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UNITED STATES ATOMIC ENERGY COMMISSION

INTERPRETATION AND EVALUATION OF THE
URANIUM OCCURRENCES NEAR GOODSPRINGS,
NEVADA

Final Report

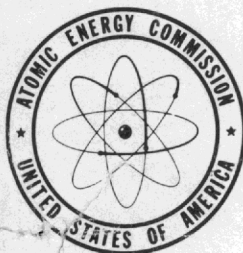
By
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Final Report
on
INTERPRETATION AND EVALUATION
OF THE
URANIUM OCCURRENCES NEAR GOODSPRINGS, NEVADA

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December 31, 1954.

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ABSTRACT

The uranium occurrences near Goodsprings, Clark Co., Nevada, are divided into two distinct types which differ from each other in geographic distribution, localization of mineralization, mineralogy and origin. None of the known deposits is of present commercial significance and therefore this study emphasizes the genetic rather than the economic aspects.

East of Goodsprings in an area at least 4 by 16 miles and in a single prospect 2 miles north of Goodsprings carnotite is found as thin films and specks on fractures in late Paleozoic sedimentary rocks and in Tertiary and later tuff and gravel. The carnotite was probably deposited above the water table from groundwater that derived uranium and vanadium from a tuff which formerly covered the region. The tuff remnants carry about 10 ppm uranium, or about 2 1/2 times that of the average granite. Structural control of groundwater circulation appears to be the principal feature in the localization of this mineralization.

Many of the base metal mines of the Goodsprings district exhibit anomalous radioactivity attributable to uranium and its decay products. Most commonly the radioactivity is localized by limonite, hydrozincite or chrysocolla. Secondary uranium minerals are found in 3 mines, but no primary uranium minerals have been identified. The radioactivity from these materials which are free from visible uranium minerals is attributed to the adsorption of uranium from solution by colloidal materials during the oxidation of the primary sulfide ore bodies. Laboratory studies show that the uranyl carbonate, uranyl hydroxide and uranyl ions are adsorbed by colloidal hydrous ferric oxide or basic zinc carbonate. Upon crystallization of the adsorbent, the uranium either is returned to solution or forms discrete uranium minerals. The source of the uranium is believed to have been a primary uranium mineral (presumably pitchblende) which was associated more closely with the primary copper and iron sulfides than with those of zinc and lead. The volcanic rocks which once covered much of the area possibly could have contributed small amounts of uranium to the oxidizing base metal ores, but this effect was probably of minor importance. No geographic limits of uranium mineralization could be established, but there is a tendency for the more western mines to have the better uranium showings.

INTRODUCTION

General Statement

This report is based on the field and laboratory studies of the uranium mineralization in the vicinity of Goodsprings, Clark Co., Nevada. The location of the region is shown in figure 1.

The uranium mineralization is readily classified into two types which differ from each other in localization, mineralogy and origin. The first type, discussed in Part I of this report, consists of wide-spread minor carnotite occurrences in otherwise unmineralized rocks which range in age from Pennsylvanian to Quaternary. The second type, intimately associated with the mines of the Goodsprings District, is the subject of Part II.

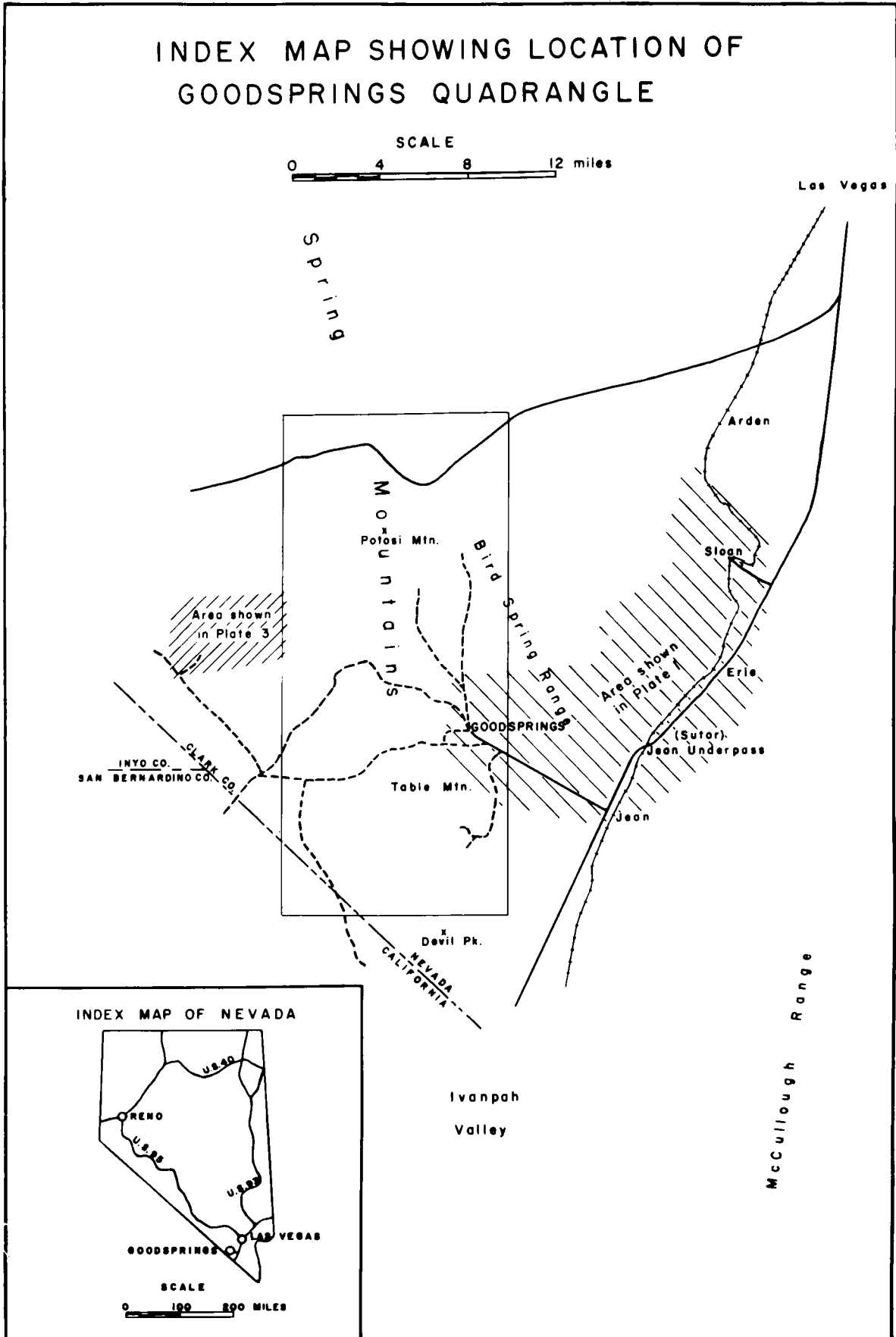
Five months during the summers of 1953 and 1954 were spent in field work which consisted principally of locating and sampling uranium occurrences. The field relations of these occurrences were studied; specimens and samples were collected; and two reconnaissance geologic maps were made in order to aid in the interpretation of the distribution of the uranium. Laboratory work included the identification of minerals and studies of their interrelations as well as extensive experimentation to determine the origin of the radioactivity of the oxidized ores.

