Uranium Deposits at Shinarump Mesa and Some Adjacent Areas in the Temple Mountain District, Emery County, Utah

By Donald G. Wyant

Trace Elements Investigations Report 51

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

RESTRICTED
SECURITY INFORMATION

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

IN REPLY REFER TO:

JAN 21 1953

This material contains information affecting the national defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

AEC - 709/3

Dr. Phillip L. Merritt, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, New York

Dear Phil:

Transmitted herewith are six copies of Trace Elements Investigations Report 51, "Uranium deposits at Shinarump Mesa and some adjacent areas in the Temple Mountain district, Emery County, Utah," by Donald G. Wyant, January 1953.

The investigation upon which this report is based was conducted in 1947. The report has been delayed due to the pressure of other work, but is being transmitted at this time for its possible value in future studies that might be undertaken in the area.

As a result of the 1947 work, 950 tons of asphaltite- and carnotite-bearing sandstone are estimated to contain from 0.01 to 0.2 percent uranium of which about half may contain from 0.1 to 0.2 percent, and 90 tons are estimated to contain 0.005 to 0.01 percent uranium. An additional 1,000 tons of potential ore containing more than 0.01 percent uranium may also be present. However, inasmuch as the main purpose of the 1947 sampling program was to determine the general uranium content of all of the Shinarump conglomerate at Shinarump Mesa and not to determine reserves of minable ore, individual ore bodies were not sampled completely.

The Survey plans no additional investigation of the Temple Mountain district at this time.

We plan to publish Part I of this report as a Geological Survey bulletin, and are asking Mr. Hosted to approve this plan.

Sincerely yours,

Arthur P Butler Jr.
for W. H. Bradley
Chief Geologist

RESTRICTED
SECURITY INFORMATION

JAN 09 2001

(200)

RESTRICTED
SECURITY INFORMATION

Geology - Mineralogy

This document consists of 98 pages,
plus 3 figures.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

URANIUM DEPOSITS AT SHINARUMP MESA AND SOME ADJACENT AREAS IN THE TEMPLE MOUNTAIN DISTRICT, EMERY COUNTY, UTAH*

By

Donald G. Wyant

January 1953

Trace Elements Investigations Report 51

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission

When separated from Part II, handle Part I as UNCLASSIFIED

RESTRICTED
SECURITY INFORMATION

USGS - TEI Report 51

GEOLOGY - MINERALOGY

Distribution (Series A)	No. of copies
American Cyanamid Company, Winchester	1
Argonne National Laboratory	1
Atomic Energy Commission, Washington	2
Battelle Memorial Institute, Columbus	1
Carbide and Carbon Chemicals Company, Y-12 Area	1
Division of Raw Materials, Grants	1
Division of Raw Materials, Denver	1
Division of Raw Materials, Hot Springs	1
Division of Raw Materials, New York	6
Division of Raw Materials, Salt Lake City	1
Division of Raw Materials, Richfield	1
Division of Raw Materials, Butte	1
Division of Raw Materials, Washington	8
Dow Chemical Company, Pittsburg	1
Exploration Division, Grand Junction Operations Office	6
Grand Junction Operations Office	1
Technical Information Service, Oak Ridge	6
Tennessee Valley Authority, Wilson Dam	1
U. S. Geological Survey:	
Mineral Deposits Branch, Washington	2
Geochemistry and Petrology Branch, Washington	1
Geophysics Branch, Washington	1
Alaskan Geology Branch, Washington	1
Fuels Branch, Washington	1
L. R. Page, Denver	2
R. P. Fischer, Grand Junction	1
A. E. Weissenborn, Spokane	1
J. F. Smith, Jr., Denver	1
N. M. Denson, Denver	1
R. W. Swanson, Spokane	1
L. S. Gardner, Albuquerque	1
A. H. Koschmann, Denver	1
E. H. Bailey, San Francisco	1
C. E. Dutton, Madison	1
R. A. Laurence, Knoxville	1
R. J. Roberts, Salt Lake City	1
J. D. Love, Laramie	1
TEPCO, Washington (Including master)	5
	66

CONTENTS

Page

Abstract 5
Introduction 6
  Location. 6
  Previous work 8
  Present work. 9
  Acknowledgments 10
General geology. 10
  Shinarump conglomerate. . . . .
    Chert-pebble conglomerate unit 19
    Sandstone-mudstone unit. 21
    Lime-pellet conglomerate unit. 23
    Upper white sandstone unit 25
Radioactivity and sampling 26
Uranium ore deposits 41
  Mineralogy. 42
  Ore bodies at Shinarump Mesa. 50
    Ore bodies in the chert-pebble conglomerate unit 51
    Ore bodies in the sandstone-mudstone unit. 52
    Ore bodies in the lime-pellet conglomerate unit. 56
  Ore bodies at the South Temple workings 58
  Ore bodies at the North Temple workings 65
  Other deposits. 65
  Summary of the characteristics and interrelationships of the ore minerals and mineraloids. 67
Origin of the deposits 73
Outlook and suggestions for prospecting. 86
Summary and conclusions. 88
Bibliography 90

ILLUSTRATIONS

Figure 1. Index map of Temple Mountain district, Emery County, Utah 7

2. General section of rock formations in the San Rafael Swell, Utah. 12

3. Geologic section and map of the surface of Shinarump Mesa, Emery County, Utah . . . . . In envelope

4. Sketch sections surrounding Shinarump Mesa, Emery County, Utah . . . . . In envelope

ILLUSTRATIONS (Continued)

Page

Figure 5. Maps and sections of the South Temple workings, Temple Mountain district, Emery County, Utah . . . . In envelope

6 to 16. Columnar sections SH-1 to SH-11, inclusive, Shinarump Mesa, Emery County, Utah 28-38

TABLES

Table 1. Analyses of channel samples, Shinarump Mesa, Temple Mountain district, Emery County, Utah 39

2. Analyses of bituminous sandstone and conglomerate, Temple Mountain district, Utah 49

3. Analyses of samples, Through adit, South Temple workings. 64

4. Radiometric and chemical analyses of selected samples, Temple Mountain district, Emery County, Utah. 72

URANIUM DEPOSITS AT SHINARUMP MESA AND SOME ADJACENT AREAS IN THE TEMPLE MOUNTAIN DISTRICT, EMERY COUNTY, UTAH

By

Donald G. Wyant

ABSTRACT

Deposits of uraniferous hydrocarbons are associated with carnotite in the Shinarump conglomerate of Triassic age at Shinarump Mesa and adjacent areas of the Temple Mountain district in the San Rafael Swell of Emery County, Utah. The irregular ore bodies of carnotite-bearing sandstone are genetically related to lenticular uraniferous ore bodies containing disseminated asphaltitic and humic hydrocarbon in permeable sandstones and were localized indirectly by sedimentary controls. Nearly non-uraniferous bitumen commonly permeates the sandstones in the Shinarump conglomerate and the underlying Moenkopi formation in the area. The ore deposits at Temple Mountain have been altered locally by hydrothermal solutions, and in other deposits throughout the area carnotite has been transported by ground and surface water.

Uraniferous asphaltite is thought to be the non-volatile residue of an original weakly uraniferous crude oil that migrated into the San Rafael anticline; the ore metals concentrated in the asphaltite as the oil was devolatilized and polymerized. Carnotite is thought to have formed from the asphaltite by ground water leaching.

It is concluded that additional study of the genesis of the

asphaltitic uranium ores in the San Rafael Swell, of the processes by which the hydrocarbons interact and are modified (such as heat, polymerization, and hydrogenation under the influence of alpha-ray bombardment), of petroleum source beds, and of volcanic intrusive rocks of Tertiary age are of fundamental importance in the continuing study of the uranium deposits on the Colorado Plateau.

INTRODUCTION

The asphaltic ores of uranium and vanadium in the Temple Mountain district, Emery County, Utah have long been of interest to geologists and, occasionally, to miners. The ore can now be treated successfully commercially and the importance of the district will probably increase with additional prospecting and the further increase and application of factual geologic data. From these data, interpretation may lead to additional discoveries of ore in the San Rafael Swell, and would probably aid in the better understanding of the genesis of other uranium deposits elsewhere in the Colorado Plateau.

Location

The Temple Mountain district (fig. 1) is within the boundaries of the San Rafael Swell in unsurveyed T. 24 and 25 S., R. 11 E., Salt Lake base and meridian. The South Temple workings are about 7 miles northwest of the Garvin ranch, now the A. J. Denny ranch, which is about 2 miles west of a point on Utah State Highway 24, 36 miles southwest of Green River, Utah. Shinarump Mesa is 6 miles northwest of the South

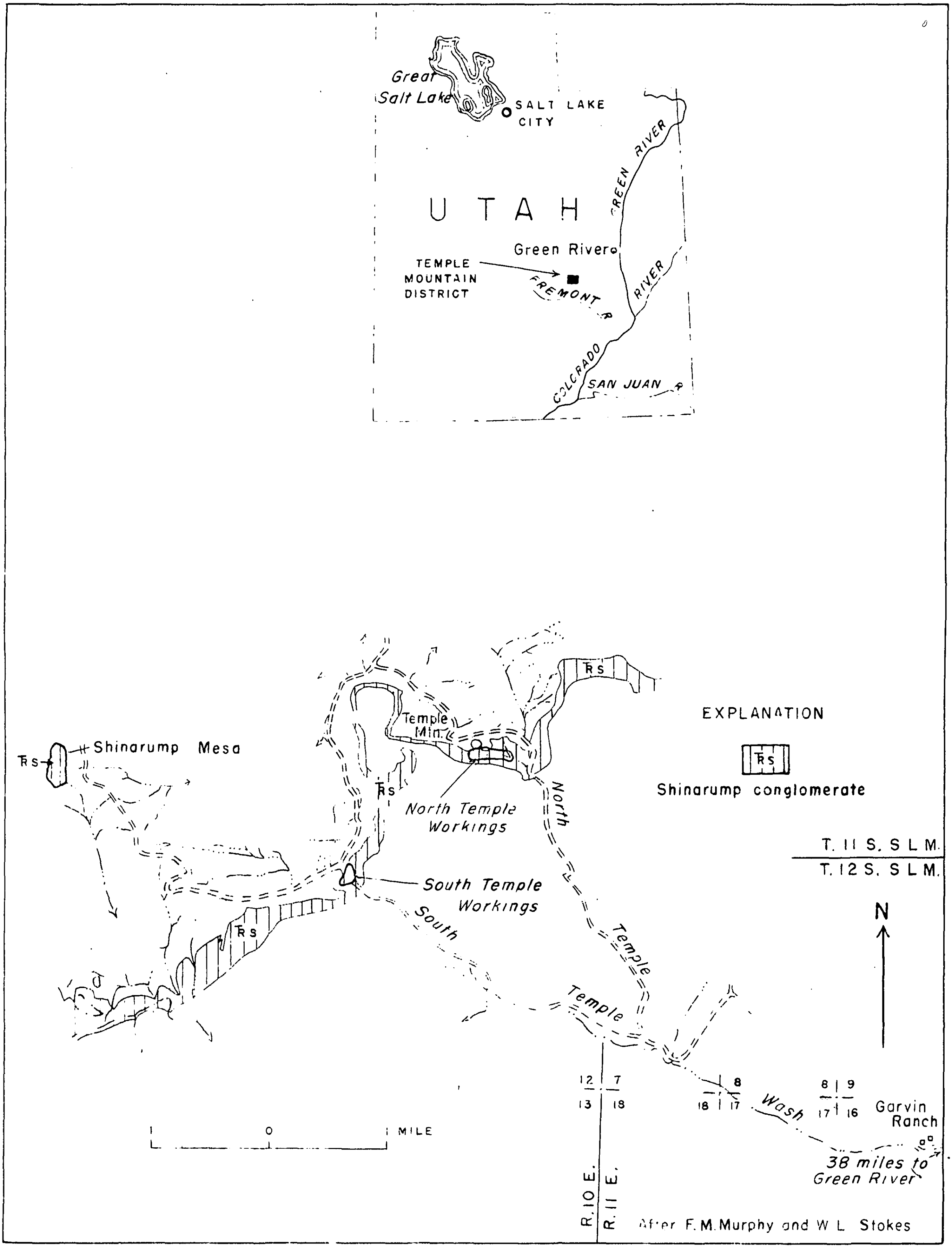

FIGURE 1—INDEX MAPS, TEMPLE MOUNTAIN DISTRICT, EMERY COUNTY, UTAH.

Temple workings. The relative locations of the other deposits described in this report are given in figures 1, 3-5.

Previous Work

Several geologists have studied this district and surrounding areas. The most detailed investigations of the San Rafael Swell have been made by Gilluly and Reeside (1928) and by Gilluly (1929). Reports describing areas in the San Rafael Swell outside of the Temple Mountain district have been written by Boutwell (1905), Hess (1911, 1912), and Baker (1947). The Temple Mountain district has been studied by Hess (1922, 1933), Murphy (1944), Chesterman and Main (1947), and Stokes (1947).

Occurrences of uranium and vanadium in the San Rafael Swell have been known since 1904 when Boutwell (1905) described the deposits that are about 15 miles southwest of Green River. Boutwell observed the association of the ore minerals with plant remains and concluded that the deposits may have been formed by precipitation of uranium and vanadium by the organic matter.

The first report concerning the uranium-vanadium deposits at Temple Mountain was written in 1922 by Hess (1922) who suggested that uranium and vanadium may have been leached from other rocks and subsequently precipitated by asphalt in an ephemeral sea or lake. Murphy (1944) studied the Temple Mountain district in 1943 and 1944, and Chesterman and Main (1947) reexamined the North and South Temple workings in 1945.

In 1946 Stokes (1947) measured 43 stratigraphic sections of the Shinarump conglomerate, at approximately 1,000-foot intervals, in an area that extends 4 miles northeast and 5 miles southwest of Temple Mountain. This work was for the purpose of determining the limits of mineralization and some of the factors that localized uranium and vanadium minerals in the Temple Mountain district.

Present Work

Subsequent to the stratigraphic work of Stokes, the writer investigated Shinarump Mesa and some adjacent areas to determine the average uranium content of the Shinarump conglomerate that caps Shinarump Mesa and to determine whether the deposits on Shinarump Mesa are large bodies of low-grade uranium ore, or small lenses of high-grade ore. Upon completion of the sampling program required to fulfill these objectives, selected, small uraniferous areas were mapped and studied in detail in an attempt to find guides to ore and the control of ore deposition. The conclusions drawn from this work, although tentatively applied to the entire Temple Mountain district, should be considered as preliminary.

Between January and April 1947 the writer, assisted by E. V. Stratton, measured metrically and radiometrically 11 sections spaced at approximately equal intervals around the periphery of Shinarump Mesa. All or parts of these sections were sampled by E. B. Dingle.

Between June and August 1947 the writer, assisted by G. V. Carroll, mapped Shinarump Mesa by means of plane table and telescopic alidade, made vertical sketch sections of its scarp, and examined the area radiometrically. A small area that includes some of the South Temple workings was also mapped and reconnaissance made of part of the North Temple workings to check some of the geologic conclusions reached at Shinarump Mesa.

Laboratory work consisted of preliminary petrographic and mineralogic study, and the chemical analysis of samples.

Acknowledgments

The writer is indebted to W. P. Huleatt, under whose immediate supervision the work was carried out, for many helpful suggestions. W. Lee Stokes greatly aided the writer through conferences in the field and discussions of some of the writer's geologic conclusions. Garland B. Gott assisted by discussing many of the problems related to origin of these deposits. R. P. Fischer assisted by outlining the problems involved in making reserve estimates in this type of ore and by summarizing for the writer much of the available information about carnotite deposits. Petrographic and mineralogic studies were made by Joseph Berman.

GENERAL GEOLOGY

One of the more conspicuous structural and topographic features of the Colorado Plateau province is the San Rafael Swell, an anticline that extends from the Water Pocket fold approximately 70 miles northeast to the Book Cliffs. The structure is 30 miles across at its widest point. The central part of the San Rafael Swell is, in general, an area of moderately low relief and badland topography that has been named Sinbad. Surrounding Sinbad is the "Reef"—a wall of resistant Jurassic sandstones—through which two perennial rivers and many intermittent streams have carved deep canyons and other erosional forms characteristic of the Colorado Plateau.

Although the rocks in the San Rafael Swell range from Permian to Recent in age (fig. 2), the formations that crop out in the Temple Mountain district are of Triassic and Jurassic age, and are, from oldest to youngest, Moenkopi, Shinarump, Chinle, Wingate, Kayenta, and Navajo. The Moenkopi formation of Triassic age, including the Sinbad limestone member, crops out over most of the Sinbad area but the Coconino and Kaibab formations of Permian age are exposed in the deeper gullies 1 to 5 miles west of Shinarump Mesa (Baker, 1946, 1947, pl. 1). The Moenkopi formation is typically a succession of maroon, ripple-marked shales and siltstones, and buff sandstones. The formation is topographically expressed by smooth slopes or intricately fretted badlands. The Shinarump conglomerate of Triassic age overlies the Moenkopi formation, forms a light-colored bench around the inner side of the "Reef", and constitutes the caprock of Shinarump Mesa and of other erosional remnants. The Chinle formation also of Triassic age overlies the Shinarump conglomerate and forms a prominent maroon to chocolate band between the Shinarump bench and the cliffs of younger rocks that compose the "Reef". The "Reef" is composed of the massive, white to pink resistant sandstones of the Wingate, Kayenta, and Navajo formations of the Glen Canyon group of Jurassic age.

