* Selected papers on uranium deposits in the United States: U. S. Geol. Survey Circ. 220, p. 26-29.

The principal domestic source of uranium and vanadium has long been the carnotite and roscoelite deposits in sandstone of the Morrison and Entrada formations of Jurassic age on the Colorado Plateau. Other known uranium deposits occur in sandstones that range in age from Paleozoic to Recent; many of these differ from the carnotite deposits in mineralogy, host rock, localization, and possible origin. The deposits may be grouped on the basis of mineral or metal assemblage into (1) uranium-vanadium deposits; (2) copper-uranium-vanadium-carbonized wood deposits; (3) uraniferous asphalt deposits; and (4) miscellaneous deposits including carbonate deposits.

In general, these deposits occur in lenses of argillaceous sandstone or conglomerate interbedded with shales. Commonly associated materials are iron oxide, carbon, and copper compounds. The localization of some of these deposits appears to be controlled by initial sedimentary features of the enclosing rock, that of others by porosity, fractures, and proximity to the surface. Some of the uranium minerals may have been deposited from ground water, some may have formed by weathering and oxidation of other minerals, and some may be hydrothermal in origin. The report includes a map showing the location and types of uranium deposits in sandstone, and briefly describes an example of each type.

288 Zareski, G. K., 1954, Reconnaissance of uranium occurrences at Wray Mesa, San Juan County, Utah, and Montrose County, Colo.: U. S. Atomic Energy Comm. RME-69(Pt. 1), 15 p., issued by U. S. Atomic Energy Comm. Tech. Inf Service, Oak Ridge, Tenn.

Reconnaissance examination was made of several uranium deposits on Wray Mesa. The deposits occur in sandstone at several horizons in the Salt Wash member of the Morrison formation of Jurassic age, and in sandstone lenses near the base of the Brushy Basin member of the Morrison formation. The ore minerals are carnotite, tyuyamunite, and black uranium and vanadium minerals. Exposed formations are of Jurassic and Cretaceous age, and the rocks dip about 3° NW.

289 Zeller, H. D., and Baltz, E. H., Jr., 1954, Uranium-bearing copper deposits in the Coyote district, Mora County, N. Mex.: U. S. Geol. Survey Circ. 334, 11 p.

Uranium-bearing copper deposits in the Sangre de Cristo formation of Pennsylvanian and Permian age south of Coyote, N. Mex., occur in lenticular carbonaceous zones in steeply dipping beds of shale and arkosic sandstone. Samples from these zones average 3 percent copper and contain as much as 0.067 percent uranium. Metatyuyamunite is disseminated in some of the arkosic sandstone beds, and uraninite was identified in some of the copper sulfide nodules found in the shale. The sulfide nodules are composed principally of chalcocite with some bornite, covellite, pyrite, and malachite. Some nodules replaced wood.

The copper and uranium were probably deposited with the sediments and concentrated into zones during compaction and lithification. Carbonaceous material in the Sangre de Cristo formation provided the environment that precipitated uranium and copper from mineral-charged connate waters forced from the clayey sediments.

290 Anonymous, 1955, Uranium, a comparison of its geologic occurrence in California and in the Colorado Plateau: Calif. Div. Mines, Min. Inf. Service, v. 8, no. 5, p. 1-7.

Uranium deposits are known to occur in igneous, sedimentary, and metamorphic rocks at about 100 localities in California. These localities are indicated on a map. In the Taft-McKittrick area of San Luis Obispo and Kern Counties, carnotite and other secondary uranium minerals coat fractures in shale beds of Tertiary age. In the Rosamond-Mojave area of Kern County, secondary uranium minerals occur along fractures and bedding planes and as disseminations in tuffaceous sedimentary and rhyolitic rocks of the Rosamond formation of Miocene age. In Kern Canyon in Kern County, autunite and other uranium minerals occur in and near shear zones in granitic rocks. Uranium deposits are also known in many other scattered areas in California.

Uranium deposits in other areas of the United States and the world are described in order to provide a general concept of geologic occurrence that might be useful in the search for uranium deposits in California. Descriptions of these deposits are taken largely from other publications. These include Finch (1955, see ref. 75), Nininger (1954, see ref. 193), Fischer and Hilpert (1952, see ref. 86), Everhart (1951, see ref. 70), Fischer (1950, see ref. 83), and Bain (1950, see ref. 4).

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