This project was proposed and directed by Prof. Chas. H. Behre, Jr. and was sponsored by Columbia University under Contract AT(30-1)-1550 with the U. S. Atomic Energy Commission. The detailed field and laboratory studies reported here were carried out by Paul B. Barton, Jr., hereinafter referred to as the writer.

Acknowledgments

The writer was ably assisted in the field by Mr. Erlend Frederickson. Among those who visited the author in the field and offered interesting suggestions were Dr. D. F. Hewett of the U. S. Geological Survey, Dr. W. H. Bucher of Columbia University and Messrs. H. E. Nelson, E. E. Thurlow and D. C. Barrett of the Atomic Energy Commission. Mr. Leo Miller was of much assistance in the experimental adsorption work. Mr. T. G. Lovering of the U. S. Geological Survey has been helpful in the discussion of the radioactive limonites. The men engaged in mining, especially Messrs. R. E. MacDonald and R. Robbins of Goodsprings, readily gave assistance whenever requested. To all these, and to many others, I should like to express thanks.

Figure 1



Previous Work

General Geologic Setting

The Goodsprings Mining District has produced a considerable amount of zinc and lead during the past half century, though production is now almost nil due to present low metal prices. In addition to zinc and lead, small amounts of copper, silver, gold, platinum metals, cobalt, vanadium and uranium have been shipped. All of the mines of the district are relatively shallow; and, except for the Potosi mine, oxidized minerals form the bulk of the ore.

U. S. Geological Survey Professional Paper 162 by D. F. Hewett (1931) is by far the most comprehensive publication on this area. The present study has been greatly facilitated by the description of the stratigraphy, structure and mines in the Goodsprings Quadrangle given in that paper.

About 13,000 feet of sedimentary rock are exposed in the Goodsprings Quadrangle. These range in age from upper Cambrian through Jurassic(?). The stratigraphic column as modified after Hewett (1931) is shown on page 10. The pre-Tertiary sedimentary rocks have been greatly deformed by post-Jurassic folding, thrust faulting from the west and late normal faulting. The earliest igneous rocks are small granite porphyry intrusions along thrust zones. Tertiary volcanic rocks include rhyolitic to andesitic plugs, flows and tuffs and minor dikes and flows of basalt.

Throughout the area there is widespread alteration of limestones to coarsely crystalline, cream colored dolomite; this is especially prevalent near the ore deposits. Usually the dolomitization is confined to the massive beds lower than the Bird Spring formation.

Erosion has carved the area into mountains which rise as much as 5000 feet above the alluvium filled valleys. The present outlines of the ridges seem to be controlled by erosion along old faults and not by recent fault scarps.

This area has the typical desert climate of the southern Basin and Range province. Although climatological data are not available for Goodsprings, a reasonable estimate of temperature and rainfall may be obtained by comparing nearby points. The following data are from the U. S. Weather Bureau, Climatological Data, 1947:

Table 1

Station	Elevation	Average Temp		Average	Distance and
		July	January	Annual Ppt.	direction from
					Goodsprings
Kyle Canyon (Spring Mtns.) Nev.	7,150	65.3	-	-	32 miles NNW
Las Vegas, Nev.	2,033	86.5	45.4	4.70 in	29 miles ENE
Boulder City, Nev.	2,525	89.4	45.7	5.53 in	36 miles E
Searchlight, Nev.	3,445	84.1	44.2	8.36 in	38 miles SE

Stratigraphic Column of the Southern Spring Mountains
(modified after Hewett (1931))

Period	Formation member	Thickness (in feet)	Lithology
Quaternary			Unconsolidated gravels and fine sediment.
Tertiary		Several hundred	Volcanics and unconsolidated sediment
unconformity			
Jurassic (?)	Aztec	2100	Massive, cross-bedded sandstone.
Triassic	Chinle	1000 [±]	Red shale and sandstone.
	Shinarump	10-30	Conglomerate and sandstone.
	Moenkopi	750-950	Dolomite and red shale
unconformity			
Permian	Kaibab	300 [±]	Cherty limestone.
	Toroweap	250	Massive limestone with sandy beds at top
	Supai	1000-1100	Sandstone and red shale.
Penn.	Bird Spring	2500 [±]	Thin to thick-bedded limestone, dolomite, sandstone and shale.
Miss.	unconformity		
	Monte Cristo		
	Yellowpine	60-120	Massive ledge of dark limestone.
	Arrowhead	10-20	Thin-bedded limestone and shale.
	Bullion	185-300	Massive dark limestone, now largely dolomite.
	Anchor	65-400	Massive, cherty, gray limestone.
	Dawn	60-400	Thin-bedded dark limestone.
Devonian	Sultan		
	Crystal Pass	150-260	Very thin-bedded light gray limestone.
	Valentine	75-380	Light gray limestone and dolomite
	Ironsides	5-125	Massive dark dolomite.
Devonian(?) to Cambrian	Goodsprings	2450 [±]	Thin to medium-bedded gray dolomite with some sandstone and shale.

Goodsprings, lying between the points for which the data are given and at an elevation of 3,695, may be assumed to have a similar climate. Daily maximum temperatures at Goodsprings during the summer are 100° to 115° F.; winter minima range from 15° to 40° F. Most of the precipitation occurs during the winter; but there are occasional brief, heavy showers in summer. It is to be noted that the higher points of the region receive much more rain than the lowlands, and it is estimated from the above data that Goodsprings receives 6 to 10 inches of rain per year.