The structure of the San Rafael anticline is aptly described by

System	Series	Group and formation	Thickness (feet)	Character	Remarks
Quaternary.		Alluvium and terrace gravel.		Sandy clay, sand, and gravel in alluvial fans; terrace gravels on benches along streams.	
		—Unconformity—			
Cretaceous.	Upper Cretaceous.	Mancos shale.	4,000±	Gray marine shale, sandy beds in lower part, rather persistent sandstone members about 200 feet above the base and 600 feet above the base.	
		Dakota (?) sandstone.	0–55	Conglomerate; coarse and fine sandstone, in places quartzitic; gray and greenish clay.	
		—Unconformity—			
Cretaceous (?).	Lower Cretaceous (?).	Morrison formation.	415–847	Clay and shale, variegated, dominantly green-gray, maroon, and mauve; gray sandstone and conglomerate, very lenticular, massive, and cross-bedded; such lenses especially numerous toward the base, where they form the Salt Wash sandstone member; subordinate thin lenticular limestones; a rather persistent conglomerate 250 to 350 feet below the top.	McElmo, except basal part, of Cross;[a] McElmo of Emery;[b] Upper McElmo of Lupton[c, d] and Dake.[e] At base is Salt Wash sandstone member of Lupton,[c] Emery,[b] and Dake.[e]
		—Unconformity—			
Jurassic.	Upper Jurassic.	San Rafael group: Summerville formation.	125–331	Thin-bedded chocolate-colored sandstone; earthy red-brown sandstone and shale; some gypsum, and a little limestone in some sections.	According to W. T. Lee,[f] probably basal McElmo at type locality; basal part of McElmo of Cross[a] and middle part of McElmo of Lupton;[c, d] part of lower McElmo of Dake[e] included in Navajo by Emery.[b]
		San Rafael group: Curtis formation.	76–252	Green-gray conglomerate and shale, and gray heavy-bedded sandstone.	Included in Navajo by Emery;[b] Salt Wash of Lupton.[d]
		Unconformity—			
		San Rafael group: Entrada sandstone.	265–844	Thin-bedded red shale and sandstone at the base; heavy, massive red-brown earthy sandstone above; weathers into rounded forms and steep cliffs.	Upper La Plata sandstone of Cross;[a] included in Navajo sandstone by Emery;[b] "varicolored sandstone and shales" of Longwell and others;[g] included in McElmo of Lupton,[c, d] in lower McElmo (Sundance?) of Dake.[e]
		San Rafael group: Carmel formation.	170–650	Dense limestone and buff and red sandstone at the base; toward the top dominantly red and green shale with thin sandstones and heavy beds of gypsum.	Base of McElmo of Lupton;[d] included in "marine Jurassic" of Dake[e] and Lee;[h] Todilto (?) formation of Emery;[b] "gypsiferous shales and sandstones" of Longwell and others;[g] middle La Plata of Cross[a] and Paige.[i]
		—Unconformity (?)—			
Jurassic (?).		Glen Canyon group: Navajo sandstone.	440–540	Tan to light-gray massive cross-bedded calcareous sandstone, with a few thin local limestones.	Gregory's usage;[j] lower La Plata of Cross;[a] included in Wingate sandstone by Emery.[b]
		Glen Canyon group: Todilto (?) formation.[1]	44–240	Red-brown sandstones, green and red shale, and shale conglomerate, irregularly interfingering and channeled.	Included in Wingate sandstone by Emery.[b]
		Glen Canyon group: Wingate sandstone.	360–400	Buff to tan, pink, and dark-gray massive cross-bedded limy sandstone, with a few thin lenses of limestone. In most places stained red by wash.	Gregory's usage;[j] lower part of Wingate sandstone of Emery;[b] Upper Dolores sandstone of Cross.[a]
		—Unconformity—			
Triassic.	Upper Triassic.	Chinle formation.	141–225	Green and red micaceous sandstone and thin red-brown shales; limestone conglomerate; variegated marl; all lenticular, channeled, and interfingering.	Lower Dolores of Cross.[a]
	Upper (?) Triassic.	Shinarump conglomerate.	70–178	Cross-bedded lenticular conglomerate, sandstone, clay, and shale; interfingering. Much silicified wood. Quartz and chert pebbles predominate in the conglomeratic portions.	
		—Unconformity—			
	Lower Triassic.	Moenkopi formation.	735–850	Green-gray pyritic shale; gypsiferous green and red shale; red micaceous ripple-marked sandstone; gray to buff sandstone; red sandstone. Very limy throughout. A massive, persistent light-gray marine limestone and sandstone member 140 to 200 feet above the base and 40 to 150 feet thick—the Sinbad limestone member.	
		—Unconformity—			
Carboniferous.	Permian.	Kaibab limestone.	0–85	Light-gray to cream-colored cherty limestone; some oölite; somewhat sandy in places.	Present only in patches in San Rafael Swell; only uppermost part of typical Kaibab.
		Coconino sandstone.	715	White to buff sugary, friable to hard massive cross-bedded quartz sandstone of uneven grain. Some grit toward the base, and the lowest 40 feet largely limestone. Base not exposed.	May include chronologic equivalents of part of typical Kaibab limestone, typical Coconino sandstone, Hermit shale, and part of Supai formation.

[a] Cross, Whitman, Stratigraphic results of a reconnaissance in western Colorado and eastern Utah: Jour. Geology, vol. 15, p. 641, 1907.
[b] Emery, W. B., The Green River Desert section, Utah: Am. Jour. Sci., 4th ser., vol. 46, pp. 551-577, 1918.
[c] Lupton, C. T., Oil and gas near Green River, Grand County, Utah: U. S. Geol. Survey Bull. 541, pp. 115-133, 1914.
[d] Lupton, C. T., Geology and coal resources of Castle Valley in Carbon, Emery, and Sevier Counties, Utah: U. S. Geol. Survey Bull. 628, pp. 19-26, 1916.
[e] Dake, C. L., The horizon of the marine Jurassic of Utah: Jour. Geology, vol. 27, pp. 634-646, 1919.
[f] Lee, W. T., personal communication.
[g] Longwell, C. R., and others, Rock formations of the Colorado Plateau in southern Utah and northern Arizona: U. S. Geol. Survey Prof. Paper 132, pp. 1-23, 1923.
[h] Lee, W. T., Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Misc. Coll., vol. 69, No. 4, 1918.
[i] Paige, Sidney, The La Plata group in the plateau country (unpublished), read before the Am. Assoc. Adv. Sci., December, 1924, Washington, D. C.
[j] Gregory, H. E., The geology of the Navajo country: U. S. Geol. Survey Prof. Paper 93, 1917.

(1) *Now Kayenta formation.*

After J. Gilluly and J. B. Reeside, Jr.

Figure 2. - General section of rock formations in the San Rafael Swell, Utah

the nautical term "swell". In cross section from southeast to northwest the flat-lying rocks of the Green River desert are bent upward abruptly to form the steep southeast flank of the structure; farther to the northwest they arch over the axis and dip gently to the northwest. This major structure is modified locally by minor structural terraces, such as those of Temple Mountain and Shinarump Mesa, and by subsidiary folds such as the Woodside Dome near the northeast end of the San Rafael Swell. Other minor structural elements are faults and fractures.

Numerous faults have been mapped by Baker (1946, 1947) in the San Rafael Swell. Most of them are steeply dipping, northwestward trending, normal faults that have apparent displacements ranging from 20 to 300 feet. Other faults with smaller displacement trend dominantly eastward or northeastward in the Temple Mountain district. These faults, together with those trending northwestward, form a conjugate system although their relative ages are unknown. A conjugate joint system, with also northwest and northeast strikes, shows clearly on aerial photographs of the Temple Mountain district and may be related to the conjugate set of faults. Both faults and fractures are probably younger than the major folding.

There are several small masses of altered rock in the district, the largest, at Temple Mountain, where an approximately circular or elliptical area of the Shinarump, Chinle, and Wingate formations has been sheared, in part reconstituted, and bleached. Around the periphery of this altered zone the apparently unaltered Moenkopi formation has been warped downward to form a saucer-shaped depression about 1,000 yards in diameter. The altered rock, according to Murphy (1944), is white, red, mottled brown, buff, green, or gray, commonly light to dark gray on fresh surfaces; local areas are highly siliceous; much of the compact and granular rock is composed of fine- to medium-grained quartz in clear angular to rounded grains with scattered flakes of a sericite-like mineral and more or less bitumen. Calcareous beds of shale, marl, and mudstone traced by him into the alteration zone are there noncalcareous. Murphy characterized the altered rock as highly faulted and fractured and resistant to erosion. A mass of gossan or iron oxide at the upper edge of the Chinle formation shows, according to Hess (1922, p. 274), the nodular structure characteristic of pyrite concretions and contains vertical cracks filled with globular masses of hydrocarbon; according to Murphy (1944), the intensely fractured gossan contains hematite, goethite, siderite, magnetite, and jarosite. Webber (in Murphy, 1944) found crystal-lined vugs filled with asphaltite in the altered rock, and notes that the North Temple alteration zone is marked and partly bounded by a subsided block "strongly suggestive of the mineralization stoping pipe type of deposit of Locke" (1926).

Another such area is about 1,000 feet west of Shinarump Mesa where the rock of the Moenkopi and Shinarump formations has been altered and eroded, leaving a hill of resistant, altered rock surrounded by a saucer-shaped depression about 400 feet in diameter of inward dipping, unaltered red Moenkopi shales, silts and silty sandstones. The altered rock is, for the most part, composed of dark gray, white-weathering, fine-grained, calcareous, silty sandstone that is slightly bituminous, and of brown, sand chert-pebble conglomerate let down about 100 feet from the overlying Shinarump conglomerate. The most intensely altered rock is a relative jumble of highly-fractured, steeply dipping, iron-stained sandstone, in part siliceous. A body of bleb-like, uraniferous asphaltite about 1.5 feet thick and 4 feet long in Moenkopi sandstone at the western edge of the alteration zone is alined parallel to, and limited on the southwest by, the fault bounding the area of altered rock; this fault dips steeply southwestward and its trace to the southeast disappears beneath talus but trends toward the fault zone at the edge of Shinarump Mesa (fig. 3, south of Sh-8); northwestward, the fault dies out.

A third area of bleached, brecciated, and partly silicified rock was observed in the Moenkopi formation near the old road (1947) between the South Temple workings and Shinarump Mesa, and there may be other similar zones in the district. The distribution of uranium and vanadium minerals is, in part, related to alteration zones.

Although no igneous rocks are exposed in the Temple Mountain district, the bleaching, shearing, silicification, addition of significant quantities of metals, and partial reconstitution of rocks and minerals, have been attributed by Webber (in Murphy, 1944) to alteration by relatively deep-seated hydrothermal solutions. It should be noted that the Sinbad limestone member of the Moenkopi formation is only a few hundred feet stratigraphically beneath the Shinarump conglomerate and its removal by these solutions may have formed a slump block. Radiometric traverses across the altered rock west of Shinarump Mesa show that some of the rock is radioactive. The results of Murphy's work in the district indicate that some of the altered rock at Temple Mountain and near the road between the South Temple workings and Shinarump Mesa is also radioactive.

The uranium-vanadium deposits at Shinarump Mesa and at the North and South Temple workings are in the Shinarump conglomerate of Triassic age and consequently the writer's investigations were largely confined to a detailed study of this formation in the district. The Shinarump conglomerate extends over nearly 100,000 square miles in the Colorado Plateau province, an unusually large area for a formation that averages less than 75 feet in thickness. It consists predominantly of conglomerate and sandstone lenses with subordinate lenses of mudstone and siltstone. Silicified and carbonized wood fragments are locally abundant (Baker, A. A., 1946 (1947), p. 60).

The continental origin of the Shinarump conglomerate is well established, but inasmuch as few fossils have been found in the formation, its age is variously designated as lower, upper, or undifferentiated Triassic. The Shinarump conglomerate lies unconformably on the Moenkopi formation, and grades upward into the Chinle formation. The significance of the unconformity between the Shinarump conglomerate and the underlying Moenkopi formation is controversial, but the unconformity is most commonly believed to represent a long period of erosion after which the Shinarump was deposited as the basal conglomerate of the overlying Chinle formation.

Stokes (1950), however, points out that the characteristic lensing and interfingering sandstones and conglomerates of the Shinarump show current-bedding of the type generally associated with fast-running water. He believes that the conglomerate represents the gravel that served as the cutting agent during the formation of a pediment by lateral corrasion of streams. The conglomerate and the surface of planation are, therefore, contemporaneous.

The Shinarump conglomerate, resistant to weathering relative to the underlying and overlying formations, forms cliffs and benches and is the protective caprock of mesas.

The Shinarump conglomerate in the Temple Mountain district, ranges in thickness from 10 to 129 feet; the average thickness in the 43 sections measured by Stokes is 61 feet. At Shinarump Mesa 11 measured sections gave an average thickness of 54 feet for the Shinarump although an undetermined thickness of the formation has been eroded from the top of the mesa. However, the uppermost beds present are probably very close to the base of the Chinle formation. The contact at the top of the Shinarump conglomerate is gradational, whereas the base of the formation is marked by an unconformity. At Shinarump Mesa this surface of unconformity has an average relief of three or four feet, although local channels as much as 17 feet deep have been cut into the shales of the underlying Moenkopi formation.

The Shinarump conglomerate at Shinarump Mesa is divisible into four principal rock units. In order of decreasing age, they are (1) the chert-pebble conglomerate unit, (2) the sandstone-mudstone unit,

(3) the lime-pellet conglomerate unit, and (4) the upper white sandstone unit, each of which is composed of several subunits or facies. The distribution of these units and subunits is shown on figures 3 and 4 which also show the extreme lenticularity of the rocks and the prevailing northwest direction of current flow.

The division of the Shinarump conglomerate into four principal rock units is based on dominant or characteristic lithologic component, but, as shown on figure 4, this division is also, in general, stratigraphic. Each main unit is composed predominantly or characteristically of that component subunit or facies for which it is named, but each main unit also contains lenses and intergradations of other subunits or facies that were differentiated to show the geology more clearly. The boundaries between all units are, therefore, arbitrary and cannot be considered strict lithologic or time boundaries. The fact that mudstone, for example, is a minor constituent in the lime-pellet conglomerate unit between SH-3 and SH-5 (fig. 3), and in the chert-pebble conglomerate unit below the Northeast adit (fig. 4), but is a characteristic component of the sandstone-mudstone unit, is interpreted to mean that slack-water conditions allowed the deposition of mudstone at times during the deposition of both the lime-pellet conglomerate unit and the chert-pebble conglomerate unit, but that slack-water conditions were more widespread during the deposition of the sandstone-mudstone unit. Similarly, the inclusion of lenses of chert-pebble conglomerate in the sandstone-mudstone unit (fig. 4, section D-E, below West adit) means that a source of chert pebbles was available for the streams during the deposition of the sandstone-mudstone unit, but the bulk of the chert-pebble conglomerate is confined to the main chert-pebble conglomerate unit at the base of the Shinarump, and was apparently laid down during a definite period of time early in the deposition of the formation.

That these principal rock units are only approximate time units, on the other hand, is shown by the lateral intergradation of the sandstone-mudstone unit with the chert-pebble conglomerate unit between SH-11 and P, section O-P (fig. 4), and also northeast of the North adits (fig. 4, section A-B), as well as by lateral intergradations of the sandstone-mudstone unit with the lime-pellet conglomerate unit in section M-N (fig. 4).

This four-fold division of the Shinarump seems justifiable at Shinarump Mesa and near Temple Mountain, but its validity in surrounding areas remains to be proved.

Chert-pebble conglomerate unit

The chert-pebble conglomerate unit, commonly the basal lithologic and stratigraphic unit of the Shinarump conglomerate, except locally where absent because of channeling, rests directly on the Moenkopi formation. The unit ranges in thickness from a few tenths of a foot to about 40 feet. It is composed predominantly of about equal amounts of interlensed and inter-graded chert-pebble conglomerate and hard, blocky sandstone. Much less abundant are small lenses of mudstone, massive sandstone, some of which is bituminous, friable sandstone, or intergradational lime-pellet conglomerate.

The brown chert-pebble conglomerate subunit or facies is composed of approximately equal amounts of medium-grained sand grains of quartz and chert, and of siliceous pebbles. The subrounded to well-rounded siliceous pebbles are predominantly chert, but are subordinately quartzite, quartz, jasper, petrified wood, and bone; they average about one inch in diameter. The subunit generally occurs at the base of the unit, and is commonly loosely cemented with silica and stained by iron oxides. Topographically, the rock is a cliff-former.

The hard, blocky sandstone is medium-grained, hard, blocky, buff to brown. The grains, most of which are quartz, are tightly cemented with iron oxide, calcite, or silica and the rock therefore is resistant and weathers into blocks. The rock is cross-bedded with individual beds ranging in thickness from a few inches to one foot. Hard, blocky sandstone occurs throughout the Shinarump in lenses ranging up to 380 feet long and 14 feet thick, but is most abundant in the main chert-pebble conglomerate unit and the lime-pellet conglomerate unit.

Silicified and/or carbonized logs are relatively abundant in the chert-pebble conglomerate unit but only some of those that have been carbonized contain uranium and vanadium minerals. At several places "log jams", or concentrations of logs, were found (fig. 4, section I-J, near the Southeast adit; and section K-L, near K). The abundance of logs at irregularities of the Moenkopi-Shinarump contact indicate that the "log jams" formed at the edges of local Triassic stream channels.

Sandstone-mudstone unit

The sandstone-mudstone unit is commonly in the lower third of the Shinarump conglomerate overlying the chert-pebble conglomerate unit, but in places local channels have cut through the underlying unit (fig. 4, section C-D) permitting the sandstone-mudstone unit to rest directly on the Moenkopi formation. The unit ranges in thickness from a few inches to 37 feet. The predominant component by bulk is massive light-colored sandstone, commonly bituminous, but an abundant and characteristic component is mudstone. Less abundant components are siltstone, mudstone-gravel, friable sandstone, platy sandstone, chert-pebble conglomerate, hard, blocky sandstone, and intergradations of these components.

The massive, light-colored sandstone is typically buff to white and composed mainly of medium- to coarse-grained quartz grains with subordinate muscovite loosely cemented with calcite and some clay-like material. It ranges in thickness from a knife edge to 30 feet and in general forms long, more- or less-continuous lenses. The sandstone is cross-bedded with the individual beds ranging in thickness from 6 inches to 2 feet. It is commonly impregnated with white-weathering brown to black bitumen. The bituminous sandstone weathers to rounded exfoliated forms, whereas the non-bituminous sandstone is expressed topographically by cliffs that in many places overhang.

Mudstone, commonly closely associated with mudstone-gravel mixture and siltstone is a characteristic component of the sandstone-mudstone unit, although it does occur, locally, in both the underlying chert-pebble conglomerate unit, and the overlying lime-pellet conglomerate unit (fig. 3, between SH-3 and SH-5). The mudstone is typically gray-green, fractured, soft, non-calcareous, and occurs in lenses as much as 17 feet thick and 160 feet long (fig. 4, section C-D, SH-8), although most lenses are only from a fraction of a foot to 4 feet thick and from 60 to 100 feet long. Greenish or brown, thinly laminated siltstone occurs typically in deltaic bodies adjacent to mudstone and both mudstone and siltstone were probably deposited in shallow, quiet water. The inclusion of pebbles and galls of mudstone and siltstone in other clastic rocks indicates that these deposits were later torn up. In places the pebbles and galls were redeposited with chert pebbles to form a mudstone gravel mixture. These fine-grained rocks weather commonly to indented shelves.

Friable sandstone, although not abundant, is an important component of the sandstone-mudstone rock unit inasmuch as it is commonly the host rock of ore deposits. It forms lenses as much as 100 feet long and 15 feet thick (fig. 4, North adit), although most lenses are smaller and some are so small that they cannot be shown on the section (fig. 4). Most of this sandstone is confined to the sandstone-mudstone unit, although some lenses of ore-bearing friable sandstone were found in the underlying chert-pebble conglomerate unit as well as in the overlying lime-pellet conglomerate unit.

The friable sandstone subunit or facies resembles the massive, light-colored sandstone in color and general composition, but differs in its general lack of cement, more closely spaced current beds, and the common abundance of uraniferous hydrocarbon grains and irregularly-shaped, interstitial fillings. Because of its friability the rock weathers to indented shelves or caves. The current beds commonly range in thickness from only one-sixteenth of an inch to one inch.

Lime-pellet conglomerate unit

The lime-pellet conglomerate lithologic unit is in the upper part of the Shinarump conglomerate and constitutes the surface rock over most of Shinarump Mesa (fig. 3). The unit is composed predominantly of lime-pellet conglomerate and closely associated sandy lime-pellet conglomerate, but also contains abundant inter-lensed massive sandstone and platy sandstone. Minor components are hard, blocky sandstone, mudstone, and friable sandstone. In thickness, the unit ranges from 6 to 53 feet. It inter-lenses with the underlying sandstone-mudstone unit in sections M-N and K-L (fig. 4).

The light gray to buff lime-pellet conglomerate subunit or facies is so named from the small- to medium-sized calcareous siltstone pellets that are an abundant constituent. Lime-pellet conglomerate forms lenses as much as 400 feet long and 20 feet thick in the lime-pellet conglomerate unit; lenses of smaller dimensions are more abundant in this main unit and are less abundant components of both underlying rock units. The rock is characterized by crudely sorted or unsorted materials of many different sizes and compositions all well cemented with calcite. Calcareous siltstone pellets, sandstone and mudstone fragments predominate.

Some of the marly pellets show concentric structure and resemble similar pellets in the conglomerates of the Chinle formation. Next in order of abundance are chert pebbles apparently identical to those in the chert-pebble conglomerate facies. Clear, unfrosted quartz grains, some of which are the smoky or morion variety of quartz, are conspicuous. Other minor constituents are silicified or carbonized logs, fossil plant fragments, and fragmented fossil bones. By admixtures of quartz sand, the lime-pellet conglomerate facies or subunit grades laterally into sandy lime-pellet conglomerate. With the loss of larger pebbles and fragments the gradation is, in places, complete from sandy lime-pellet conglomerate to massive, platy, or hard, blocky sandstone. The unit is expressed topographically by vertical cliffs divided into rough imbricated plates by differential erosion of the long foreset beds.

Stokes (1947, p. 12) thought that the large, gently inclined, and imbricated current beds, as well as the crude sorting, indicate deltaic deposits that were formed at those places where the streams flowed into relatively quiet water and dumped their load of coarse clastic material. The fact that mudstone and siltstone, which were deposited in relatively quiet water, generally underlie the lime-pellet conglomerate facies may support this theory.

Lenses of platy sandstone are distributed throughout the Shinarump conglomerate but are perhaps most abundant in the lime-pellet conglomerate unit. The rock is light-colored, buff to white. The numerous, closely spaced current beds are accentuated by weathering and this characteristic together with a commonly finer grained texture, differentiate platy from massive sandstone subunits or facies.

Because the lime-pellet conglomerate lithologic unit constitutes the surface rock of most of Shinarump Mesa, the northwest pitch of the current beds in the unit was observed in many places (fig. 3). Where clearly exposed, the festoon-type current beds are in the form of plunging synclines or "canoes", the open ends of which presumably faced downstream. Thus, the direction of the axis of the "canoe" indicates the direction in which the water was flowing when the unit was deposited. The largest "canoe", southeast of triangulation station 10 (fig. 3), is about 100 feet across and 200 feet long; it probably indicates the site of an old channel, persistent throughout much of the time of deposition of the lime-pellet conglomerate unit.

Upper white sandstone unit

The upper white sandstone unit is so termed to distinguish the sandstone that lies immediately below the basal Chinle formation and above the lime-pellet conglomerate unit from other light-colored sandstones stratigraphically lower in the Shinarump. The unit forms the topographic high points on Shinarump Mesa and is characterized by its thin, irregular, closely-spaced current beds which weather to uneven slopes or rough cliffs. The rock is typically fine-grained, white, and poorly cemented. The cementing material is calcite, iron oxide, or a claylike material. Near the top of section SH-8 (fig. 3) the rock contains thin, irregular patches of bitumen that are uncommon elsewhere in the unit. Between SH-6 and SH-8 (fig. 3) the rock is loosely cemented with calcite and was mapped as a subunit or facies.

Generally speaking, the foregoing description of the lithology and stratigraphy of the Shinarump conglomerate is applicable to the formation where examined elsewhere in the Temple Mountain district. The general association of ore bodies with friable cross-bedded sandstone lenses that are commonly confined to the sandstone-mudstone lithologic unit, it is felt, warrants the semi-detailed description.

RADIOACTIVITY AND SAMPLING

During this investigation, a field counter of the UMDC type equipped with an impulse register was used to detect gamma radiation. The instrument was equipped with two interchangeable gamma probes; one with a normal background counting rate of 13 counts per minute and the other with a normal counting rate of 55 counts per minute. The probe with the low counting rate was used to determine the radioactivity of the units traversed in the sections measured (figs. 6 to 16) as well as of the crushed channel samples. It was also used in five radiometric traverses across the top of Shinarump Mesa. The gamma probe with the higher counting rate was used during the mapping program to check the top of the Mesa for concealed ore bodies, to delimit visible ore zones, and to make a radiometric reconnaissance of the scarp of the mesa.

Radiometric examination of individual rock units was made by placing the probe in contact with the rock for an interval of five minutes and recording the counts per minute. Where the rock unit was thicker than 3 feet observations were taken at about 3-foot intervals.

Radiometric analyses of crushed channel samples were made in the field.

Figure 4 shows the radiometric measurements of the rocks that crop out around the scarp of the Mesa. All rocks stained by carnotite or that contain black hydrocarbon grains were abnormally radioactive.

The radioactivity of the rocks and the location of channel samples in 11 measured sections is illustrated in figures 6 to 16 inclusive. These 11 sections are located at approximately equal intervals around the cliff face of Shinarump Mesa and were measured metrically and radiometrically from the base of the Shinarump. At five of the 11 localities, samples were cut across all exposed parts of the Shinarump. At three of the localities samples were cut across all units below the upper white sandstone, and at the three remaining localities samples were cut only of the radioactive units. The samples consisted of the fragments removed from 2- by 5-inch channels cut in cleaned faces of the rock and the length was determined by stratigraphy. Individual samples weighed about 12 pounds per linear foot. All samples were crushed to minus 1/4 inch in a portable crusher and reduced in an automatic splitter coupled to the crusher to two duplicates weighing 3 to 5 pounds each.

The radiometric and chemical analyses of the samples from these sections tabulated in table 1 show that most of the rocks are essentially barren of radioactivity or uranium.

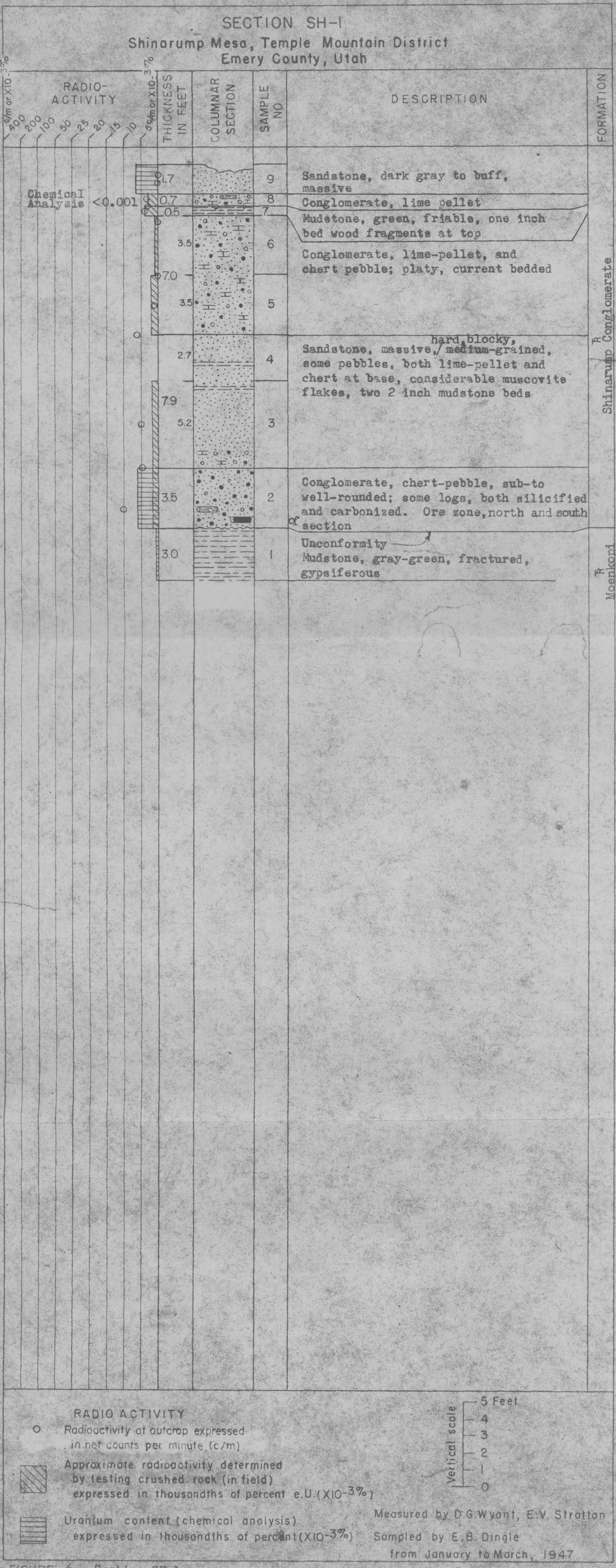

FIGURE 6.—Section SH-1.

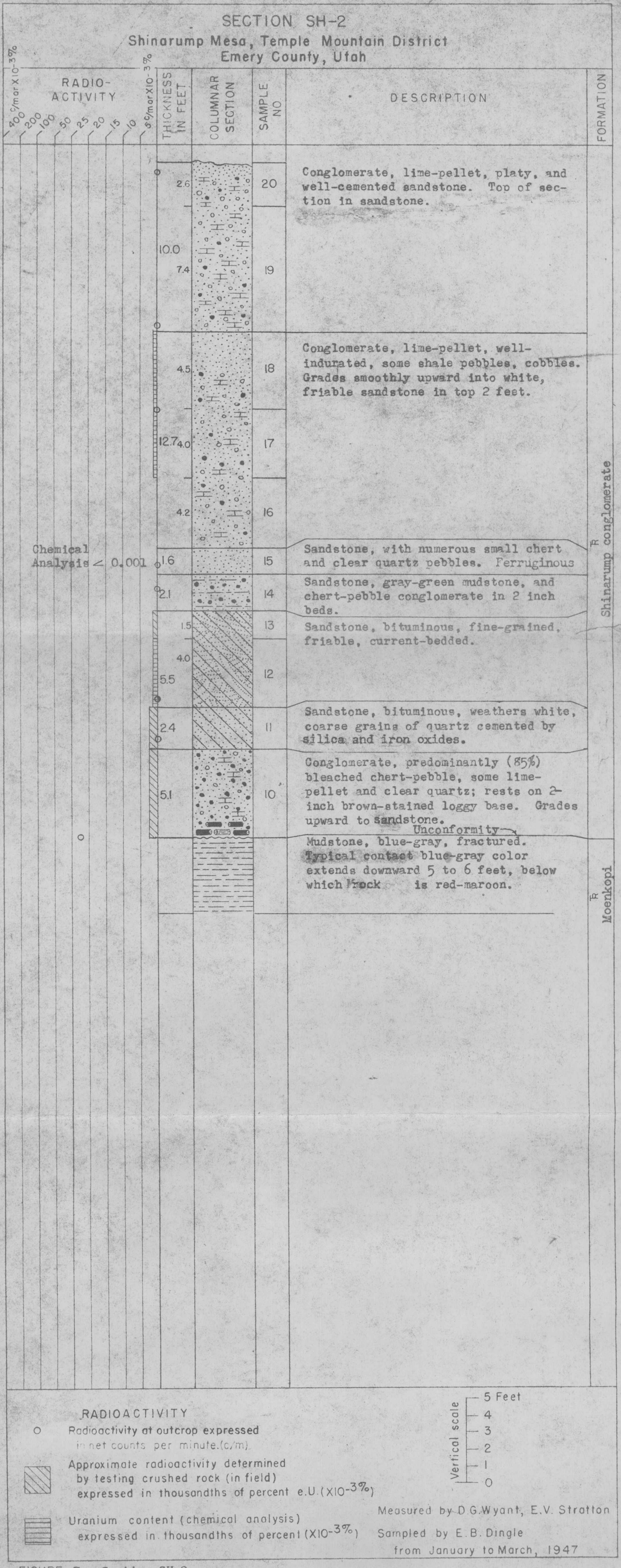

FIGURE 7.—Section SH-2.

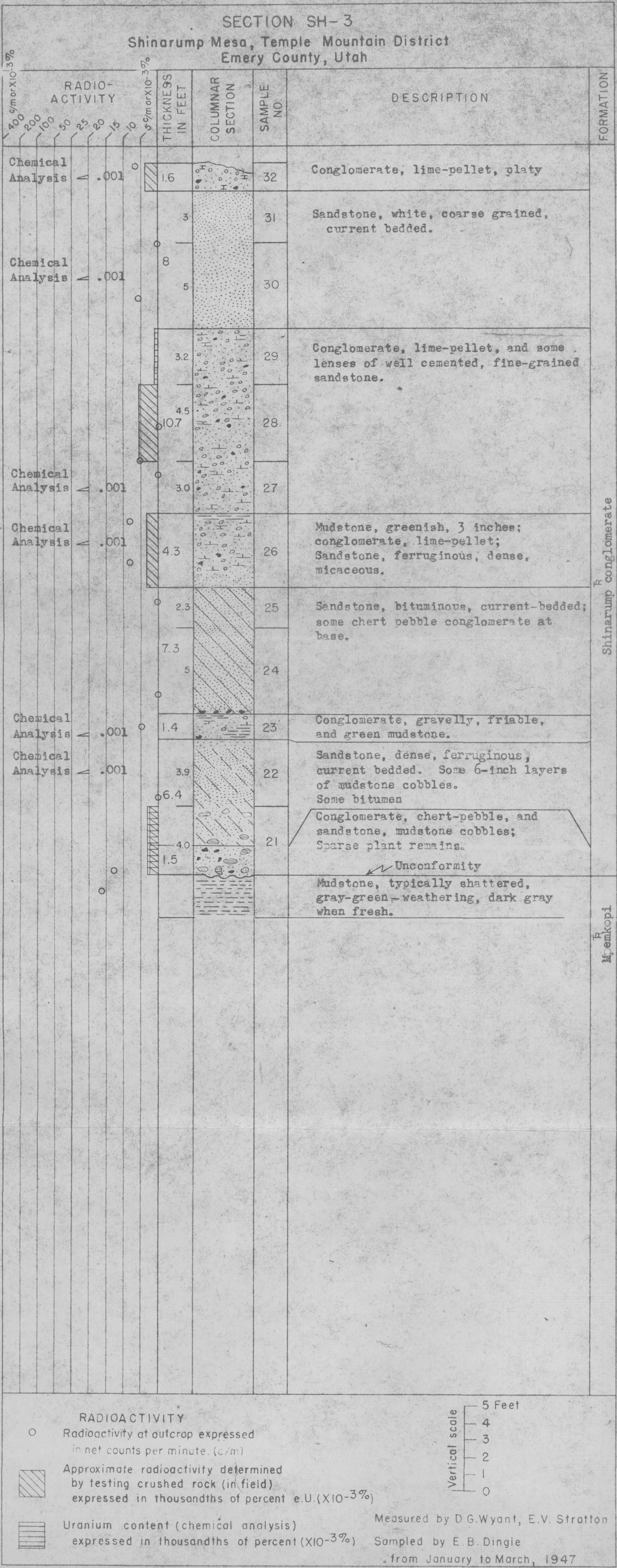

FIGURE 8.—Section SH-3.

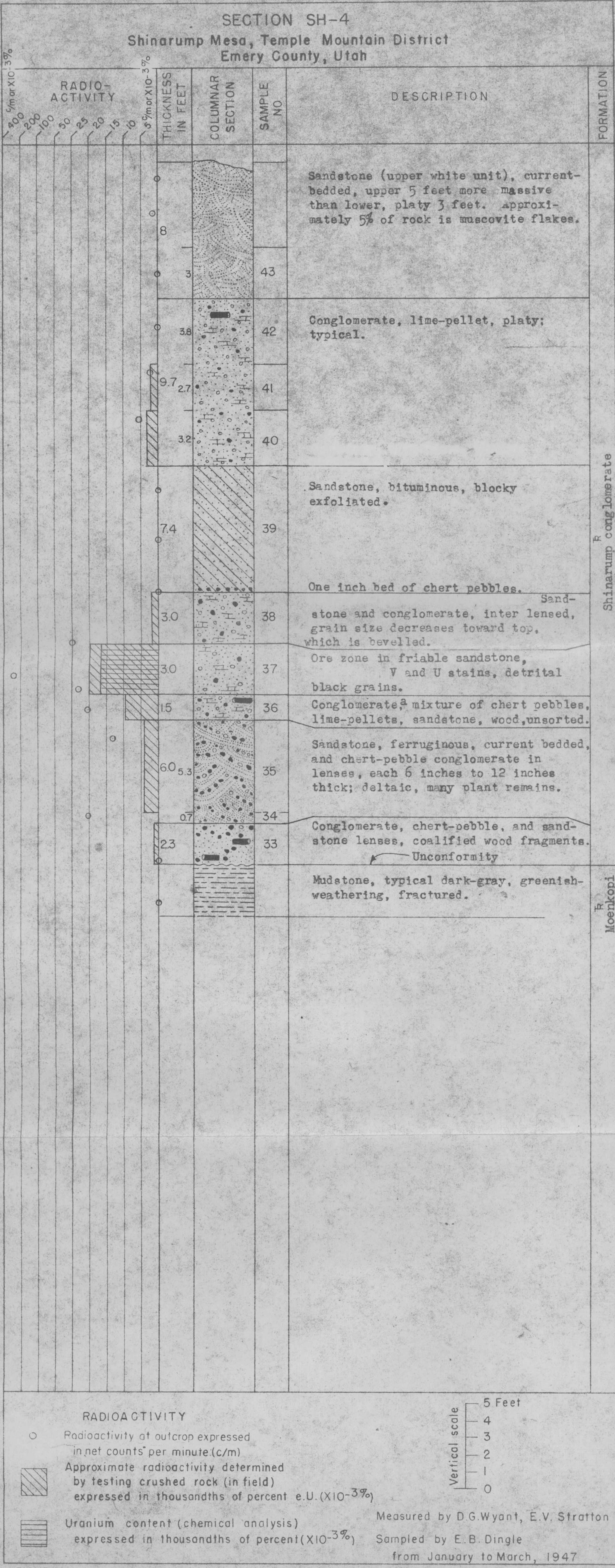

FIGURE 9.—Section SH-4.

31

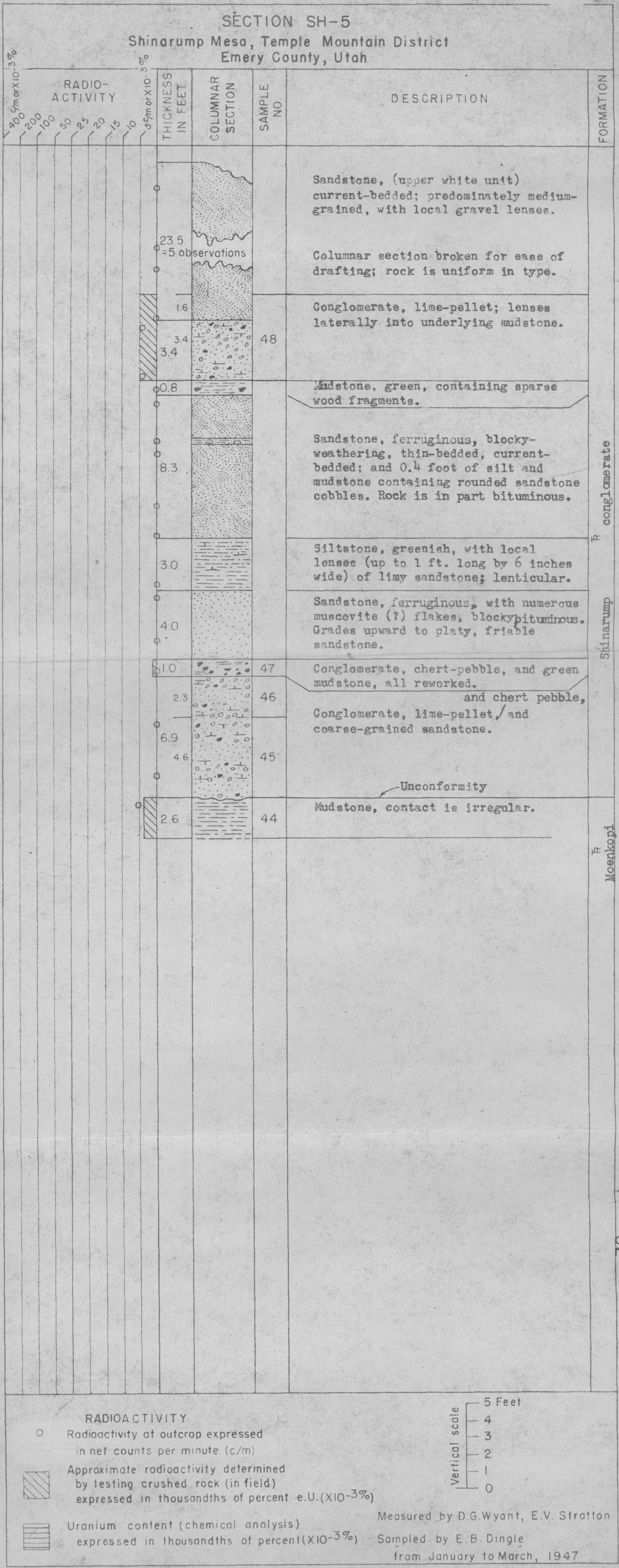

FIGURE 10.--Section SH-5.