Uranium Occurrences

Uranium minerals from the Goodsprings area were first described by D. F. Hewett in 1923. He noted three occurrences: (1) in Tertiary "rhyolite" along the railroad tracks two miles south of Sloan, (2) in "sandstone that underlies the earliest Permian limestone" (Supai formation) one mile north of Sutor, and (3) in the sandy horizon of the Kaibab formation two miles north of Goodsprings. By optical methods, E. S. Larsen of the U. S. Geological Survey determined that the mineral from the two sedimentary formations was carnotite and that that from the "rhyolite" was probably carnotite. Hewett stated that all three areas showed mineralization as thin films along fractures and that the known deposits were not rich enough to be mined profitably. He suggested that the carnotite was "deposited by groundwaters during recent geologic time."

During the Second World War interest in the deposits was revived. The deposits along the railroad tracks were examined by Hill and Carper of the Union Mines Development Corp. who reported at least a trace of tyuymanite in every railroad cut between Jean and Arden. They regarded the uranium as having been leached from "hills to the west" and recommended the examination of the hills.

The zinc stockpile at Jean was also sampled for uranium by means of bead tests during this period. This led to the discovery of the uranium deposit at the Green Monster zinc-lead mine. Then, because of general similarity between the Green Monster and other mines of the district, reconnaissance studies were made of most of the mines. Positive results were found by the Atomic Energy Commission at the Lincoln, Singer-Tiffin, Copper Flower Quartz Lode (Vanadium Wedge), and Surprise mines and at the Paradise prospect.

A. L. Brokaw of the U. S. Geological Survey mapped the Green Monster mine as part of the program to develop base-metal deposits during the war; it was later sampled for uranium by M. H. Staats of the Geological Survey. Brokaw (unpublished report) states that the mineralization is localized in the Bullion dolomite member of the Monte Cristo formation where the contact between the dolomite and the overlying Arrowhead limestone is sheared almost parallel to the bedding. The uranium minerals were identified as kasolite and possibly dumontite, (Staatz, 1950). A small experimental shipment of selected uranium ore was made early in 1951, but there have been no further shipments.

PART I: THE URANIUM OCCURRENCES EAST OF THE
MINING AREA

Introduction

The deposits mentioned by Hewett (1923) fall into a single type of occurrence which differs from that observed in mines in mineralogy, in type of localization and in origin.

Carnotite is found in a great many places east of the Goodsprings Quadrangle and at a single locality two miles north of Goodsprings. Plate 1 shows the locations of these occurrences and gives a general indication of the geology east of the Goodsprings Quadrangle. This is a reconnaissance map compiled from 1:23,000 aerial photographs. The only control is provided from a 1:4800 map of the railroad right-of-way which was made available by the Union Pacific Railroad. A small part of the map covering carnotite localities 5 through 10 is reproduced from a 1:6000 plane table map prepared by Mr. Frederickson under the author's supervision.

Stratigraphy

The parts of the stratigraphic column which are of significance in these deposits include the Bird Spring, Supai and Toroweap formations and the Tertiary and Quaternary volcanics and gravels.

Bird Spring Formation

The Bird Spring formation crops out widely throughout the region; however, carnotite was observed in it only in a few exposures near the railroad from three miles north to two miles south of Sloan. The formation consists of thick to thin-bedded limestones, dolomites, shales and quartzites whose total thickness is about 2500 feet according to Hewett (1931). Longwell and Dunbar (1936) have shown on paleontological evidence that the age of the formation extends from upper Mississippian through Wolfcampian (Permian). Most of the beds are relatively pure limestone, some are cherty, while other are almost certainly sedimentary dolomites. The sedimentary dolomite is fine grained and apparently not recrystallized; this is in great contrast to the coarsely crystalline, white to cream colored, obviously secondary dolomite which is so common in the lower formations.

In contrast to the lower formations, the Bird Spring is composed of greatly varying lithologies which weather differently. This fact, and the great range in thickness of the bedding cause the formation to crop out in a very characteristic terrace and scarp manner which is easily recognized on aerial photographs.

Supai Formation

The Permian Supai formation is poorly exposed north of Jean Underpass in a westward dipping homocline. In the Goodsprings Quadrangle Hewett (1931) records a total of 1150 feet of unfossiliferous sandstone, red shale and gypsum. The lower third is thin bedded red shale and sandstone.

The middle unit, 400-500 feet thick, is uniform, massive, cross-bedded, white to buff or pink, medium to fine grained quartz sandstone. Festooned cross-bedding several tens of feet in magnitude shows inclined surfaces of removal; thus it is probably of aeolian origin. This rock was quarried for building stone at three places north of Jean Underpass.

The upper unit of the Supai is composed of red and buff sandstone, sandy red shale and gypsum. In section 2, T. 24 S., R. 59 E. there are several openings exposing six to eight feet of clean white gypsum. This upper unit was reported by Hewett to contain several prospects showing traces of carnotite on fractures.

Carnotite has been observed in all three of the units of the Supai formation, though the amount found was small.

Toroweap Formation

These strata were included as the lower part of the Kaibab formation by Hewett (1931); but McKee (1938) subdivides the Kaibab of Hewett, introducing the Toroweap formation for the lower beds and restricting Kaibab to the upper beds.

This formation and the overlying Kaibab are well exposed as a ridge trending north near Jean Underpass along the boundary between R. 59 and 60 E. in T. 23 and 24 S. A discontinuous band of Toroweap and Kaibab crops out in Goodsprings Valley beginning three miles north of town and continuing southward almost as far as the Lincoln mine.

The Toroweap formation is 250 feet thick and has two distinct lithologic units which are here classed as members. The lower member consists of about 200 feet of massive, medium grained gray limestone. The upper member is composed of about 50 feet of red sandy shales and siltstones with thin buff sandstone and limestone near the top. The sandy horizon crops out very poorly, and no completely exposed sections were found. The basal two-thirds of this unit are red shales and siltstones, and the upper third consists of buff, fine grained, calcareous, quartz sandstone interbedded with gray limestone near the top. Thin intraformational conglomerates are also present in the upper 10 feet. Near Goodsprings poor exposure prevented any exact section measurement; but although the sandy horizon is thinner, probably of the order of 30 feet, the relations of the red shale and the buff sandstone and limestone remain the same. Hewett (1931, p. 87) reports gypsum from this member.