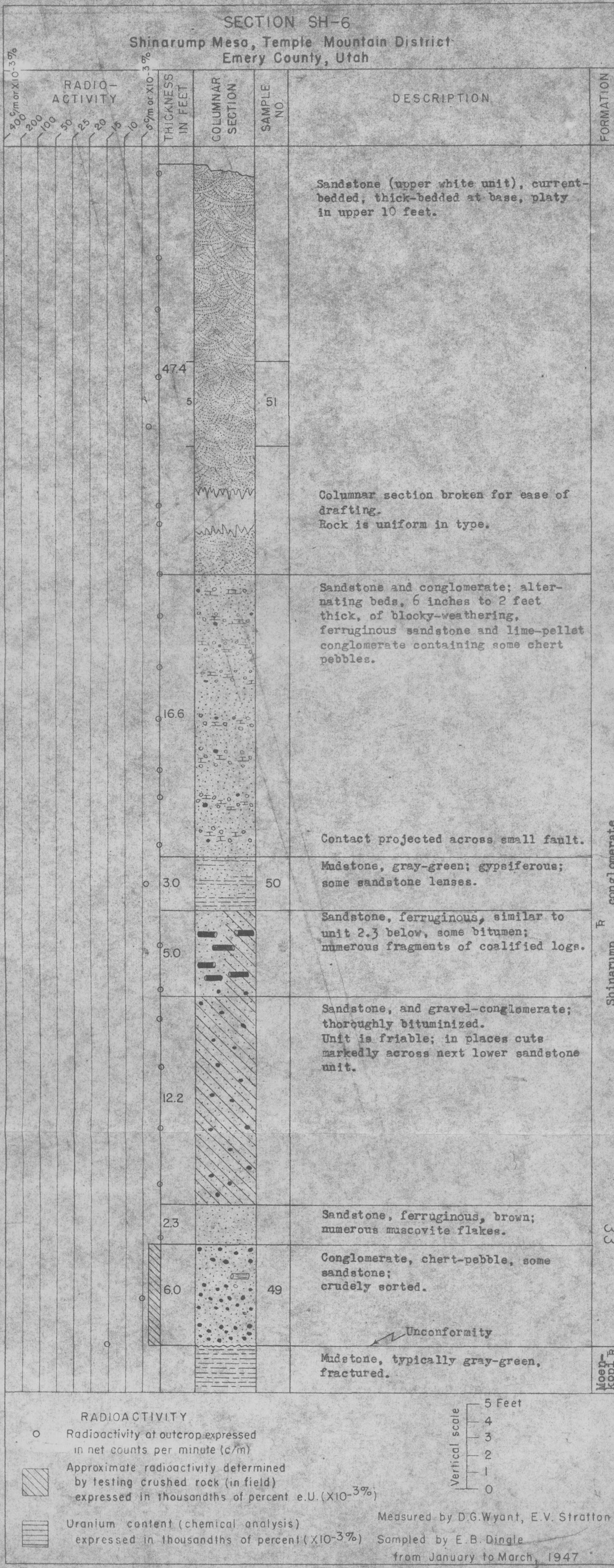

FIGURE 11.--Section SH-6.

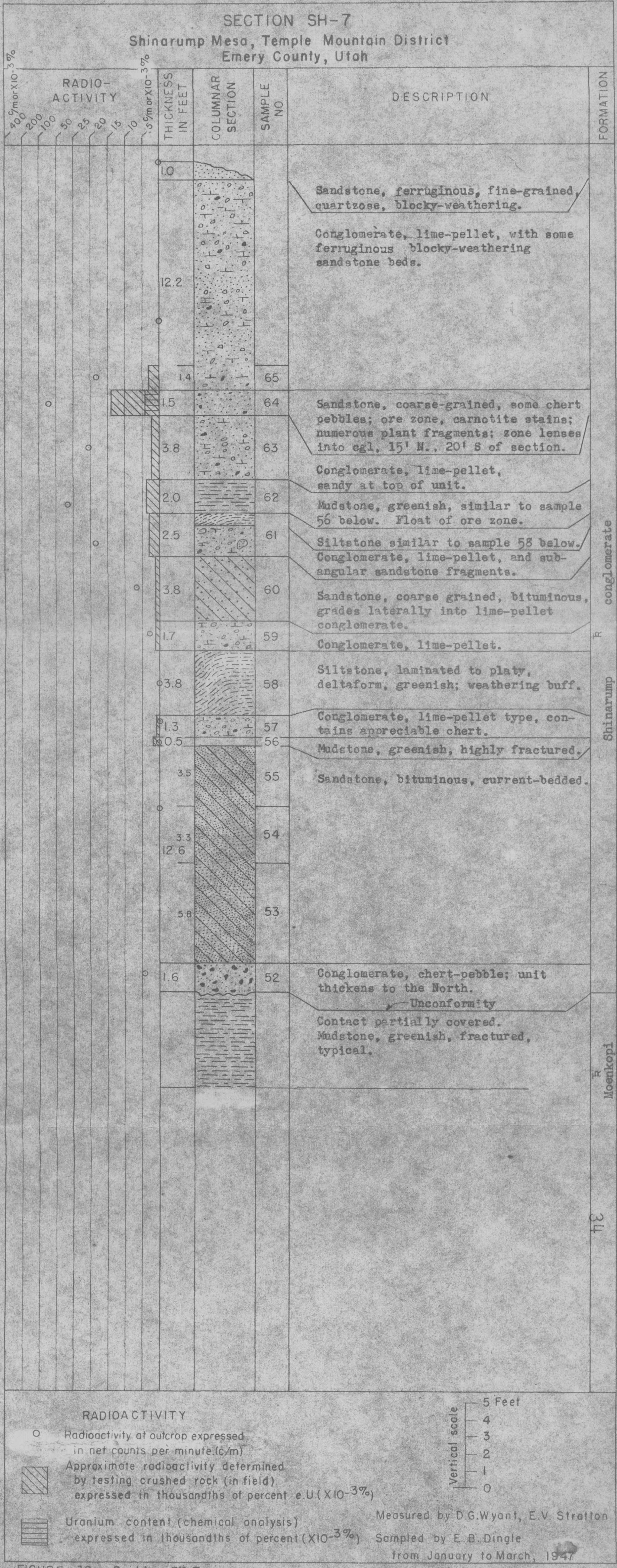

FIGURE 12.—Section SH-7.

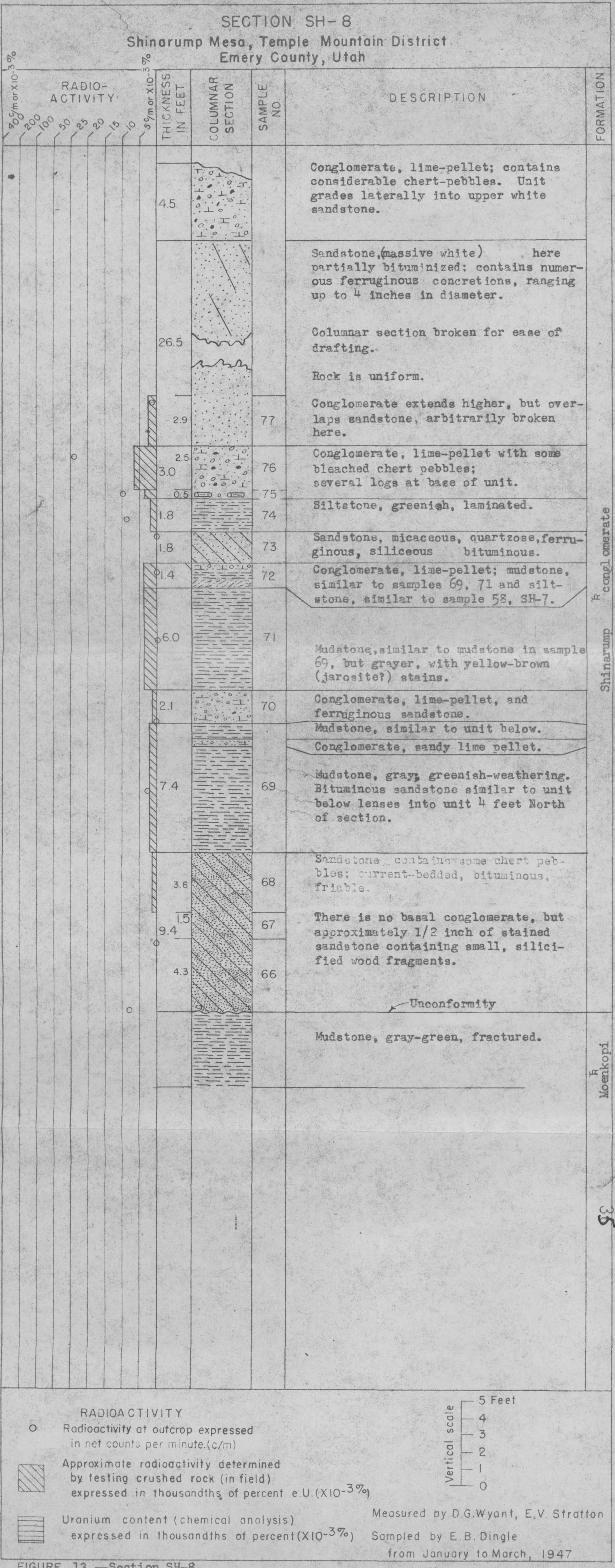

FIGURE 13.—Section SH-8.

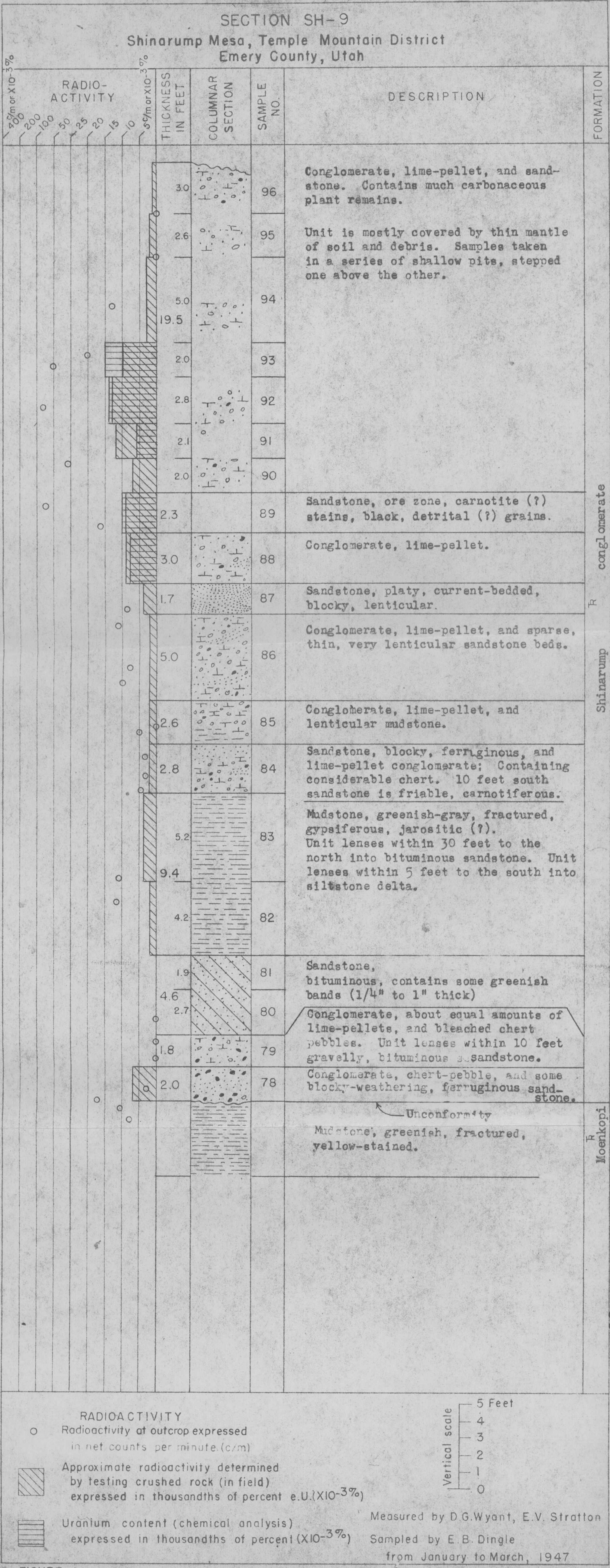

FIGURE 14.--Section SH-9.

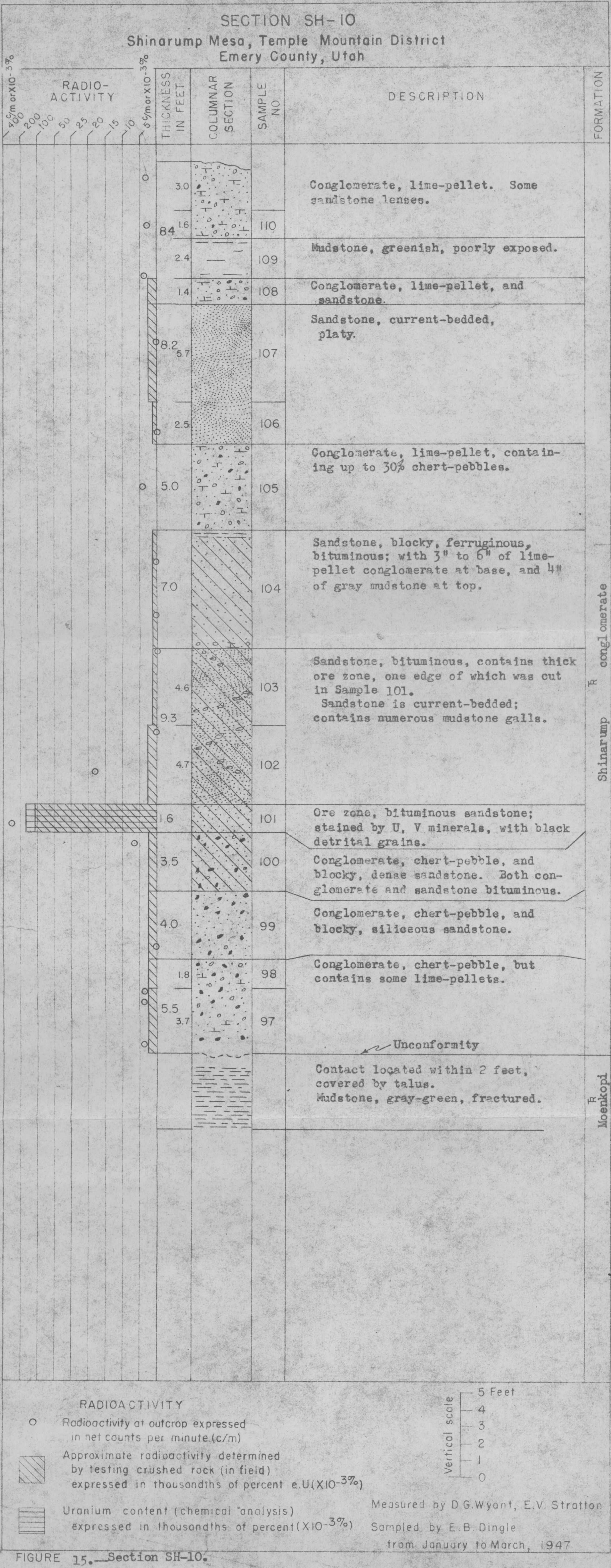

FIGURE 15.—Section SH-10.

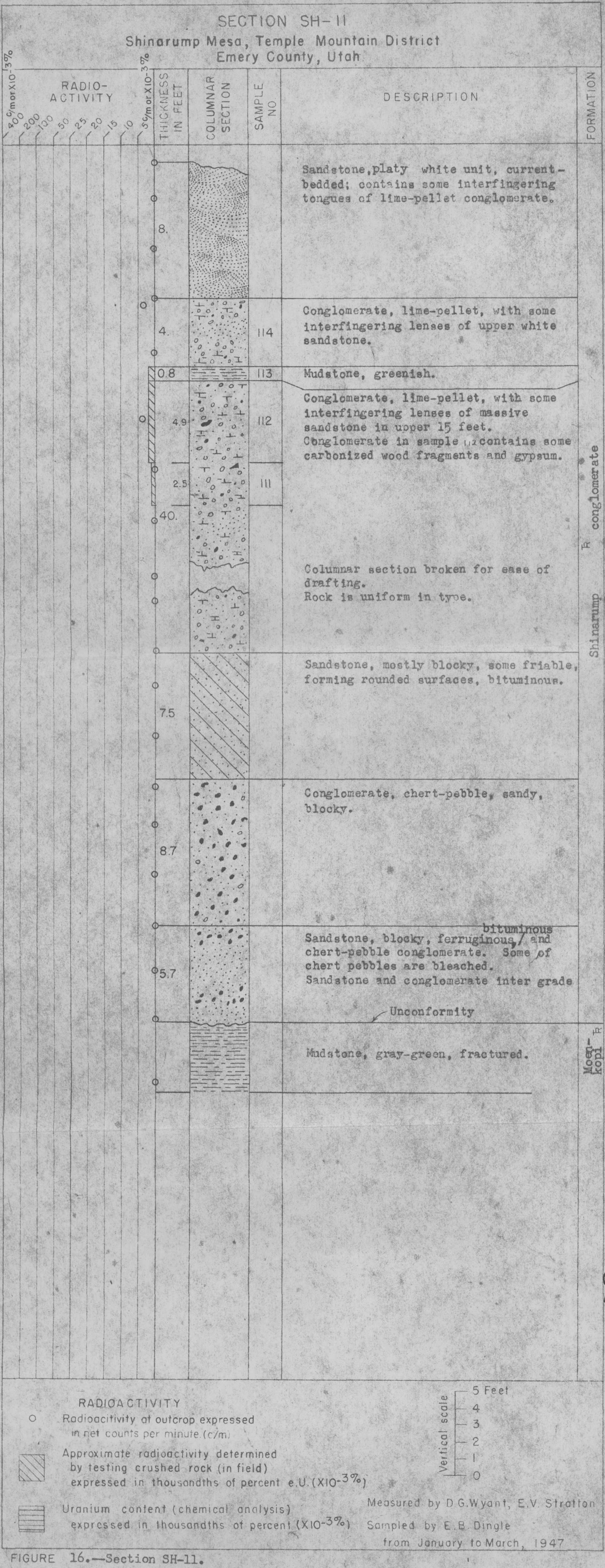

FIGURE 16.—Section SH-11.

Table 1.-- Radiometric and Chemical Analyses of Samples from Shinarump Conglomerate

Sample number	Channel sample (feet)	Equivalent uranium 1/ (percent)	Uranium (percent)	Lithology
		Section SH-1		
1	3.0	0.000	0.001	Shale 2/.
2	3.5	0.003	0.006	Chert-pebble conglomerate.
3	5.2	0.003		Conglomerate lens.
4	2.7	0.000		Sandstone from shale lens.
5	3.5	0.002		Lime-pellet conglomerate.
6	3.5	0.001		Lime-pellet conglomerate.
7	0.5	0.005		Mudstone.
8	0.7	0.003	< 0.001	Lime-pellet conglomerate.
9	1.7	0.000	0.006	Massive sandstone.
		Section SH-2		
10	5.1	0.002		Chert-pebble conglomerate.
11	2.4	0.002		Massive bituminous sandstone.
12	4.0	0.000	0.001	Massive bituminous sandstone.
13	1.5	0.001		Massive bituminous sandstone.
14	2.1	0.000		Mudstone-gravel mixture.
15	1.6	0.001	< 0.001	"Hard", blocky sandstone.
16	4.2	0.000		Lime-pellet conglomerate.
17	4.0	0.000	0.001	Lime-pellet conglomerate.
18	4.5	0.000	0.001	Lime-pellet conglomerate.
19	7.4	0.000		Lime-pellet conglomerate.
20	2.6	0.000		Massive sandstone.
		Section SH-3		
21	4.0	0.002	0.003	Chert-pebble conglomerate.
22	3.9	0.000	< 0.001	"Hard" blocky-sandstone.
23	1.4	0.000	< 0.001	Mudstone, conglomerate.
24	5.0	0.000		Massive bituminous sandstone.
25	2.3	0.000		Massive bituminous sandstone.
26	4.3	0.006	< 0.001	Lime-pellet conglomerate sandstone.
27	3.0	0.000	< 0.001	Lime-pellet conglomerate sandstone.
28	4.5	0.006		Lime-pellet conglomerate sandstone.
		Section SH-3 (continued)		
29	3.2	0.000	0.001	Lime-pellet conglomerate sandstone.
30	5.0	0.000	< 0.001	Massive sandstone.
31	3.0	0.000		Massive sandstone.
32	1.6	0.004	< 0.001	Lime-pellet conglomerate.
		Section SH-4		
33	2.3	0.001		Chert-pebble conglomerate.
34	0.7	0.000		Sandy, cherty, conglomerate, plant fragments.
35	5.3	0.004		Sandstone, and chert-pebble conglomerate.
36	1.5	0.009	0.009	Conglomerate and wood fragments.
37	3.0	0.020	0.017	Asphaltic sandstone, carnotite.
38	3.0	0.002		Bituminous sandy conglomerate.
39	7.4	0.000		Massive bituminous sandstone.
40	3.2	0.003		Lime-pellet conglomerate.
41	2.7	0.002		Lime-pellet conglomerate.
42	3.8	0.000		Lime-pellet conglomerate.
43	3.0	0.000		Massive sandstone.
		Section SH-5		
44	2.5	0.004		Mudstone 2/.
45	4.6	0.000		Chert-pebble and lime-pellet conglomerate.
46	2.3	0.000		Chert-pebble and lime-pellet conglomerate.
47	1.0	0.001		Mudstone-gravel mixture.
48	5.0	0.005		Lime-pellet conglomerate.
		Section SH-6		
49	6.0	0.004		Chert-pebble conglomerate.
50	3.0	0.000		Mudstone.
51	5.0	0.000		Upper white sandstone.
		Section SH-7		
52	1.6	0.000		Chert-pebble conglomerate.
53	5.8	0.000		Massive bituminous sandstone.
54	3.3	0.000		Massive bituminous sandstone.

1/ Field determination.

2/ Moenkopi shale.

[redacted] 40

Table 1.--Radiometric and Chemical Analyses of Samples from Shinarump Conglomerate -- continued

Sample number	Channel sample (feet)	Equivalent uranium 1/ (percent)	Uranium (percent)	Lithology
				Section SH-7 (continued)
55	3.5	0.000		Massive bituminous sandstone.
56	0.5	0.002		Mudstone.
57	1.3	0.001		Lime-pellet conglomerate.
58	3.8	0.000		Siltstone.
59	1.7	0.001		Lime-pellet conglomerate.
60	3.8	0.001		Massive bituminous sandstone.
61	2.5	0.003		Siltstone, lime-pellet conglomerate.
62	2.0	0.004		Mudstone.
63	3.8	0.002		Lime-pellet conglomerate.
64	1.5	0.014	0.004 (?)	Asphaltic sandstone, carnotite.
65	1.4	0.003		Lime-pellet conglomerate, sandstone
				Section SH-8
66	4.3	0.001		Massive, bituminous sandstone.
67	1.5	0.000		Massive, bituminous sandstone.
68	3.6	0.001		Massive, bituminous sandstone.
69	7.4	0.002		Mudstone-gravel mixture.
70	2.1	0.001		Sandstone, lime-pellet conglomerate.
71	6.0	0.004		Mudstone.
72	1.4	0.004		Mudstone, siltstone, conglomerate.
73	1.8	0.000		"Hard" blocky sandstone.
74	1.3	0.002		Siltstone.
75	0.5	0.004		Sandy lime-pellet conglomerate.
76	2.5	0.007		Sandy lime-pellet conglomerate.
77	2.3	0.003		Massive, white sandstone.
				Section SH-9
78	2.0	0.007	0.004	Chert-pebble conglomerate.
79	1.8	0.000		Bituminous sandstone, conglomerate.
80	2.7	0.000		Bituminous sandstone, conglomerate.
81	1.3	0.000		Bituminous siltstone, conglomerate.
82	4.2	0.002		Mudstone.
83	5.2	0.004		Mudstone.
84	2.8	0.002		"Hard", blocky sandstone, conglomerate.
85	2.6	0.002		Mudstone-gravel mixture.
86	5.0	0.002		Platy lime-pellet conglomerate.
				Section SH-9 (Continued)
87	1.7	0.004		Sandstone.
88	3.0	0.009	0.008	Sandstone.
89	[illegible]	0.009	0.010	Asphaltic sandstone carnotite.
90	2.0	0.007	0.007	Sandy lime-pellet conglomerate.
91	2.1	0.012	0.006	Sandy lime-pellet conglomerate.
92	2.8	0.013	0.014	Sandy lime-pellet conglomerate, asphaltic.
93	2.0	0.010	0.015	Sandy lime-pellet conglomerate, asphaltic.
94	5.0	0.003		Sandy lime-pellet conglomerate.
95	2.6	0.002		Lime-pellet conglomerate.
96	3.0	0.001		Lime-pellet conglomerate.
				Section SH-10
97	3.7	0.002		Chert-pebble conglomerate.
98	1.8	0.002		Chert-pebble conglomerate.
99	4.0	0.002		Sandstone, chert-pebble conglomerate.
100	3.5	0.002		Sandstone, chert-pebble conglomerate.
101	1.6	0.110	0.15	Asphaltic, bituminous, friable sandstone
102	4.7	0.003		Friable sandstone, bituminous.
103	4.6	0.001		Massive bituminous sandstone.
104	7.0	0.001		Blocky bituminous sandstone.
105	5.0	0.000		Lime-pellet conglomerate.
106	2.5	0.001		Platy sandstone.
107	[illegible]	0.002		Platy sandstone.
108	1.4	0.002		Sandy lime-pellet conglomerate.
109	2.4	0.000		Mudstone.
110	1.6	0.00		Platy lime-pellet conglomerate.
				Section SH-11
111	2.5	0.001		Lime-pellet conglomerate.
112	4.9	0.002		Lime-pellet conglomerate, gypsum, jarosite (?).
113	0.8	0.003		Mudstone.
114	4.0	0.000		Lime-pellet conglomerate, sandy.

1/ Field determination.

URANIUM ORE DEPOSITS

Commercial production of radium from uranium-bearing ore of the Temple Mountain district began in 1914 (Hess, 1914, p. 944) and continued during the first world war. During the war years, according to Hess (Hess, 1922, p. 457), a considerable tonnage of ore was shipped that averaged about 1.75 percent U_3O_8 and 4 percent V_2O_5. From about 1919 to 1950 the district has been essentially idle. Total production up to 1950 is unknown but to judge from the amount of dump material and underground workings is probably less than 500 tons. Since 1950 a small but steadily increasing amount of uranium and vanadium-bearing ore has been produced. Most of this ore has come from the deposits on Temple Mountain although a small quantity has been mined from the deposits at the north end of Shinarump Mesa. In the earlier period of activity an attempt was apparently made to mine selectively only the carnotiferous rock leaving the uraniferous hydrocarbon, hot because it is not of ore grade, but because it was milled with difficulty.

There are two main types of uranium deposits in the Temple Mountain district, one type in which the uranium is in hydrocarbon grains, pellets, blebs, or vein-like masses and a second type in which the principal uranium mineral is carnotite; the carnotite is commonly associated with dark vanadium minerals; the hydrocarbons may be subdivided into humic and asphaltic (petrolific) hydrocarbons _/. The

---

_/ The term hydrocarbon is used for all dark brown or black organic material; it includes solid asphaltite, liquid bitumen, and carbonized or coalified plant fragments.

distinction of these two types of deposits probably has little economic significance at Shinarump Mesa where, except for two ore bodies in which the only ore mineraloid is hydrocarbon grains or blebs, the ore contains both uraniferous hydrocarbon and carnotite. At the South and North Temple workings, however, the distinction between the two ore types is economically significant because they differ in mode of occurrence, grade, and mill treatment methods.

Asphaltic hydrocarbon was observed in all ore bodies examined, although in some it is sparsely disseminated as grains or irregularly-shaped blebs that are only from 0.1 to 0.5 mm in diameter.

The term "ore" is used in this report to denote all mineralized rock containing more than 0.005 percent uranium; ore is commonly easily recognizable by the presence of black hydrocarbon or of yellow, black, green, or red stains on the rock.

Mineralogy

Hess (1925, pp. 63-78) identified as uranium or vanadium-bearing minerals in the Temple Mountain district rauvite ($CaO.2UO_3.6V_2O_5.20H_2O$), metatorbernite ($Cu (UO_2)_2 (PO_4)_2, 8 H_2O$), uvanite ($2 UO_3.3V_2O_5.15 H_2O$), hewettite ($CaO.3V_2O_5. 9 H_2O$), carnotite ($K (UO_2) (V_2O_4) .1/2- 1\frac{1}{2} H_2O$), and the mineraloid, uraniferous asphaltite. Murphy (1944), tentatively, identified five more ore minerals, pintadoite ($2CaO.V_2O_5.9H_2O$), zeunerite (?) ($Cu (UO_2)_2(AsO_4)_2.8H_2O$), pascoite ($2CaO.3V_2O_5.11H_2O$), vanoxite (?) ($2V_2O_4.V_2O_5.8H_2O$), and, schroeckingerite ($Ca_3NaUO_2(CO_3)_3(SO_4)F.10H_2O$). From samples collected by the writer, Mary E. Thompson, mineralogist, identified zippeite ($2UO_3.SO_3.5\text{-}6H_2O$), and tentatively identified tyuyamunite ($Ca\ (UO_2)_2(VO_4)_2.nH_2O$), thucholite (Th, U, hydrocarbon), and vanadiferous hydromica or "roscoelite" ($4H_2O.2K_2O.2(Mg,\ Fe)O.2Al_2O_3.3V_2O_3.10SiO_2$).

The principal ore minerals observed by the writer were carnotite and associated black vanadiferous minerals (uvanite, rauvite, vanoxite), and the mineraloids, black uraniferous hydrocarbons. The other minerals listed above are much less abundant and some of them (zeunerite, schroeckingerite, meta-torbernite), occur only in specimen quantities.

Carnotite is commonly associated with uraniferous hydrocarbons, black vanadium minerals or in some places with the orange, green, or red vanadium minerals pintadoite, pascoite, and hewettite. Carnotite coats many of the galls of mudstone, the fracture and joint surfaces of some rocks, and in some places fills interstices in sandstone. In hand specimens of ore from the North adits ore body on Shinarump Mesa, Joseph Berman, mineralogist, noted that the subrounded quartz grains, some of which show secondary growth, clastic hydrocarbon particles, and sparse feldspar grains are bonded by bitumen and carnotite (?). He described the carnotite (?) as a yellow uranium-bearing, anisotropic crystalline powder, having indices of refraction that average approximately 1.67. In specimen No. UTM36-47 from the Through adit, South Temple workings, Berman observed soft, fibrous, fluorescent tschermigite (?), $(NH_4)Al\ (SO_4).\ 12\ H_2O$, and yellow fibrous halotrichite (?), $FeSO_4.Al_2(SO_4)_3.22H_2O$, on a thin layer of carnotite (?), that also is disseminated throughout the friable asphaltic sandstone. The vanadate minerals commonly are in irregular bands adjacent to, and more or less parallel to hydrocarbon bodies.

Uraniferous hydrocarbons are of two types, asphaltic hydrocarbon, and humic hydrocarbon. Asphaltic hydrocarbon, the more abundant type, commonly occurs as clastic grains or as irregular-shaped blebs filling interstices; less commonly it occurs as veinlike, massive layers containing a small but variable amount of admixed sand grains; rarely the asphaltic hydrocarbon occurs as botryoidal pellets. The asphaltic hydrocarbon is typically jet black, of vitreous lustre, and relatively hard; it breaks with a conchoidal fracture. The humic type of uraniferous hydrocarbon occurs as clastic, typically well-rounded grains with a dull to vitreous lustre; the humic grains may show cell structure, and may be traversed by minute cracks (presumably owing to slaking upon loss of volatiles); the grains are fragments of coalified or carbonized wood or other large plants. Granules of hard, vitreous asphaltic hydrocarbon without either minute cracks or distinguishable cell structure in places occur in haloform concentrations near large fragments of carbonized wood; these granules may represent asphaltized humic grains.

From the hand specimens of friable asphaltic sandstone previously described from the North adits ore body in Shinarump Mesa, the granular hydrocarbon was separated mechanically by Berman from the bituminous cement. Radiometric analysis of the two resulting fractions shows the radioactivity to be concentrated in the granular fraction. The uraniferous hydrocarbon grains are indistinguishable from asphaltite. They are the same size as the quartz grains and are concentrated in the rock in thin beds with other detrital components in the closely-spaced beds of the cross-bedded sandstone. In many ore bodies these asphaltite grains, together with rounded grains of uraniferous humic hydrocarbon, occur in friable sandstone that is commonly pitted by the removal of some of the hydrocarbon grains. The asphaltic grains are probably identical with the material described as detrital by Hess (Hess, 1933, p. 458). Uraniferous botryoidal pellets of asphaltite are uncommon in the deposits examined in the Temple Mountain district and were not studied in detail. They stud fracture surfaces in an adit in the North Temple workings; some of the large asphaltite grains in the Through adit may be such pellets. Physically, they resemble the other asphaltic hydrocarbons in relative hardness, and in color and lustre of broken surfaces, but differ in their botryoidal surfaces and mode of occurrence. Pellets, identical in appearance, associated with carnotite and copper carbonates on fracture surfaces of the Shinarump conglomerate, were collected by E. P. Beroni and H. C. Granger, U. S. Geological Survey, from Frey Point, White Canyon, Utah. Similar pellets were seen by the writer at the Lone Tree and Dexter deposits on the west side of the San Rafael Swell, where they occur in sandstone and mudstone beds of both Shinarump and Moenkopi formations. At the Lucky Strike deposit on the west side of the San Rafael Swell pellets are sparse, but the section of one was surrounded by an annular ring of hydrocarbon. They resemble in appearance and uranium content the mineraloid thucholite (Ellsworth, 1928, Spence, 1930).

In many of the hand specimens studied the uraniferous hydrocarbon is in the form of irregular-shaped blebs that appear to fill interstices of the sandstone and resemble "dead oil", the oxidized, nonvolatile residue left after the removal of liquid hydrocarbons. A specimen, No. UTM 39-47, of uraniferous sandstone from the North Temple workings is composed of quartz sand and hydrocarbon. As seen under a binocular microscope, approximately 60 percent of the material consists of transparent, subangular to subrounded quartz grains averaging 0.2 to 0.5 mm in diameter. Many of the quartz grains have crystal faces and some are coated with hydrocarbon. The remaining 40 percent of the sample consists of black or dark brown opaque grains or blebs of hydrocarbon, and the thin coatings of hydrocarbon around the quartz grains. The hydrocarbon is apparently asphaltite for it shows no cell structure.

Some of the asphaltite grains show indentations probably caused by forceful contact with the quartz grains but many are irregular in shape and merely fill interstices. The asphaltite is jet black, vitreous and breaks with a conchoidal fracture. When magnified 40 diameters, some of the dark brown, irregular blebs appear to be minutely botryoidal, contain exceedingly small white inclusions and probably are bituminized interstitial clay. On heating, the powdered sample lost approximately 35 percent of its weight and left an ash consisting of quartz grains and of grains and blebs of a spongy yellowish-gray substance. When treated with 1:1 nitric acid and filtered, the residue became a mixture of clean quartz grains, spongy white to buff blebs, and a yellow powder thought to be a vanadium compound. The filtrate, on evaporation, produced a yellow uraniferous precipitate.

In some of the ore deposits in the North and South Temple workings the uraniferous hydrocarbon forms continuous beds or fracture fillings that range from one-fourth of an inch to two inches in thickness. This material resembles coal, gives a distinctly tarry odor when broken or heated, and is highly radioactive. Surfaces of specimens are globular or spheroidal. Two specimens of this material from the Main adit, South Temple workings, were studied petrographically by Mary E. Thompson, mineralogist. Sample No. 103 contains only a small amount of sand grains and is composed largely of a uranium-bearing type of hydrocarbon, possibly thucholite, that is coated with gypsum; this sample contains 8 percent equivalent uranium. Sample No. 106 is composed of about equal amounts of quartz sand grains and "..amorphous, black, pitchy material that is probably thucholite" and which is coated with brilliant yellow-green, brightly-fluorescent zippeite; the specimen contains 10.5 percent equivalent uranium.

Another sample of this more massive type of uraniferous hydrocarbon from a fracture along the Through adit in the South Temple workings was examined. The sample, No. UTM 6-47, before grinding, was jet black with a vitreous lustre and contained a lower proportion of quartz grains than did sample No. UTM 39-47. When powdered and heated the material lost 45 percent of its weight and the resulting ash was similar to that produced from sample 39-47. A nitric acid treatment also produced similar results except that the precipitate formed by evaporating the filtrate to dryness was yellowish-red instead of yellow. Analysis showed that this minutely crystalline substance contains uranium, considerable iron, and vanadium. The components of the gray-buff residue from heating could not be determined by petrographic methods; the minute grains show anomalous birefringence or none at all, and appear to consist partly of stained quartz and partly of aggregates of other minerals too small to identify that may be glass formed during the heating.

Two autoradiographs, one of this massive, veinlike, hydrocarbon, the other of granules of hydrocarbon, show that the source of the alpha radiation is evenly distributed through the mineraloid.