The following section was measured in Sec. 12, T. 24 S., R. 15 E.
near carnotite locality 22.

	feet
Limestone: medium crystalline, gray, massive; chert makes up 25-35 percent of rock.	50 plus
Limestone: medium crystalline, gray, little chert.	7
Covered	7
Limestone: light gray with white chert	3
Total Kaibab	<u>67 plus</u>
Intraformational conglomerate: limestone fragments in buff sandstone matrix.	3
Sandstone: finegrained, buff to red, poorly exposed.	3
Limestone: fine to medium crystalline, gray; 2" ribbons of gray chert.	6
Covered	6
Sandstone: red; includes some limestone pebbles.	1
Sandstone: thin-bedded to laminated, red, fine grained.	3
Covered	7
Sandstone: red, calcareous, fine grained.	9
Shale: slope covered by fragments of silty, red shale.	14
Limestone: laminated and mud-cracked at top, grades downward to alternating 2" dark and light beds; chert ribbons in middle and decreasing downward.	15
Limestone: massive, light gray, finely crystalline; little chert.	29
Limestone: very cherty; separate nodules of light chert weather dark, forming re-entrants.	6
Limestone: gray, massive, fine to medium crystalline, few cherty layers.	81
Limestone: medium to thick-bedded, buff, finely crystalline with few chert nodules; includes grains of quartz sand.	12
Covered: probable position of friable, calcareous sandstone.	10
Limestone: massive, gray, few layers of chert, grades downward into 6-7 feet of buff calcareous sandstone.	44
Total Toroweap	<u>251</u>
Supai red shale	

The Kaibab as defined by McKee consists of over 200 feet of very cherty, massive limestone and dolomite. Bedding is obscure and parallel to the ragged ribbons of chert which may constitute as much as 25 or 35 per cent of the rock.

Marine fossils are common in the Toroweap limestone, and a few may be found in the Kaibab limestone. No organic material, plant or animal, is found in the sandy beds.

Gravels (Tertiary and Quaternary)

Much of the area shown in Plate 1 is covered by gravels which are interbedded with the volcanic rocks to be described later. The thickness of these deposits is not known, but it is probable that it would be measured in hundreds if not thousands of feet. Most of the gravels are partially cemented by caliche which in a few places is very dense.

Two types of gravels are recognized. The first and older contains many pebbles and boulders up to a foot in diameter of crystalline rocks in addition to the usual fragments of limestone, dolomite and chert. The crystalline rocks include metaquartzite, pink and gray granites, phyllites, garnet and biotite schists, acid volcanics and basalt. Cleavage fragments of apparently fresh pink feldspar are also common. These early gravels are best exposed in the low hills at Jean Underpass and in the railroad excavations from 1/4 to 1 mile north of Erie. The source of the crystalline rocks is the Pre-Cambrian complex on the west side of the McCullough Range which was part of a middle and late Tertiary basin which drained northward toward Las Vegas. These gravels are dated as late Tertiary on the basis of the interbedded Erie tuff which is tentatively considered Miocene (D. F. Hewett, personal communication).

The second and younger gravels are related to the present drainage and their composition is determined by the type of material exposed in their watersheds. In the region of the carnotite occurrences, these gravels consist almost entirely of limestone, dolomite and chert fragments.

Volcanic Rocks

Goodsprings Quadrangle.- Volcanic rocks are widespread in the southern portion of the Goodsprings Quadrangle. The principal areas described by Hewett (1931) are Big Devil Peak, Table Mountain and near the Sultan mine. The Big Devil is a plug of rhyolite about a mile in diameter; the other two are areas of tuff capped by andesite flows. The tuffs certainly were much more extensive than at present and probably covered at least the entire southern half of the quadrangle as isolated remnants are found as far north as the Paradise prospect.

East of the Goodsprings Quadrangle.- The groups of rocks here designated as the Erie Tuff is of great interest in the discussion of the uranium deposits. These are the oldest known volcanic rocks in the

area mapped, being of probable Miocene age according to Hewett (personal communication). They will be discussed in detail following the description of the younger extrusive rocks.

A large mass of volcanic rocks forms rugged hills southeast of the highway at Erie (western edge of T. 24 S., R. 60 E.). This was at first thought to be the source of the Erie tuff, but it is now believed that this material overlies the tuff and is therefore younger. The hills are composed of light gray latite flows with phenocrysts of biotite and sanidine. This group of flows probably outlines a former crater. On the east, south and southwest there is an area of younger andesitic flows and agglomerates.

The most recent volcanic activity was the extrusion of basalt, remnants of which are found in a few valleys. The rock at the surface is scoriaceous with vesicles occasionally filled with calcite. In hand specimen the rock is dark gray and contains phenocrysts of plagioclase, augite and oxidized biotite up to 10 mm across. At a point 1800 feet west of carnotite locality 10 the basalt has vertical flow lines and seems to cut across the Bird Spring limestones; this is probably one of the fissures through which the basalt was extruded.

The Erie Tuff.- This tuff has been studied by Mr. Frederickson under the supervision of the author, and much of the following description is taken from Frederickson's unpublished manuscript.

As shown on Plate 1, the tuff crops out in a discontinuous band approximately parallel to the tracks of the Union Pacific Railroad from the vicinity of Sloan to a point two miles north of Jean. To the northwest of this band it has been removed by erosion, and to the southeast it dips beneath more recent deposits.