The uraniferous hydrocarbons are in some places associated with another nearly non-uraniferous hydrocarbon that is generally viscous, brown, and for convenience, may be termed bitumen. Sixteen channel samples of massive sandstone or conglomerate impregnated with bitumen were taken at various localities around Shinarump Mesa. With the exception of the samples taken from the North adit none contained more than 0.002 percent equivalent uranium by field test (table 1); of three representative samples analyzed none contained more than 0.001 percent uranium (table 2) in the laboratory. Specimen No. UTM 29-47 (table 3) from the base of section SH-7 (figs. 3-4, 11) is a non-uraniferous, bituminous sandy conglomerate composed of quartz grains and clay galls bonded with bitumen. The quartz grains are for the most part clear and euhedral. The galls are flakes and irregular-shaped masses of quartz silt and clay. The bitumen fills interstices and in a few places has impregnated clay-silt galls; it is dull brown on stained surfaces but jet black where it is as much as a millimeter in thickness.

Table 2.--Analyses of bituminous sandstone and conglomerate, Temple Mountain district, Utah.

Sample number	Description and Remarks	Equivalent uranium (percent)	Uranium (percent)
UTM-29-47	Hand specimen of bituminous conglomerate with sparse asphaltite (?) grains from base of section SH-7, Shinarump Mesa.	0.001	0.001
SH-2-12	Bituminous sandstone from base of section SH-2, Shinarump Mesa.	0.000	0.000
SH-8-66	Bituminous sandstone from section SH-8, Shinarump Mesa.	0.001	0.001

Recent work by Ralph Erickson of the U. S. Geological Survey _/ has shown that the viscous bituminous hydrocarbon from the Temple Mountain district contains a small amount of uranium as well as other metals. These metal components are detectable in the ash left after combustion of the bitumen which was first extracted from the rock. Bituminous sandstones are widespread in the San Rafael Swell, and wherever samples were taken and analyzed by Erickson, the ashed bitumen contains trace amounts of uranium and other metals.

_/ Ralph Erickson, informal communication.

Murphy (1944) tentatively identified several secondary minerals more or less associated with the ore minerals and mineraloids in the altered rock at Temple Mountain: pyrite, realgar, galena, magnetite, hematite, goethite, siderite, jarosite, chamosite, azurite, malachite, carnotite, celadonite, turgite, scorodite, calcite, and dolomite. From the same rock Hess (1922) identified, in addition, copiapite.

Ore bodies at Shinarump Mesa

With the exception of a few, small podlike ore bodies the Shinarump conglomerate at Shinarump Mesa is almost entirely barren of uranium. For the most part the rock either contains more than 0.01 percent uranium or less than 0.002 percent. (See figs. 3, 4, and table 1.)

The 21 ore bodies observed are apparently confined to sandstone lenses within three main rock units, the chert-pebble conglomerate unit at the base of the Shinarump, the sandstone-mudstone unit, and the lime-pellet conglomerate unit. Other rock units appear to be barren. The two largest exposed bodies of ore, those at the North and at the Northeast adits, are in the sandstone filling a Triassic stream channel that trends northwestward. The body south of the Northeast adit is a lens 120 feet long and a maximum of 6 feet thick. Other small bodies from 1 to 6 feet thick, and from 3 to 45 feet long, are exposed on the cliff face east of the North adits, at the West adit, and in sections C-D and I-J (fig. 4). The shapes of the ore bodies and their outcrop size are determined by the shape and size of the friable sandstone lenses in which the ore occurs. Most of the ore is exposed on the scarp of the mesa, for on the upper surface of the mesa, ore bodies were discovered only near the tops of measured sections SH-7, SH-8, and SH-9 (fig. 3).

Uraniferous, black, hard hydrocarbon, the dominant ore mineraloid, is common to all ore bodies, and carnotite to most of them. The uraniferous hydrocarbon appears to be predominantly asphaltite and subordinately carbonized plant material. The asphaltite is for the most part in the form of fillings or irregularly shaped blebs between sand grains, although subrounded grains of asphaltite are common. Grains of carbonized plant material are less-abundant, but, together with the granular asphaltite (that may be in part asphaltized humic hydrocarbon), are prevalent in the richer ore bodies and near carbonized logs. Large botryoidal pellets of hydrocarbon were not observed.

Ore bodies in the chert-pebble conglomerate unit

The ore minerals in most of the ore bodies in the chert-pebble conglomerate rock unit are disseminated in lenses of friable sandstone or poorly consolidated conglomerate that are as much as 3 feet thick and 50 feet long. Four of these ore-bearing lenses were found, most of them from 3 to 10 feet above the base of the Shinarump conglomerate. The proportion of hydrocarbon to carnotite, as well as the type of hydrocarbon, varies; for example, in the ore body at the base of the Shinarump conglomerate about 100 feet east of the North adits (fig. 4, section A-B), no carnotite was seen and all of the hydrocarbon is asphaltite blebs. On the other hand, in the discontinuous ore zone in and north of the Southeast adit (fig. 4, section I-J) only a few hydrocarbon grains were seen, most of which were humic hydrocarbon. The ore body in measured section SH-4 (fig. 4, section I-J) is a flat lens of friable sandstone 38 feet long and a maximum of 3 feet thick, containing grains and blebs of hydrocarbon and some carnotite. Sample No. 37, cut from this ore body, was 3 feet long and contained 0.017 percent uranium, although according to radiometric observation, the sample represents the leaner part of the ore body that may in richer parts contain as much as 0.05 percent equivalent uranium; the sample contained 0.92 percent vanadium. At several places around the mesa scarp, thin films of carnotite were seen in the basal few inches of the chert-pebble conglomerate subunit or facies at the base of the formation. The carnotite in this site commonly coats carbonized log fragments or chert pebbles and forms ore zones too small to be delineated.

Ore bodies in the sandstone-mudstone unit

Of the 21 exposed ore bodies at Shinarump Mesa, 15 occur in lenses of friable sandstone within the sandstone-mudstone rock unit. Uraniferous hydrocarbon is the dominant mineraloid, although the dark vanadate minerals are relatively abundant in the ore body at the North adits, and the yellow vanadate, carnotite, is common. Of the uraniferous hydrocarbons, the irregularly shaped blebs of asphaltite are generally most abundant, although granular asphaltite and granular carbonized plant fragments in about equal proportions predominate in the richest parts of some ore bodies. These granular hydrocarbons appear to be clastic components of the friable sandstone, for the subangular to subrounded grains are the same size, or slightly larger than the other clastic particles, and are concentrated in thin, mutually-truncating current beds that are in places no thicker than the grains; such a sequence of beds somewhat resembles Recent black sand deposits. In four ore bodies the host rock is friable sandstone more or less impregnated with bitumen; in eight ore bodies the friable sandstone is not bituminous although bituminous rock is within a few feet; in three ore bodies there is no bituminous rock exposed in the immediate vicinity.

The deposits range in grade from less than 0.01 to 0.65 percent uranium. Available analyses suggest that the vanadium content ranges from five to ten times the uranium content.

Representative of the ore bodies in the sandstone-mudstone rock unit of the Shinarump conglomerate at Shinarump Mesa is the ore body at the North adits. (See fig. 4, section A-B.) The cross-section of the ore body exposed on the cliff face is in the shape of an irregular, flat-bottomed lens, convex upward, the maximum base length of which is 50 feet and the maximum thickness, 10 feet; a thin lens of ore at the base of the ore body that is about 2 feet thick may extend an additional 40 feet westward under talus. The rock is a gray-green, friable, slightly bituminous sandstone containing a considerable proportion of clay galls. The ore body is at the lower, southwestern edge of a larger lens-shaped body of barren, gray-green, slightly bituminous, friable sandstone and bituminous massive sandstone. Current beds within the ore body range in thickness from one-sixteenth of an inch (beds one grain thick) to one inch and rarely extend farther than 2 feet, whereas the current bedding in the overlying and adjacent friable and massive sandstone lens is on a coarser scale.

Grains of uraniferous hydrocarbon, most of which appear to be asphaltite, are concentrated along individual current beds, and blebs of uraniferous asphaltite are disseminated throughout the ore. The quantity of the uraniferous, granular asphaltite increases as one approaches the central part of the lens, and in this richer part, brown to black vanadate minerals coat the grains of the rock. Carnotite is not abundant, but stains quartz grains, penetrates clay galls, and forms hazy, surficial bands that parallel the current beds. The amount of bitumen gradually decreases upward but overlaps the ore. A hand specimen, No. UTM 3-47, representative of this material is a coarse-grained, friable current-bedded sandstone composed largely of quartz grains, some of which are black, and of varying amounts of hydrocarbon grains and blebs, poorly bonded by clay that is stained brown by bitumen and vanadium compounds. Carnotite stains are sparse. The quartz grains are subrounded to subangular and the clastic hydrocarbon grains are rounded to subrounded. The hydrocarbon grains and blebs comprise at least 40 percent of the specimen, and in places as much as 60 percent; where this hydrocarbon is most abundant the rock is most uraniferous, most friable, and the rock is pitted by removal of the solid hydrocarbon. It is estimated that about 10 percent of the solid, uraniferous hydrocarbon is clastic, humic grains (carbonized plant fragments), about 50 percent is clastic asphaltite grains, and about 40 percent is asphaltite blebs; in the absence of cell structure, humic grains were distinguished under the microscope from asphaltite grains by cracks caused by slaking of the carbonized vegetal material. The proportion of uraniferous hydrocarbon decreases away from the uraniferous parts and the proportion of bonding bitumen rises.

Another specimen, No. UTM 40-47, from the margin of this ore body is a sandstone containing clay galls and a few asphaltite grains and blebs. Carnotite (?) has impregnated most of the clay and coats some of the asphaltite grains. The edge of one asphaltite bleb feathers into gypsum and halotrichite (?) which form fibrous veinlets throughout the specimen.

The grade of the ore body varies with the amount of ore minerals. Sample 101, 1.6 feet in length, was cut from the thin eastern end of the ore body; it contains 0.11 percent equivalent uranium by field test, 0.15 percent uranium, 3 percent vanadium. Radiometric observations suggest that the richest part of the ore body may contain as much as 0.4 percent equivalent uranium over a width of 1 foot more and a length of 10 feet.

The "fine-grained" current bedding and the general relation of the ore-bearing friable sandstone to the surrounding units suggest that the ore body is at the southwest edge of a Triassic stream channel in which the water flowed northwestward. This channel, or two similar ones, projects southeastward to the vicinity of the Northeast adit where two entire channels, as outlined by the channel fill of friable bituminous sandstone, are ore-bearing. At the adit carnotite stains and clastic grains of asphaltite and carbonized wood (?) form a halo about 6 feet in diameter around two large carbonized logs. Grains of both humic and petrolific hydrocarbon increase in number toward the logs, and it is likely that some of the asphaltite grains are asphaltized carbonized wood (?).

Ore bodies in the lime-pellet conglomerate unit

Three uranium-bearing lenses of fine- to medium-grained friable sandstone were found in the lime-pellet conglomerate rock unit, one near the top of measured section SH-9 (fig. 4, and also fig. 14), one at the fracture between measured sections SH-8 and SH-9 (fig. 4), and the other at the West adit (fig. 4, and fig. 12). The ore bodies range from 8 to about 50 feet in length and from 1 to about 14 feet in thickness. Principal ore minerals are carnotite (?) and uraniferous hydrocarbon, with carnotite predominating; granules of the hydrocarbon are asphaltic or humic.

The dimensions of the ore body near the top of measured section SH-9 are not exactly known because of lack of exposures; the lower part of the ore body exposed on the cliff face is shown in figure 4 and the sampled section on figure 14. The sandstone lens at the base of the uraniferous area is about 50 feet long and 2 feet thick, of which about 25 linear feet with a thickness of 1 foot are ore-bearing. Samples Nos. 88 to 93, inclusive (fig. 14, table 1), cut in pits on the surface of the mesa, cover a vertical interval of 14 feet, and possibly represent several ore-lenses, or a surface incrustation of carnotite over the sampled area. The samples contain from 0.007 to 0.015 percent equivalent uranium, from 0.007 to 0.015 percent uranium, and from 0.03 to 0.11 percent vanadium. Carnotite in thin films predominates, although granular asphaltite and humic hydrocarbon are locally abundant.

The uraniferous friable sandstone lens at the fracture between measured sections SH-8 and SH-9, is 8 feet long and 1 foot thick. Although Murphy's sample of this body (Murphy, 1944), TM-3, which is 2.6 feet long, contained 0.38 percent uranium, radiometric observations suggest that most of the ore is much less uraniferous. The ore consists of black hydrocarbon grains in friable sandstone, with sparse carnotite (?) stains. A hand specimen, No. UTM 14-47, from near triangulation 7 (fig. 3) is of sandy lime-pellet conglomerate with fracture surfaces coated with carnotite (?). Major constituents are predominantly quartz grains and subordinately gray-green silt or clay, cemented by calcite. Most of the subangular to subrounded quartz grains are clear but some are frosted; about 10 percent are "smoky". Minor constituents are muscovite (or bleached biotite) flakes, clastic asphaltite and carbonized plant grains, nodules of limonite and manganese oxide, and carnotite (?). The carnotite (?) coats the other constituents and is concentrated in small patches along fracture surfaces.

The uraniferous lens at the West adit is 2 feet thick at the thickest part and 40 feet long. Channel sample 64, cut across 1.5 feet, contained 0.014 percent equivalent uranium by field test, but only 0.004 percent uranium; the sample contained 1.29 percent vanadium. The ore minerals and mineraloid are about equal proportions of hydrocarbons and carnotite (?); many of the granules are of humic hydrocarbon. A considerable amount of carbonized, macerated plant fragments covers the roof of the adit and together with asphaltite grains that may be in part asphaltized carbonized plant material, darken the rock; no comparable amount of such material was observed in the other ore bodies in the lime-pellet conglomerate.

The paragenesis of the ores at Shinarump Mesa is not exactly known and will remain so until more exact methods have been devised to distinguish between humic and asphaltic hydrocarbons and to determine the products of alpha-ray bombardment of each type. The hydrocarbon appears to be the primary ore and the carnotite definitely secondary.

Ore bodies at the South Temple workings

Part of the South Temple workings, shown on figure 5, was mapped to show the presence of the ore types first distinguished at Shinarump Mesa. The ore bodies at the South Temple workings (fig. 5) resemble those at Shinarump Mesa in mineralogy, in their localization within local sandstone channel fills, and in their stratigraphic position within the Shinarump conglomerate, but they are thicker, more continuous, and richer, and therefore, have been more extensively exploited. The exposed cliff face in many places is coated by thin films of carnotite and related vanadates that form bands and patches extending for several feet above and below ore bodies.

The ore bodies are of two general types, concentrations of uraniferous hydrocarbons and concentrations of carnotite and related vanadates, although the two types overlap in places. Exposed ore bodies are confined to the main sandstone-mudstone rock unit in the middle or lower third of the Shinarump conglomerate. They are lenticular bodies of friable sandstone, containing differing amounts of gray-green mudstone galls, ore minerals, and mineraloids in two stratigraphic "zones", one above, and one below a central lens of massive, bituminous sandstone. In the upper "zone", the largest ore body exposed on the cliff face is a lens 260 feet long and as much as 12 feet thick; another smaller lens of ore is in the same stratigraphic "zone". The largest ore body in the lower "zone" is a lens about 130 feet long and as much as 7 feet thick; three smaller ore bodies from 23 to 40 feet long and from a knife edge to 4 feet thick are in the same general stratigraphic position.

These ore bodies were explored during the first world war by a number of adits, drifts, and cross-cuts that in many places are interconnecting. Mining, since 1947, has enlarged considerably some of the surface openings and generally altered the appearance of the cliff face. Since some ore is currently (1952) being produced, the grade of the shipped ore is presumably greater than 0.1 percent U_3O_8, the lowest grade permissible at the buying stations. The uranium content of Murphy's samples (Murphy, 1944) ranged between 0.017 and 1.7 percent; the V_2O_5 content, between 0.04 and 5.10 percent.

The uraniferous hydrocarbons resemble those in the ore at Shinarump Mesa, that is, there are clastic grains of humic and petrolific hydrocarbon (plant and asphaltite grains), and there are also irregularly shaped blebs of asphaltite. In addition, however, the asphaltic hydrocarbon occurs as veinlike masses as much as 2 inches thick that fill porous sandstone beds or bedding plane fractures.

The vanadate minerals, principally carnotite (?), are more abundant than they are at Shinarump Mesa. Most of the carnotite is in surficial films that commonly form wavy and indistinct layers from 1 to 3 inches thick separated by alternating layers, equally thick of barren sandstone; these layers are generally from a few tenths of a foot to 3 feet above concentrations of uraniferous hydrocarbons and the entire zone of diffusion bands may be as much as 3 feet wide. Some of the carnotite, however, in the Main adit (fig. 5) fills interstices between the quartz grains in sufficient amount to constitute a carnotite ore body or roll.

The ore body at the Main adit is a lens 18 feet long and 4 feet thick within the lower "zone" of ore lenses. This lens, which is pale buff, massive bituminous sandstone, is composed of porous, and only slightly bituminized sandstone. The rock is colored light yellow by interstitial carnotite, and contains a very few grains and blebs of asphaltic hydrocarbon; the porosity may have been caused by the leaching of the hydrocarbon because in two of the small pits, relict grains or films of hydrocarbon were noticed. A hand specimen, No. UTM 20-47, from the portal of this adit is a porous, well-sorted, medium-grained, quartz sandstone with a minor amount of clay cement. The quartz grains are clear and for the most part euhedral, although some are subrounded. Interstitial carnotite (?) forms diffused bands through the otherwise uniform rock. Two of the cavities contained granules or blebs of relict hydrocarbon. Within the adit, and outlined by the workings, is the unmined portion of what according to Fischer _/ was a roll of carnotite

---

_/ Fischer, R. P., informal communication.

---

ore. A roll of carnotite ore is an irregular lens-shaped concretionary pod the boundaries of which generally conform to bedding surfaces but in detail transect the bedding; they are commonly sharply delimited from barren rock and are most common in the Salt Wash sandstone member of the Morrison formation. The roll in the Main adit was at least 30 feet long, a maximum of 10 feet in height, and of undetermined width; the long axis of the roll trends northeastward; little ore is now left in the walls.

The ore body in part explored by the Through adit (fig. 5, underground map of Through adit) is the large ore lens in the upper "zone" of ore lenses above the massive, bituminous sandstone. This ore body is 260 feet long and as much as 12 feet thick as exposed in cross-section on the cliff face. The surface of the rock shows it to be a lens of slightly bituminized, white-weathering, gray sandstone containing a considerable proportion of gray-green clay galls. Within it uraniferous hydrocarbons, largely grains and blebs of asphaltite, but also clastic, rounded grains of carbonized wood (?), are concentrated in lenticles and along mutually truncating beds of the current-bedded rock; current bedding is "fine-grained" and resembles that at the North adits ore body on Shinarump Mesa. Carnotite forms surficial layers and penetrates the rock along some of the current beds.

The ore body was intersected at the floor of the Through adit 100 feet from the portal, and extends from there to the northernmost and southernmost cross-cuts (samples FM-5087 and 5081, respectively). The ore-bearing friable sandstone is sharply limited to the northwest by an overlying bed of massive, bituminous sandstone that truncates the ore bed, and has cut down through it into an underlying mudstone. The ore-bearing lens, therefore, extends southeastward into the cliff at least 260 feet, the length of the exposure on the cliff face. Inasmuch as the major control of the ore appears to be bedding, because the ore-bearing bed is a channel filling, and because the Triassic channels trend generally northeastward in the district, it is probable that the ore body extends considerably farther down the general dip of the beds to the southeast (fig. 5, section B-B'). In the approximate center of the ore body at sample FM-5082 (fig. 5) the ore is at least 6 feet thick. At the face of the northernmost cross-cut at sample FM-5087, the ore is only 5 inches thick; at the face of the southernmost crosscut at sample FM-5081 there are at least 4 feet of ore. According to the analyses of Murphy's samples (Murphy, 1944) shown on table 3, the ore ranges in grade between 0.02 and 0.51 percent uranium, and between 0.07 and 1.7 percent V_2O_5. The samples are from 1.5 to 5.0 feet long, but it should be noted that some of the samples include much sandstone that is only weakly mineralized with vanadates adjacent to thinner beds of hydrocarbon ore.