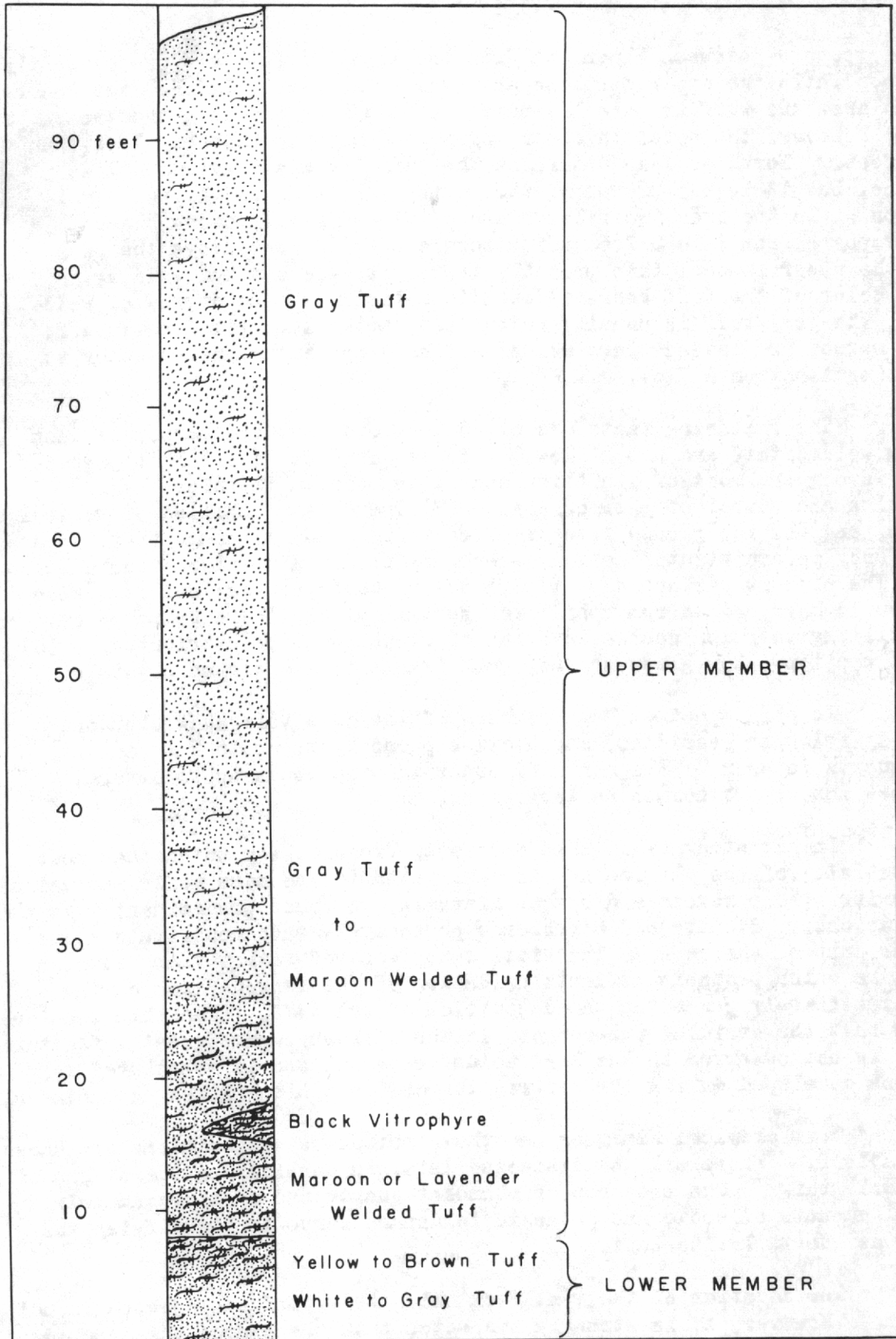
Frederickson has recognized two members which may be traced with assurance throughout most of the exposures. Each of these members may be further subdivided in many localities but the subdivisions cannot be correlated between widely separated outcrops. A generalized stratigraphic section of the Erie tuff is shown in Figure 2.

At the bottom of the section is a white to beige or light umber pumiceous tuff which maintains a rather uniform thickness of five feet over most of the area. It grades upward into a yellow to brown tuff which becomes increasingly dense and vitreous toward the top. The thickness of the yellow tuff is nearly constant at three feet. These two units constitute the lower member and are sharply separated from the overlying member with which it is wholly conformable. The radioactivity of the lower member as measured by the scintillometer is slightly lower than the upper, and carnotite is extremely rare.

The upper member is about 100 feet thick where it is best preserved about three miles south of Sloan. It consists of maroon welded tuff which may grade vertically (or laterally ?) into lavender or gray tuff. In

Figure 2

Generalized Stratigraphic Column of the Erie Tuffs



the exposures between Sloan and Erie the lower 25 feet are predominantly maroon while the upper portions are usually gray. In the Jean Underpass area the tuff is pale lavender near the base and is gray near the top; however, the total thickness preserved here is probably less than 25 feet. North of Jean Underpass the tuff becomes gray and less dense, but it is not proven whether this is lateral or vertical variation. In the area two miles south of Sloan, a very dense black vitrophyre from 1 to 3 feet thick occurs 8 to 10 feet above the base of the upper member; this probably represents the maximum welding. The color of the tuff bears a definite relation to the degree of welding; the gray tuff is usually porous and easily identified as a tuff; the maroon and lavender are welded and hand specimens are not easy to distinguish from a flow.

The following facts are cited to prove that the maroon horizon is a welded tuff and not a flow. (1) It conforms to an old topography. (2) Throughout most of its thickness it is uniform in color, degree of welding and number of phenocrysts. (3) There is no chilled or vesicular base, and the top grades into unwelded tuff. (4) Although there is a tendency toward stratification, there are no definite flow structures. (5) The present surface dips toward the probable source; and as a flow it would have had to run uphill for several miles, there being no evidence of tilting to which such a reversal of slope could be attributed. (6) Thin sections show glass shards, rock fragments and broken crystals.

In hand specimen both members of the Erie tuff show abundant glassy feldspar (sanidine) and biotite phenocrysts up to 2 mm across; no quartz is seen. Fragments of other igneous rocks up to several inches across are common as inclusions.

In his study of 15 thin sections, Frederickson noted that most, if not all, of the plagioclase is restricted to the more mafic inclusions. Likewise, the pyroxene and opaque minerals are found predominantly in the inclusions. Biotite and hornblende phenocrysts each constitute about 1 per cent of the rock. The biotite is deep red rather than brown, a feature which probably reflects oxidation of the ferrous iron during and immediately preceding the deposition of the tuff. The thin sections show that the sanidine phenocrysts in the vitrophyre are greatly fractured. This is not observed in the less welded material and is attributed to stress developed during the contraction of the cooling glassy groundmass.

Four chemical analyses and their normative compositions are shown in Table 2. These will be discussed later in considering the origin of the Erie tuff. The presence of abundant quartz and of approximately equal amounts of sodic and potassic feldspars serve in classifying the rock as quartz latite tuff.

The location of the vent from which this tuff was ejected is not known. However, it is strongly suspected that the source was located to the southeast, very probably in the area now covered by the previously mentioned latite and andesite flows. The uniformity of the tuff along

Table 2

Chemical Analyses and Calculated Norms of the Erie Tuffs
(Analyses by H. B. Wiik)

	Gray Vitrophyre	Semi-vitreous Yellow Tuff	Maroon Tuff	Lavender Tuff (Minus CaCO ₃)	
SiO ₂	68.10	64.51	70.07	57.89	(65.10)
TiO ₂	0.44	0.49	0.52	0.56	(0.63)
Al ₂ O ₃	14.52	14.22	15.09	14.41	(16.22)
Fe ₂ O ₃	2.04	1.65	1.66	2.13	(2.40)
FeO	0.46	0.50	0.35	0.28	(0.32)
MnO	0.08	0.08	0.08	0.07	(0.08)
MgO	0.59	1.84	0.94	1.12	(1.26)
CaO	1.07	1.77	1.15	7.82	(1.80)
Na ₂ O	3.75	3.41	4.43	4.05	(4.56)
K ₂ O	6.65	4.55	5.83	5.59	(6.29)
P ₂ O ₅	0.05	0.04	0.07	0.14	(0.16)
H ₂ O ₊	2.45	4.86	0.26	0.99	(1.11)
H ₂ O ₋	0.22	2.16	0.04	0.00	(0.00)
CO ₂	<u>0.05</u>	<u>0.06</u>	<u>0.00</u>	<u>4.90</u>	<u>(0.00)</u>
	100.47	100.14	100.49	99.95	(99.93)
Q	18.80	Q	22.61	Q	18.60
or	40.22	or	28.92	or	34.39
ab	32.39	ab	31.04	ab	37.29
an	3.17	an	8.72	an	4.00
di	1.31	C	0.74	sp	0.01
hy	0.91	hy	4.95	hy	1.85
mt	0.47	mt	0.47	di	1.08
hm	1.75	hm	1.45	hm	1.65
il	0.86	il	1.00	il	0.91
ap	0.12	ap	0.09	ap	0.16
				Q	9.95
				or	37.58
				ab	38.95
				an	5.23
				sp	0.48
				hy	2.42
				di	1.66
				hm	2.42
				il	0.85
				ap	0.32

(In all cases CaCO₃ is assumed to be caliche and not an integral part of the rock.)

the line of exposure, which is in a northeast-southwest direction, suggests that the source was either to the southeast or northwest. And inasmuch as there are no volcanic rocks in view for at least several tens of miles to the northwest, the logical conclusion is that the vent was to the southeast.

Structure

The complex structural history of the folded and faulted Paleozoic and Mesozoic rocks of the Goodsprings Quadrangle is carefully described by Hewett (1931). From the Bird Spring thrust eastward to Sloan Hill the structure is comparatively simple. The beds dip gently west, and there are a few normal faults of moderate displacement which trend a few degrees west of north. The gravels and volcanic rocks are occasionally broken by steeply dipping minor faults and joints the majority of which range in strike from due N to N25°W.

The tuff-capped gravel hills near Jean Underpass have been faulted up to their present position by faults trending north whose displacement may be of the order of 50 or 100 feet. Another fault with a northwest strike and with much larger displacement is believed to be responsible for the divide at Erie and formed the escarpment east of the playa near Jean Underpass. These faults are probably related to much diminished northward continuations of the very large middle Pleistocene normal faults bordering Ivanpah Valley which lies to the south (Hewett, personal communication).

At Sloan Hill the gentle westward dip of the beds that continues from the Bird Spring thrust is suddenly broken, and a complexly faulted horst of Sultan and Monte Cristo formations is exposed (Deiss, 1951, p. 128). These beds are extensively broken and dolomitized but are not mineralized.

Summary of Geologic Events with Respect to the Uranium Occurrences East of the Goodsprings Quadrangle

1. Deposition of Paleozoic and Mesozoic sediments with relatively little disturbance and few disconformities. So far as the preserved record is concerned, this is discontinued following the deposition of the Aztec (Navajo) sandstone.
2. Folding and thrust faulting accompanied by the intrusion of porphyry bodies along thrust planes in the Goodsprings Quadrangle.
3. Development of a drainage pattern in which the area south of Sheep Mountain (specifically, the west side of the McCullough Range) drained northward toward Las Vegas. This drainage is responsible for the gravels which contain fragments of crystalline rocks and which occur between Jean Underpass and the valley south of Sloan. During this time the Erie tuff was ejected from a source which was probably southeast of Erie.

4. Development of the northerly trending faults and joints. These fractures are assumed to have formed contemporaneously with the large normal faults bordering Ivanpah Valley, which Hewett (personal communication) assigns to the middle Pleistocene. The basalts shown on Plate 1 probably were extruded during this deformation. Hewett correlates them with the Halloran basalts which he dates as late early Pleistocene. The latite and andesite flows southeast of Erie are later than the gravels and tuff mentioned in stage 3, but their time relation to the normal faults was not determined.

5. Institution of the present closed drainage during and after the faulting of stage 4. The divide at Erie was formed at this time. There is no indication (such as old shore lines or channels across divides) that the present closed basins have been lakes for more than short periods of time or that the drainage at any time since the faulting has been more continuous than at present.

Descriptions of the Uranium Occurrences

Carnotite is found in most of the excavations along the Union Pacific Railroad from a point two miles northeast of Jean to a point three miles north of Sloan, a distance of over 16 miles. Hill and Carper (1944) report tyuyminite (carnotite) from every railroad cut between Jean and Arden. Although in the present study uranium minerals were not found in every cut, there is no reason to dispute the observation of Hill and Carper. Further extension of the mineralized area is limited by the absence of suitable exposures. Some of the highway cuts between Jean Underpass and Erie also show mineralization. Carnotite is found in several prospect pits from one to three miles north of Jean Underpass and in a single pit two miles north of Goodsprings. Plate 1 is a geologic map of the area in which the carnotite occurs. The uranium showings are marked with numbered circles which refer to the numbers in Table 3.

The uranium mineral has been identified as carnotite on the basis of X-ray diffraction patterns whose data, together with a discussion of their significance, are presented in Appendix A. Specimens also give a good positive test for vanadate when brought into contact with concentrated hydrochloric acid.

The carnotite occurs only as thin films and specks on joint or bedding surfaces of the Paleozoic sedimentary rocks and Erie tuff, or on pebbles in the gravels or mixed with the caliche. It commonly does not impregnate or replace. It is very fine grained, and crystals are difficult to distinguish even under high magnification. Usually the uranium mineral in the gravels is present as porous aggregates up to 3 or 4 mm in diameter in which the material is relatively pure. In such cases the color is a bright canary yellow. However in some localities, particularly on the tuff and occasionally on limestone pebbles, the carnotite forms a very dense film in the surface and the color becomes distinctly greenish yellow.