Most of the ore underground consists of uraniferous hydrocarbon grains and blebs in the sandstone, with only a small amount of carnotite. From near sample FM-5080, southeastward for 25 feet down the short drift, the ore becomes progressively richer and the hydrocarbon grains increase in number. From the intersection of this drift and the eastern cross-cut southward to the face of the southernmost cross-cut at sample FM-5081, the proportion of uraniferous hydrocarbon to sandstone increases still more; the eastern wall of this section of the cross-cut contains beds or tabular, veinlike masses of nearly pure asphaltite that fill bedding plane fractures and are as much as 2 inches thick. Specimen UTM 6-47 of this massive asphaltic material has been described in the section on mineralogy.

At the South Temple workings some, and perhaps all, the carnotite and related vanadate minerals were clearly formed later than the uraniferous hydrocarbon, and it is probable that uranium and vanadium were leached from the hydrocarbons and redeposited as carnotite in films on the rock surface, or as rolls within the rock, pitted by the removal of hydrocarbons. The veinlike type of massive, uraniferous asphaltite was apparently emplaced when viscous and under pressure, and therefore, presumably hot. Regardless of the time and method of metallization of the hydrocarbon grains and blebs, the position and continuity of the ore bodies are apparently controlled by rock type, which was established during the deposition of the Shinarump conglomerate. Note that the ore bodies extend no farther to the northwest (fig. 5, section C-C') than does mudstone.

Table 3.—Analyses of samples, Through adit, South Temple workings (after Murphy, 1944)

Sample no.	Length (feet)	Uranium (percent)1/	V_2O_5 (percent)	Remarks
5079	5.0	0.04	0.10	Includes 3 inches hydrocarbon ore at floor.
5080	4.2	0.02	0.03	Very sparse hydrocarbons.
5081	4.0	0.34	1.23	Little carnotite, many large hydrocarbon grains.
5082	3.2	0.24	0.52	Many hydrocarbon grains.
5083	2.0	0.32	0.46	" " "
5084	3.0	0.41	1.70	Hydrocarbon ore.
5085	4.4	0.28	0.67	Includes 1.5 feet hydrocarbon ore, some carnotite.
5086	4.4	0.05	0.07	Includes about 6 inches of hydrocarbon ore.
5087	1.5	0.51	1.24	Includes 5 inches of hydrocarbon ore but considerable carnotite is in remainder of sampled rock.

1/ Analyses in percent U_3O_8 recalculated to percent uranium.

Ore bodies at the North Temple workings

Deposits of uraniferous hydrocarbon predominate over carnotite deposits at the North Temple workings. Grains of asphaltic hydrocarbon from one-sixteenth of an inch to 1 inch in diameter are incorporated in friable sandstone. A few of these large grains of asphaltite are pellet-form with botryoidal surfaces; some of the asphaltite is irregular-shaped blebs. The grains have the vitreous lustre and the conchoidal fracture of coal, occur in lenticles in the current-bedded friable sandstones, and, although a detailed examination was not made, they appear to lie in the sandstone-mudstone rock unit. They probably constitute the lenticular, ellipsoidal ore bodies that, according to Hess (Hess, 1933, p. 456) are as much as 100 feet long, 20 feet broad, and 8 feet thick and which he characterized as erratic in nature and variable in size. The shape seems to be the result of weathering, which proceeding from the outside inward, leaves cores of comparatively unchanged material in rounded forms.

Other deposits

Since the completion of field work in 1947 the writer examined briefly other uranium deposits associated with hydrocarbons on the western side of the San Rafael Swell. In the deposits visited on the Lone Tree, Dalton, Dexter, and Lucky Strike groups of claims, uranium ore deposits were seen in cross-bedded sandstones, or conglomeratic sandstones near the base of the Shinarump conglomerate. At the Lone

Tree and Dexter deposits, the dominant ore mineraloids are carbonized wood, and hard, lustrous, botryoidal pellets of hydrocarbon. Secondary uranium minerals resembling meta-torbernite and paraschoepite are sparse on the rock surfaces; carnotite is not abundant. The ore bodies are relatively small pods from a few feet to about 50 feet long and no more than 5 feet thick. The containing rock is not notably bituminous, although nearby sandstones in the underlying Moenkopi formation were in places impregnated with bitumen, nor is the rock friable as is the host sandstone in the Temple Mountain district. The highly radioactive pellets commonly, but not invariably, occur near carbonized plant debris in cross-bedded, bituminous, or non-bituminous sandstone, at or near the base of the Shinarump conglomerate, although they were also observed in gray-green mudstone of the uppermost Moenkopi formation sparsely coated with secondary uranium minerals.

The deposit examined on the Lucky Strike group of claims resembles the Lone Tree and Dexter deposits except that, (1) the ore is in a cross-bedded sandstone that is stained gray by impregnating bitumen, and (2), the highly radioactive pellets are sparse, although irregular-shaped blebs of asphaltite are common. At all of these deposits, chert pebbles were noticed that illustrated various stages of replacement by highly uraniferous, massive asphaltite.

Deposits of uraniferous hydrocarbons and carnotite have been found by E. P. Beroni and Frank McKeown of the U. S. Geological Survey in the Chinle formation at the south end of the South Rafael Swell (Wyant, Beroni, and Granger, 1952). Highly uraniferous, botryoidal pellets, secondary uranium hydrates, sulfates, and carbonized plant fragments were seen by the writer in basal sandstones of the Shinarump conglomerate at the Oyler mine, Capital Reef, Utah, and at the Oak Creek No. 1 prospect east of Boulder Mountain, Wayne County, Utah. The carnotite deposits described by Boutwell (1904, 1905) and Hess (1913) in the canyon of the San Rafael river on the east side of the San Rafael Swell are in the Morrison formation associated with carbonized plant fragments; Hess observed some quartz veins and small joints in the deposits.

According to Heaton (1937) helium constitutes 1.31 percent of the natural gas in the Woodside dome at the northeast end of the San Rafael Swell (Gilluly, 1929, pp. 128-130). The helium, according to Rogers (1921) and Gott and Hill (1950), is probably of radiogenic origin although the source and mode of occurrence of the parent radioactive material is unknown.

Summary of the characteristics and interrelationships of the ore minerals and mineraloids

The relationship among the uraniferous, solid hydrocarbons and between them and the nearly non-uraniferous impregnating bitumen, and the relationship between the uraniferous hydrocarbons and carnotite, as well as the mode of occurrence of these ore minerals and mineraloids are of fundamental importance in understanding these deposits. In the following section the observations pertinent to these problems are summarized.

The nearly non-uraniferous character of the impregnating, viscous bitumen is illustrated by the analyses previously tabulated (table 2). The negligible uranium content of the bituminous rock is in striking contrast to the uranium content of the hydrocarbon ore (tables 1 and 3). The bitumen itself contains small amounts of uranium and other metals as shown by the recent work of Ralph Erickson. It probably migrated as a fluid into the more porous beds as indicated by its widespread occurrence in the more porous sandstones in the Temple Mountain district and throughout the San Rafael Swell in the Moenkopi, Shinarump, and Chinle formations. The bitumen, widespread though it is, does not occur in all ore bodies, and, therefore, is not an essential component of ore bodies; of the 21 ore bodies at Shinarump Mesa, eighteen are in non-bituminous rock, although in about half of these deposits bituminous rock is exposed nearby. Thin films of secondary uranium minerals do not stain the surface of bituminous rock unless the rock also contains some uraniferous, solid hydrocarbon.

The solid uraniferous hydrocarbons comprise grains, interstitial blebs, botryoidal pellets, and veinlike masses of asphaltite; and grains of carbonized vegetal matter. So far as known they are confined to the Shinarump conglomerate in the Temple Mountain district except in or near zones of altered rock.

Concentrations of the uraniferous asphaltite grains with associated irregular-shaped blebs of asphaltite conform to the bedding planes of closely-spaced current beds that may be truncated by beds lithologically similar except for the sparseness of asphaltite. The grains of asphaltite conform in degree of sphericity and, generally, in size to the accompanying quartz grains, although at the North Temple workings some grains as much as 1 inch in diameter were seen in a medium-grained sandstone; some are indented by quartz grains; their removal leaves a void in the rock. These grains are most abundant within the more friable, richer ore beds, or associated with humic grains near carbonized logs or large fragments of carbonized plant debris.

The irregular-shaped blebs of uraniferous asphaltite resemble the grains of asphaltite in their black color, relative hardness, opaqueness, vitreous lustre, and conchoidal fracture. So far as known, they differ physically from the granular asphaltite only in shape which is determined by the space between quartz grains. Inasmuch as the two types of asphaltite were not analyzed separately, their relative metal contents and chemical composition are not known. The irregular blebs are more abundant and widespread than the other types of uraniferous hydrocarbon; they occur in all hydrocarbon ore bodies in interstices between clastic grains. They appear to conform to the bedding of friable current-bedded sandstone.

The botryoidal pellets of uraniferous hydrocarbon observed in the roof of the adit examined in the North Temple workings stud fracture surfaces. When broken they resemble in appearance the granular or bleblike asphaltite, and are distinguishable only by their botryoidal surface. Botryoidal pellets of asphaltite are not common ore mineraloids in the Temple Mountain district, although more may be found with additional study. Similar highly radioactive pellets were observed in three uranium deposits on the west side of the San Rafael Swell, commonly but not invariably associated with carbonized plant fragments in well-cemented conglomeratic sandstone near the base of the Shinarump conglomerate, but also in mudstones in the uppermost part of the Moenkopi formation; these mudstones were coated with secondary uranium minerals resembling metatorbernite and paraschoepite. Similar pellets stud fractures that are also coated with copper carbonates at Frey Point, White Canyon. The mode of occurrence of these pellets on fracture surfaces, in sandstone, and in mudstone, with or without close spatial association with other hydrocarbons, is markedly different from the mode of occurrence of the granular and bleblike uraniferous hydrocarbons. They resemble the characteristic shape of thucholite (Ellsworth, 1928; Spence, 1930).

The massive, veinlike type of uraniferous hydrocarbon was observed filling bedding plane fractures and porous beds; according to Hess (1922, p. 274) nearly vertical fractures of iron oxide, at the upper edge of the Chinle formation in the zone of altered rock at Temple Mountain, are filled with globular and ellipsoidal masses of asphaltite. This description could relate the botryoidal blebs to the massive asphaltite. Webber (Murphy, 1944) observed crystal-lined vugs filled with asphaltite in the alteration zone. In the Through adit, South Temple workings, the massive hydrocarbon is closely associated with large granules of asphaltite, and in places is coated with zippeite. Specimens show a distinctly globular or ellipsoidal surface. It should be noted here that massive asphaltite replaced chert pebbles in deposits on the west side of the San Rafael Swell.

Grains of uraniferous, carbonized vegetal matter (humic hydrocarbon) occur as rounded, clastic fragments of the ore beds, and are commonly associated with asphaltite grains and blebs, with which they may easily be confused.

That carnotite and related vanadates are closely related to uraniferous hydrocarbon is clearly indicated. Wavy bands of carnotite-rich rock commonly border hydrocarbon ore bodies; thin films of carnotite were observed coating asphaltite grains and blebs; wherever carnotite was found, beds of uraniferous hydrocarbon were discovered nearby. Sparse uraniferous grains and blebs of hydrocarbon were observed in the pits of porous, carnotite-bearing sandstone in the roll at the South Temple workings. Carnotite and related vanadates are secondary minerals as indicated by their presence as thin films that stain rocks and coat fracture surfaces. From hand specimens selected to represent different types of ore, six mineralogically clean separates were prepared and together with two ore samples were analyzed. According to L. F. Rader, Jr., Trace Elements Section Denver Laboratory of the U. S. Geological Survey, the analyses (table 4) show in general that carnotite is deficient in uranium decay products whereas the uranium in the hydrocarbons is essentially in equilibrium. This relationship between radioactivity and uranium content suggests that the carnotite is relatively younger than the uraniferous hydrocarbon.

These characteristics and relationships among the ore minerals and mineraloids must be accounted for in any theory of origin of the Temple Mountain ores.

Table 4.--Radiometric and chemical analyses of selected samples, Temple Mountain district, Emery County, Utah

Laboratory number	Field number	Description	Equivalent uranium (percent)	Uranium (percent)	Equilibrium ratio (percent eU/U)
		Carnotite samples			
23453	UTM-20-47	Carnotite (?) in porous pitted sandstone; Main adit, South Temple workings.	0.95	2.01	0.47
23454	UTM-40-47	Carnotite (?) in clay, with gypsum, halotrichite; North adits, Shinarump Mesa.	13.0	34.15	0.38
23455	UTM-14-47	Carnotite (?) scraped from fracture surface of lime-pellet conglomerate (sparse hydrocarbon); top of section SH-8, Shinarump Mesa.	4.0	18.38	0.22
23456	UTM-2-47	Carnotite (?) coating quartz and penetrating clay galls, picked from hydrocarbon carnotite ore; North adits, Shinarump Mesa.	0.5	0.57	0.88
		Asphaltite samples			
23457	UTM-3-47	Asphaltite and some quartz grains picked from vein of massive asphaltite; North adits, Shinarump Mesa.	2.5	5.04	0.49
23459 1/	UTM-38-47	Large asphaltite grains picked from massive asphaltic sandstone; North Temple workings.	0.56 2/	0.43	1.3
23460 1/	UTM-2-47	Asphaltite blebs picked from hydrocarbon carnotite ore; North adits, Shinarump Mesa.	0.3 3/	0.63	0.48
23461	UTM-1-47	Massive asphaltite and quartz grains from seam at west point Temple Mountain; sample "as is", not a separate.	3.6 2/	2.24	1.6

1/ Samples reanalyzed.

2/ Reanalysis shows equivalent uranium content less than that tabulated, and uranium essentially in equilibrium.

3/ Reanalysis shows equivalent uranium content greater than that tabulated, and uranium essentially in equilibrium.

ORIGIN OF THE DEPOSITS

The genesis of the uranium ores in the Temple Mountain district is a complex problem and still subject to controversy. The relationships between the several types of hydrocarbon are particularly complicated by the lack of useful criteria to use in distinguishing among them; their composition and exact physical nature are but poorly known, and they apparently change physically under different environments. The conclusions regarding these controversial matters are drawn from the study of three local areas, supplemented by some additional study of areas outside the district, but are tentatively applied to the entire Temple Mountain district; they should, therefore, be regarded as preliminary and subject to change as new data are discovered. An understanding of the genesis of the Temple Mountain ores undoubtedly would be important in determining the genesis of other, allied ore deposits both in the San Rafael Swell and, perhaps, also elsewhere in the Colorado Plateau. Accordingly, the problems of genesis are treated fully, perhaps more fully than the data justify.

Hess (1922, 1933) observed the difference between the detrital asphaltite grains and the impregnating bitumen but believed they had a common origin; he also noted that the asphaltite is richer in uranium and vanadium than the bitumen. He believed that the hydrocarbons were derived from older deposits, such as tar seeps, and were deposited while soft (bituminous, according to the writer's usage) with other detrital material. Hess thought that the uranium and vanadium had been leached from older rocks, such as weathered uraniferous veins, carried in solution, and precipitated by bitumen in a transitory sea or lake. By absorbing metals some of the bitumen was thereby transformed to hard, uraniferous asphaltite. He noted the effects of hydrothermal activity at Temple Mountain but relegated to it the minor role of altering the previously formed deposits and transporting ore minerals upward and outward; he first thought the ore was pitted by the weathering of the asphaltite, but later (1933) attributed the pits to the leaching of the asphaltite by hot water.

Murphy (1944, p. 5) did not distinguish between the two types of hydrocarbon but noted as follows:

> "In places, there can be little doubt as to the original sedimentary character of the bitumen; in other places, ... [there has been] a selective impregnation of the sandstone by asphaltitic material....."

Webber (in Murphy, 1944) ascribed a major role to hydrothermal solutions which he thought introduced the hydrocarbons, uranium, vanadium, and other metals with sulfur and sulfates. He believed that the most strongly bituminized areas contain the most uranium and vanadium, and that the hydrocarbons were the last materials introduced into the rocks. He believed that the rock was altered by solutions of epithermal type and probably close to the telethermal end of the epithermal temperature and pressure range. The rock was reconstituted by the recombination of iron, silica and calcite, with some added sulfates and other material, that were dissolved by the solutions.

Stokes (1947) ably summarized the problems and concluded that the field evidence indicates that the uranium and vanadium minerals in the

Temple Mountain district may have been precipitated by bitumen or asphaltite from ground water that circulated through porous channel sandstones in the Shinarump conglomerate. He was undecided as to whether the hydrocarbons are syngenetic or epigenetic but noted that petroleum source beds are known in the region and believed the general occurrence of asphaltite and bitumen may imply that the hydrocarbons are residues from migrating crude oil. Stokes agreed with Hess that the role of the hydrothermal activity was minor, in that previously-formed deposits were altered; the solutions probably transported pre-existing uranium and vanadium minerals into other nearby rocks. He stated, however, that if traces of ore metals were found in other areas of altered rocks in the district, the possibility of an igneous source for the ore metals would have to be considered. In this connection it should be noted that Hess reported no radioactivity in the warm springs at the north end of the San Rafael Swell; springs that are now depositing sulfur.

At the conclusion of the field work in 1947, the writer thought that the uraniferous hydrocarbon was mostly carbonized wood fragments and asphaltite which were introduced as uraniferous detrital constituents of the Shinarump sands; the viscous impregnating bitumen was thought to be non-radioactive, and to have been introduced, by migrating crude oil, into the porous rocks after the development of the San Rafael anticline. The uranium and other metals were thought to have concentrated residually by oxidation and devolatilization of the original petroleum that fed the tar seeps. The uranium in the carbonized wood was thought to have been introduced by uraniferous ground waters which also leached the ore metals from asphaltite and redeposited some of them as carnotite.

Since 1947 the laboratory study of specimens demonstrated the presence of several types of uraniferous asphaltite, necessitating a re-evaluation of original field notes. Also new discoveries were made of uranium associated with hydrocarbons. Some of these in the Capital Reef and Circle Cliff areas southwest of the San Rafael Swell were studied by the writer in 1950. Others were examined briefly in 1952, when Shinarump Mesa and Temple Mountain were also revisited. New data were also contributed by Garland B. Gott and Ralph L. Erickson who have continued actively investigating the uraniferous hydrocarbons. Finally, a period of reflection, and the stimulating and crystallizing conversations with Gott have changed some of the writer's ideas concerning the genesis of the Temple Mountain ores.

The data obtained by the earlier workers, by the writer, and by more recent investigators indicate that the genesis of the uranium ores of the Temple Mountain district is complex. The most important factors to be considered in understanding the genesis of the ores are, in the writer's present opinion, (1) the distinction between, interrelationships of, mode of introduction of, and localization of the hydrocarbons, (2) the relationship of carnotite and related vanadates to uraniferous hydrocarbons, (3) the source and time of introduction of the uranium and vanadium, (4) the nature and role of hydrothermal processes, and (5) the relationship of the Temple Mountain deposits to other uranium deposits of the region and to helium-rich natural gas.

The rounded grains and macerated fragments of carbonized wood (humic hydrocarbon) are clearly original clastic components of the rock; inasmuch as some fragments are not now uraniferous, probably none were uraniferous when deposited.

The physical characteristics, difference in metal content, spatial relationships of the deposits, and mode of occurrence of the solid uraniferous asphaltites and of the viscous impregnating bitumen suggest that there is a valid distinction between them. That the distinction implies a different origin is questionable. The bitumen undoubtedly migrated into the porous sandstones as a liquid hydrocarbon, and was probably localized after regional deformation, but before the local deformation and rock alteration, by impervious rock dams and structural terraces. Because the bitumen impregnates porous sandstones in several formations throughout the San Rafael Swell and because wherever sampled and analyzed the ash contains uranium and other metals in about the same relative proportions as do unashed samples of solid uraniferous asphaltites _/, a bitumen probably is genetically related to the solid hydrocarbons; as discussed below, bitumen probably represents an intermediate stage in the process of transformation of crude oil into asphaltite.

_/ Erickson, Ralph L., Informal communication.

All types of the solid, uraniferous asphaltite resemble each other in physical appearance on broken surfaces and in their radioactivity, but the chemical characteristics are yet incompletely known. The blebs and grains differ in mode of occurrence from the pellets and massive, veinlike types. Almost all characteristics of the grains of solid, uraniferous asphaltite, including physical nature, metal content, close association, and concentration in beds showing stratigraphic control are also common to the blebs of solid, uraniferous asphaltite; their only difference is shape. These common characteristics suggest that the grains and blebs shared a common origin. The most obvious explanation is that asphaltic hydrocarbon was deposited, as Hess suggested (1922, 1933), as detrital grains contemporaneously with the accumulating sands; the grains were localized in relatively slow-moving water with quartz grains in or on the margins of the Triassic stream channels. Under this interpretation of the data a slight difference in hardness would allow the softer fragments to flow on compaction and fill granular interstices, or even to coalesce around quartz grains as tar does on modern beaches on the California coast.

Both the botryoidal pellet and the massive, veinlike-type of solid, uraniferous asphaltite have similar surface shapes and, in places, line or fill fractures; therefore, they could hardly be detrital in origin. They probably were formed much later than the asphaltic grains and blebs, from which they may have been derived, although they could also be derived from the viscous bitumen. They do not necessarily show close affinity for either other types of asphaltic hydrocarbon or for bitumen, and the process of pellet growth in solid rock is unknown.

The equilibrium ratio of samples of carnotite and asphaltite (table 4) suggest strongly that the carnotite is younger than and, therefore, may have been derived from, the uraniferous asphaltite. This genetic relation is supported by the field evidence and the petrographic study of ore specimens; some of the carnotite, related vanadates, and uranium salts appear definitely to be secondary minerals derived from asphaltite. Whether the carnotite in the "roll" of carnotite-bearing, porous, pitted sandstone at the Main adit, South Temple workings, is derived from asphaltite is open to query although the equilibrium ratio of sample UTM 20-47 (table 4) and the presence of thin films of asphaltite in pits in the pitted sandstone strongly support the genetic relation. It is, of course, possible that carnotite may have been the first uranium-vanadium mineral deposited, and that it was localized by the asphaltite. If such were the case, however, the asphaltite might be expected to show peripheral rings of greater radioactivity, or at least a gradual decrease in uranium content inward from the surface of the impervious asphaltite. Autoradiographs of two asphaltite specimens show that the radioactivity is evenly distributed throughout the asphaltite.

Data are meagre concerning the source and time of introduction of uranium, vanadium, and other metals into the hydrocarbons, and the answers are, therefore, speculative. The transformation of liquid bitumen into asphaltite in Shinarump time by adsorption or absorption of metals held in solution in transitory lakes, as postulated by Hess (1933, p. 276), might account for the even distribution of radioactivity in asphaltite, and would also explain the relative scarcity of metals in what is now bitumen. Preliminary investigation by Gott _/ suggests

_/ Informal communication.

that metals concentrate in the residual or heavier fraction of fractionating crude oil, whereas no data known to the writer suggest that bitumen is transformed into asphaltite by absorbing or adsorbing metals. What is now known of the conditions prevailing during Shinarump time, or for that matter, during Triassic and Jurassic time, however, suggests that lakes were not characteristic; moreover, the theory would not explain the metal content nor the widespread distribution of the impregnating bitumen.

Neither the magmatic source of the metal-bearing hydrocarbons in "mineralization stoping pipes" (Webber, in Murphy, 1944), nor the gradual adsorption or absorption by hydrocarbons of metals in ground water moving through porous sandstone channels (Stokes, 1947) are, in the light of current knowledge, adequate explanations; under the magmatic theory neither the metal content nor distribution of impregnating bitumens are accounted for; furthermore, the alteration appears to have taken place in the present erosion cycle. Neither the widespread impregnating bitumens, nor the uniform distribution of radioactivity in asphaltite and of metals in bitumen is explained satisfactorily by the ground water theory.

The writer agrees with Hess and Stokes that the role of hydrothermal activity was probably a minor one; the hydrothermal activity and consequent rock alteration took place after much of the erosion of the San Rafael Swell, perhaps in the present erosion cycle, and probably much later than the introduction of the solid and fluid hydrocarbons. The hot solutions, commonly believed to be a late stage of deep-seated igneous intrusion, probably leached carnotite, bitumen, asphaltite, and other metals from their original positions and carried them outward and upward into the rocks in and adjacent to fault and fracture zones. The massive, veinlike type of asphaltite and, possibly, some of the botryoidal pellets derived from pre-existing hydrocarbons were forced into fractures when the temperature dropped or the solutions lost force or stagnated (Webber, in Murphy, 1944). As the temperature lowered, bitumen permeated the altered rock. If the hydrothermal solutions traversed rock containing uranium and vanadium minerals, or if the magmatic solutions themselves contained uranium and vanadium, the solutions might have added, of course, to the metal content of the bitumen and asphaltite already present in the Shinarump conglomerate.

The effects of such hydrothermal action might extend much farther from the source of heat than do the obvious faults, and the bleached and reconstituted rocks. Heated ground water would accelerate chemical-physical reactions at a considerable distance from the locus of heat, and might have leached some of the asphaltite and bitumen from the ore bodies at Shinarump Mesa and Temple Mountain resulting in the friable, or pitted sandstone, now characteristic of these ore bodies, but not, so far as known, characteristic of ore bodies in other deposits in the San Rafael Swell. It is also possible that these reactions would result in the formation of ore bodies. Certainly the volatile portion of hydrocarbons would be more readily affected than would ground water or rocks.

The apparent lack of zones of structurally and chemically altered rock in or near other deposits of uraniferous hydrocarbon in the San

Rafael Swell seem to indicate that the botryoidal pellets are formed in other ways than under hydrothermal conditions; they also seem to indicate, for that matter, that hydrothermal activity is not essential to the formation of a deposit of uraniferous hydrocarbon. Similarly, the occurrence of what may be asphaltized wood at several localities in the Colorado Plateau, with or without other petrolific hydrocarbons, seems to indicate another non-hydrothermal process the exact nature of which is unknown. Both the growth of pellets and the asphaltizing of wood may be part of the interaction of the processes of polymerization, hydrogenation, volatilization, and oxidation of both humic and petrolific hydrocarbons under the influence of alpha-ray bombardment, and perhaps influenced also by heat; much more study is clearly needed.

The occurrence of helium-bearing gas and of the uraniferous asphaltite deposits in the San Rafael Swell suggests that they may be related in origin. Their common demoninator is uraniferous crude oil.

If carnotite is derived from uraniferous asphaltite, as is strongly suspected, there may be a genetic relationship between carnotite ore bodies in the Morrison formation in the San Rafael Swell and uraniferous crude oil. Their common denominators are ground water or gaseous hydrocarbons, or both.

The foregoing interpretation of the known data, and the presence of uraniferous petrolific hydrocarbons, helium, and secondary carnotite in the same anticlinal structure suggests strongly that a metalliferous petroleum was the source of both ore metals and hydrocarbons. This means that very weakly uraniferous petroleum migrated into the rock under conditions normal to the accumulation of oil (Stokes, 1947; Gott, Wyant, and Beroni, 1952). With the loss of volatiles through oxidation or polymerization, bitumen and, ultimately, asphaltite would form. The uranium, vanadium, and other metals may have remained with the heavier fraction and thereby been concentrated residually.

If the granular and bleblike uraniferous asphaltite are syngenetic and their localization controlled by sedimentary processes, then the crude oil was formed at least by Shinarump (Middle or Late Triassic) time in order to feed Shinarump tar seeps; a new period of oil migration after the arching of the San Rafael anticline would have to be postulated in order to furnish the impregnating bitumen.

If the detrital characteristics of the granular and bleblike asphaltite, their sedimentary control, and their common spatial dissociation with bitumen can be explained otherwise, then the uraniferous crude oil would need to be introduced only once—after the formation of the anticlinal structure. The bleblike asphaltite, according to all observers, closely resembles "dead oil", or the oxidized residue of liquid bitumen. Its localization and control could be due simply to greater original porosity of the containing sandstones which was controlled by sedimentary process at the site. The granular asphaltite may represent the replacement or reconstitution of other clastic components of the rock, such as open-lattice clays _/, or carbonized plant

_/ Stokes, W. L., Informal communication.

fragments, or may represent the growth in place of asphaltite grains resembling the botryoidal pellets. The common lack of close spatial association between bitumen and asphaltite is not as easily explained. The more volatile bitumen may have moved on after emplacement in response to increase of impelling pressure owing to the heating and fractionating effects of nearby hydrothermal activity, or the release of restraining pressure, or flushing by ground water. The lack of more obvious surficial effects of hydrothermal activity in deposits in other areas than the Temple Mountain district need not necessarily preclude the presence of concealed sources of heat. The proof or disproof of these suppositions is lacking, but the possibilities are sufficiently attractive to warrant more study.

If the detrital nature and sedimentary control of the ores in the Shinarump conglomerate are thus explained, the transformation of very weakly uraniferous crude oil to highly uraniferous asphaltite must pass through intervening stages depending upon the content of volatiles, thus accounting for the nearly non-uraniferous, viscous, impregnating bitumen. This relation of metal content to volatile content would also seem to warrant more study, in the course of which an explanation might be sought for the apparent lack, in or near the bituminous sandstones of the Moenkopi formation, of solid, highly uraniferous asphaltites, or of moderately uraniferous petrolific hydrocarbons intermediate between bitumen and asphaltite.

The history of the development of the uranium deposits in the Temple Mountain district probably has been as follows:

(1) Regional uplift or westward withdrawal of the lower Triassic sea; during middle (?) Triassic time the Shinarump conglomerate gradually accumulated, from southeast to northwest, as a gravel blanket that bevelled the underlying rocks. During most of the process of pedimentation the water in the changing stream channels moved swiftly over the area, but locally slowed, permitting the deposition of fine-grained sediments and of clean, porous sandstones along the margins of the major stream channels or where tributary streams flowed into relatively quiet water.

(2) Cementation and induration of the sediments and the deposition and induration of Jurassic and Cretaceous sediments.

(3) Regional uplift followed by doming, resulting in the formation of the San Rafael anticline, accompanied by the development of faults trending northwestward, of local structural terraces at Shinarump Mesa and Temple Mountain, and of the Woodside dome.

(4) Migration of liquid, weakly metalliferous crude oils from Paleozoic and Mesozoic (?) source rocks and their entrapment in the permeable channel sandstones by terraces, domes, or impervious rock dams; possibly accompanied by replacement of grains of humic hydrocarbon and of clay. At this time helium started to accumulate in the Woodside dome, and the hydrocarbons to fractionate and polymerize; at this time also the circulation of ground water in porous channels was intensified and some ore metals may have been extracted from hydrocarbons.

(5) Erosion of the Swell, allowing oxidation, devolatilization, and continued polymerization of hydrocarbons.

(6) Local hydrothermal activity at Temple Mountain and elsewhere in the Swell accompanied, and probably preceded, by faulting and fracturing, and the slumping of overlying rocks into underlying solution cavities. The asphaltite, bitumen, and carnotite were removed from the invaded rocks and redeposited nearby in permeable host rocks; closely adjacent and peripheral to the heat source hot waters leached asphaltite from the ore bodies, and some of the contained ore metals were redeposited as carnotite rolls; at great distances from the heat some asphaltite was not leached, but more volatile bitumen moved in response to the pressure of heating.

(7) Continued erosion of the Swell and the continued modification by meteoric water of previously formed uranium deposits.

OUTLOOK AND SUGGESTIONS FOR PROSPECTING

In 1947 the Temple Mountain district was inactive because existing mills were unable to treat asphaltite ores. Since 1947 methods of treatment have been developed and the district is now (1952) a steady producer. Uranium-vanadium ore will probably continue to be mined from the district for some time. Probably most of the ore will be mined from Temple Mountain proper and the North and South Temple workings, although a small amount of shipping-grade ore could be mined from Shinarump Mesa.

The application of the following characteristics of ore bodies would aid mining, exploration, and prospecting in the district: (1) The asphaltite ore, except at Temple Mountain proper where it has been modified, occurs in friable sandstone lenses within the sandstone-mudstone rock unit of the Shinarump conglomerate; (2) asphaltite is highly uraniferous whereas bituminous sandstone is not; (3) carnotite is generally closely associated with asphaltite; (4) both carnotite and asphaltite ore bodies in the Shinarump are in friable sandstone in channels which, in general, trend northwestward; (5) the carnotite, associated with carbonized logs in the chert-pebble conglomerate at the base of the Shinarump is probably of less importance than ore stratigraphically higher in the formation.

In mining, the recognition of the Triassic channels in which the deposits are localized, should be of use. Such channels are best recognized if seen in a plane perpendicular to their trend. The thicker Shinarump sandstone channels should be traced and examined. The thick sandstone channel that underlies Temple Mountain probably extends farther to the southeast under the Reef and can only be prospected by drill holes.

In prospecting for uranium-vanadium deposits, porous sandstone lenses in the Chinle and Moenkopi formations, as well as those in the Shinarump conglomerate should be searched for carnotite and uraniferous asphaltite; in the search full use should be made of the Geiger counter. Zones of hydrothermal alteration that can be recognized by the bleaching, fracturing, silicification, and local downwarping of the rocks should be carefully examined.

Gilluly and Reeside (1928, pp. 84, 85, 90, 91, 93, 94, 96) have described detrital asphalt in and near the Sinbad limestone member of the Moenkopi formation, as well as in the Shinarump conglomerate; (1) in

Sinbad limestone north from the head of Black Box Canyon, (2) in sandstone overlying the Sinbad limestone, at the mouth of Red Canyon, (3) in sandstone below the Sinbad limestone on the cliffs south of the Muddy River, (4) in Shinarump conglomerate on the south side of Sawtooth Butte, and (5) with carnotite in Saddle Horse Canyon on the western edge of the Swell.

SUMMARY AND CONCLUSIONS

Deposits of uraniferous hydrocarbons of asphaltic and humic type and carnotite deposits occur in the Shinarump conglomerate at Shinarump Mesa and adjacent areas in the Temple Mountain district. It is now thought that the uraniferous asphaltite is the residue of weakly metalliferous crude oil introduced into the more permeable sandstones after the formation of the San Rafael anticline and that the ore metals concentrated residually in the residual fractions. The carnotite was probably derived from the asphaltite by ground-water leaching. Both types of ore deposits have been locally altered at Temple Mountain by later hydrothermal solutions and are now being modified by meteoric water. The ore bodies at Shinarump Mesa and the South and North Temple workings are localized in the more porous sandstone of the sandstone-mudstone rock unit in the lower part of the Shinarump conglomerate and thus controlled indirectly by sedimentary processes. Ore bodies at Shinarump Mesa are relatively small and pod-like, but the better ones contain more than 0.1 percent uranium. Ore bodies elsewhere in the district are larger, and contain more ore metals.

Bitumen, containing a small amount of uranium and other metals, impregnates permeable beds throughout the San Rafael Swell and represents a fraction of the original crude oil.

It is concluded that a study of the San Rafael Swell, of the petroleum source beds, of the processes effecting change in naturally occurring hydrocarbons, and of the effects of Tertiary intrusives in the broad region surrounding the Colorado Plateau might contribute data pertinent to the relations between carnotite ores and asphaltic ores.

BIBLIOGRAPHY

Baker, A. A., 1946 (1947), Geology of the Green River Desert--Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U. S. Geol. Survey Bull. 951, 122 pp.

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

Chesterman, C. W., and Main, F. H., 1947, Reconnaissance investigations for trace elements in Utah, Colorado, Nevada, California, and Oregon: U. S. Geol. Survey Trace Elements Investigations Rept. 24.

Ellsworth, H. V., 1928, Thucolite, a remarkable primary carbon mineral from the vicinity of Parry Sound, Ontario: Am. Mineralogist, vol. 13, no. 8, pp. 419, 438.

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

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, pp. 61-110.

Gott, G. B., and Hill, J. W., 1950, Radioactivity of some oil and gas fields in southeastern Kansas: U. S. Geol. Survey Trace Elements Investigations Rept. 121.

Gott, G. B., Wyant, D. G., and Beroni, E. P., 1952, Uranium in black shales, lignites, and limestones in the United States, in Selected papers on uranium deposits in the United States: U. S. Geol. Survey Trace Elements Investigations Rept. 168, pp. 49-56.

Heaton, R. L., 1937, Stratigraphy versus structure in the Rocky Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 21, no. 10, p. 1256.

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

__________, 1914, Radium, uranium, and vanadium in Mineral Resources 1914, part 1, p. 944.

__________, 1922, Uranium-bearing asphaltite sediments of Utah: Eng. and Min. Jour., vol. 114, no. 7, pp. 272-276.

__________, 1925, New and known minerals from the Utah-Colorado carnotite region: U. S. Geol. Survey Bull. 750-D, pp. 63-78.

________, 1933, Uranium, vanadium, radium, gold, silver, and molybdenum sedimentary deposits, in Ore deposits of the western States (Lindgren volume): Am. Inst. Min. Eng., pp. 456-459.

Locke, Augustus, 1926, The formation of certain ore bodies by mineralization sloping: Econ. Geol., vol. 21, pp. 431-453. Reference in Webber, B. R., in Murphy, F. M., 1944, Field survey of Temple Mountain district, San Rafael area, Utah, manuscript report: Contractor for the Manhattan Engineer district.

Murphy, F. M., September 1944 (unpublished), Field survey of Temple Mountain district, San Rafael area, Utah, manuscript report: Contractor for the Manhattan Engineer district.

Rogers, G. S., 1921, Helium-bearing natural gas: U. S. Geol. Survey Prof. Paper 121, 113 pp.

Spence, H. S., 1930, A remarkable occurrence of thucholite and oil in a pegmatite dyke: Am. Mineralogist, vol. 15, no. 11, pp. 499-520.

Stokes, W. L., 1947, Stratigraphy of the Shinarump conglomerate and its possible bearing on the origin of the vanadium deposits at Temple Mountain, Emery County, Utah: U. S. Geol. Survey unpublished report.

________, 1950, Pediment concept applied to Shinarump and similar conglomerates: Geol. Soc. Am. Bull., vol. 61, no. 2, pp. 91-98.

Wyant, D. G., Beroni, E. P., and Granger, H. C., 1952, Some uranium deposits in sandstone, in Selected papers on uranium deposits in the United States: U. S. Geol. Survey Trace Elements Investigations Rept. 168, pp. 42-48.