Table 3

TABULATION OF CARNOTITE OCCURRENCES

Locality	Scintillometer (cps)			Dominant Rock Type (Obs. Cobbles)	Nature of Exposure
	Max.	Avg.	B. G.		
1.	10	10	10	Cbs ss. and ls.	RR cut
2.	10	5	5	Cbs ss. and ls.	RR cuts
3.	10	5	5	Gravel	RR cuts
4.	15	10	5	Gravel	RR cut
5.	15	8	8	Cbs ls. and Tertiary sandstone	RR cut
6.	45		15	Cbs ls.	Prospect pit
7.	150	75	30*	Erie tuff	RR cut
8.	45	20	10	Cbs ss. and ls.	RR cut
9.	70	55	25*	Erie tuff	RR cut
10.	90	60	20*	Erie tuff	RR cut
11.	50	25	25*	Post basalt sand	RR cut
12.	50	35	25*	Erie tuff	RR cut
13.	70	35	20*	Erie tuff	RR cut
14.	30	15	10	Post tuff gravel	RR cuts
15.	15	10	10	Post tuff gravel	Highway and RR cuts
16.	15	8	8	Pre tuff gravel	Highway and RR cut
17.	30	20	10	Erie tuff	RR cut
18.	15	10	10	Erie tuff	RR cut
19.	30	20	10	Ps sandstone	Prospect pit
20.	15	10	10	Ps sandstone	Prospect pit
21.	15	15	15	Ps sandstone	Prospect pit
22.	45		15	Ps sandstone	Prospect pit
23.	15		15	Pt sandstone	Prospect pit
24.	30		15	Pt ss. and ls.	Prospect pit
25.	15		10	Pt sandstone	Prospect pits
26.	35		15	Pt sandstone	Prospect pits
27.	50		10	Pt sandstone	Prospect pit

* B. G. readings probably affected by nearby tuff.

All transitions between the two colors occur, and the X-ray study has shown them both to be carnotite.

The caliche is principally calcite or aragonite, though gypsum is common as small plates and curving aggregates of crystals up to two or three inches long. The carnotite is later than some of the caliche but seems to be contemporaneous with most of it. Manganese dioxide is common as specks and dendrites both with and without carnotite. On the tuff there are occasionally acicular crystals of celestite up to about 1 mm in length. These are associated with a coating of dull gray calcite which fluoresces and phosphoresces dull yellow.

It should be emphasized that the actual amount of uranium present, as indicated by scintillometer readings and a few uranium analyses, is very low. Therefore the study was made with more regard for the genetic problem than for the economic reasons.

Notes on Radioactivity Measurements

Two instruments were used in the field -- a Geiger counter, Model 107, Precision Radiation Instruments Inc., and a Halross scintillometer Model 939A.

According to the manufacturer, the scintillometer is designed to operate at temperatures up to 110° F. The afternoon air temperature often reached or exceeded this and it is probable that the sun heated the instrument even more. It was noted that readings decreased during the heat of the day; therefore, whenever possible the radiometric work was performed early in the morning. Also, variations in country rock, especially between tuff and limestone, resulted in widely varying background readings. It is seen from this brief discussion that a precise comparison of the radioactivity measurements is not justified.

All of the scintillometer readings are recorded in counts per second, abbreviated as cps.

Descriptions of Individual Localities

Localities 1 and 2 are situated in three railroad cuts between two and three miles north of Sloan. Here the rock is Bird Spring limestone, sandstone and shale; the bedding is nearly horizontal. A very small amount of carnotite is found as minute specks along bedding planes and joint surfaces. The distribution of these traces of uranium mineralization is not uniform however, but rather sporadic and seemingly reflecting the channels of easiest ground water circulation.

Locality 3 is along the railroad immediately south of locality 2. Carnotite is found scattered through three shallow cuts in gravels which

are loosely cemented by caliche. A little of the uranium mineral is found as coatings on pebbles, but most commonly it occurs as canary yellow aggregates in earthy white caliche.

Locality 4 is about half a mile south of Sloan. It is of interest because there seem to be two ages of gravel with differing amounts of uranium. The exposure is 500 feet long and 10 feet high. The lower five feet are more densely cemented by caliche; and carnotite is fairly common, though never abundant. The gravels are composed of chert and carbonate rock fragments with no crystalline rocks other than a few basalt pebbles. The upper gravels are less consolidated and contain pebbles and boulders of basalt similar to that which crops out east of Sloan; they succeed the older deposits without a sharp line of demarcation. Carnotite is very uncommon in this horizon. It seems reasonable to assume that the lower gravel was mineralized previous to the deposition of the younger, and that solution and redeposition of the carnotite from the older gravel resulted in the mineralization of the younger deposit. This circulation can be accomplished by capillary rise of ground water because the vertical distance involved is probably only a few feet.

Assuming that there are actually two ages of gravels represented here, there are two possible explanations in addition to the above mentioned one. The first alternative is that the carnotite was originally equally distributed between the gravels and that subsequent weathering has preferentially leached the more porous upper layer. A second alternative is possible when one considers the source of the uranium; as will be developed later, this is very probably the Erie tuff. Conceivably it is possible to call on two separate tuffs, one of an age intermediate between the two gravels, the other of more recent age than either gravel.

Locality 5 is a railroad cut about two miles south of Sloan. It cuts thick-bedded and thin-bedded limestones and dolomites of the Bird Spring formation which here dip gently northeast. A stream channel belonging to a former drainage pattern has been eroded into the limestone to a depth of at least 25 feet. Adjacent to the limestone is a layer of boulder conglomerate, but no fragments of Erie tuff could be found despite the fact that the tuff crops out only a few hundred feet away uphill. This suggests that the channel antedated the tuff. The channel is filled with very uniformly crossbedded, well sorted medium sand in a finer matrix. In thin sections the sand is composed of plutonic quartz, feldspar, pyroxene, hornblende, garnet and the like, all of which are fairly well rounded and free from alteration. This suggests that this sand was blown into the depression at a time when the climate was similar to the present dry climate so that mechanical weathering predominated over chemical weathering. Near the northern end of the cut several narrow sand dikes strike east and have a composition very similar to the channel filling. The channel is the most radioactive part of the cut, but even here the counts are very low.

At one point, immediately beneath the southern side of the channel mentioned above, an irregular mass of white silica has replaced a one foot

bed of limestone for a distance of about twenty feet. Other alteration or mineralization is lacking, and there is no anomalous radioactivity.

Small specks of carnotite were found along fractures in the crossbedded sandstone filling the channel near the top of the cut on the west side. A few showings of uranium were noted along joints and minor faults in the limestones and dolomites. Carnotite is rather common on some of the large dolomite blocks which were excavated from the cut. Some of these show mineralization on all fractures but no particular set of fractures is selectively mineralized.

Locality 6 is a prospect pit six feet deep that is dug into Bird Spring limestone which protrudes as a low knoll through the overlying tuff. Two sets of joints, one striking due north and dipping vertically, the other striking due east with a dip of 80° S, are equally mineralized by minor films of carnotite. The country rock is thin-bedded to thick-bedded limestone containing irregular bands of red chert which bleaches on weathering. The limestone is overlain by two or three feet of loose material that seems to be a mixture of decomposed tuff and caliche. This material contains scattered specks of carnotite and gives a maximum scintillometer reading of 45 cps compared to 30 cps for the yellowest part of the joint surfaces; the background is 20 cps.

Locality 7 is the first of the carnotite showings intimately associated with the Erie tuff. Carnotite occurs here as thin films on joint surfaces in the maroon welded tuff and as small specks in the caliche which fills fractures. No uranium mineralization was seen in the lower yellow tuff.

It should be mentioned that in this and in the other carnotite occurrences in the tuff and pre-tuff gravel, most of the carnotite is found along northward striking, nearly vertical joints. Yet this is not to be interpreted as preferential mineralization of one set of fractures for two reasons: (1) the principal effect of post-tuff deformation was to produce north trending fractures; there are few joints having other orientations; (2) the cut is almost parallel to the strike of the joints, and therefore the major part of the surface of the exposure is along the north trending planes, thus overstressing their prominence.

The most radioactive spot in all of these deposits (exclusive of the mines of the Goodsprings district) is found on the east side of the cut about two thirds of the way to the south end. Here a little carnotite is seen in the calcareous breccia of a minor vertical fault which strikes $N 65^{\circ} W$. The maximum scintillometer reading is 150 cps compared to a background of 30 cps; this actually very low value serves to illustrate the low grade of these deposits. The breccia zone is up to six inches wide and contains unaltered tuff fragments in a matrix of porous, pinkish-gray caliche. Elsewhere on the same fault the radioactivity is normal for the cut, and no particular concentration of

carnotite was seen. In thin section the carnotite appears as yellow specks dispersed throughout the matrix. This is in great contrast to anything else seen in these deposits and apparently explains why the radioactivity is much higher than the carnotite visible in hand specimen would seem to indicate. A selected specimen gave 0.1-0.5%U in a semi-quantitative spectrographic analysis. The feldspar appears quite fresh in both hand specimen and thin section, and there is no visual evidence of alteration or mineralization other than the caliche and the carnotite. This strongly suggests that the deposit was formed by ground water and not by hydrothermal solutions. As a final check on this assumption a semiquantitative spectrographic analysis of the carnotite-rich breccia was compared with similar analyses of the unmineralized tuff. The complete data are given in Appendix C; but it is noteworthy that only Ca, U, Ag and probably V showed any enrichment in this zone. It would be expected that hydrothermal activity would introduce other material in addition to these. Therefore, although the explanation for the increase in Ag is unknown, it is reasonable to assume that this occurrence is not of hydrothermal origin.

Locality 8 is a cut in the Bird Spring formation about three miles south of Sloan. The rock dips about 30° to the northeast and is broken by several minor faults; otherwise the occurrence is very similar to localities 1 and 2.

Localities 9, 10, 12 and 13 are railroad cuts through the Erie tuff from three to four miles south of Sloan.

The largest exposure, Locality 10, exhibits more than 50 feet of stratified, almost horizontal welded tuff. The lower 30 feet is maroon in color, and shows "bedding" in uniform layers about two feet thick. The upper 20 feet is less welded, more massive and grayer. The basal yellow and gray tuff is not exposed here but crops out at a slightly lower level at the ends of the cut. Carnotite is common but not abundant. It occurs along fractures as specks and coatings on tuff and caliche. Several specimens with very yellow films up to one foot square were found about half way up in the center of the east side. The radioactivity of this area was only 90 cps compared to 60 cps for the cut as a whole, which again shows that very little uranium is present. Several minor faults with northwesterly strikes cross the cut, but there is neither mineralization nor abnormal radioactivity along these.

Locality 11 is in the same area as the four showings mentioned above, but differs in that carnotite occurs in sand and gravel which overlies a basalt which in turn overlies the Erie tuff. Sand dikes which seem to have formed by the washing of sand between boulders of basalt are common. The radioactivity of the basalt does not exceed background, but the gravel gives up to 50 cps. Carnotite was found at the contact between the sand and the overlying gravel. The best showing is along a vertical joint which strikes north; a chip sample of this gave 0.008% c U₃O₈. No uranium minerals were found in the basalt.

Locality 14 is along the railroad one mile north of Erie. In this area there are several exposures of gravels which lie perhaps 30 or more feet above the Erie tuff. The gravels are composed of limestone, dolomite, chert and crystalline rock fragments up to a foot in diameter. Nearly horizontal bedding is faintly suggested. Cementation by caliche increases toward the south, and the cut nearest Erie shows a very dense caliche in which no carnotite could be found. Six inches of friable white crystal tuff are interbedded with gravel in one of the cuts, but it is not associated with either abnormal radioactivity or carnotite.

Carnotite occurs sporadically as coatings on pebbles and as minute specks in the caliche cement. Some small areas show specks of yellow on almost every fragment; nevertheless, the total uranium content, as judged by radioactivity, is very low. The best showings are along joints which trend north-northwest. The mineralization seems to favor certain horizons very slightly. Though the reason for this is not obvious, it may well be due to differing permeabilities.

In general the carnotite does not favor one type of pebble over another, i. e., a granite pebble is just as likely to show mineralization as a limestone pebble. However, a single two inch limestone pebble was found coated with enough carnotite to register 1 mr/hr on the Geiger counter; but the total uranium in the immediate vicinity was insufficient to raise the scintillometer reading appreciably. In this specimen dense yellowish green carnotite coats one side of the pebble in direct contact with the limestone; the other side is covered by pinkish caliche; and canary yellow carnotite appears only as a few scattered specks. In an attempt to explain this concentration of mineralization a spectrographic determination of the unmineralized core of the pebble was obtained. The details of this analysis are found in Appendix C. Vanadium was found to be 0.005-0.01%, a marked increase from the usual content of limestone which, according to Jost (1932, quoted in Rankama and Sahama, 1950, p. 601) is less than 0.0010%. It is logical to ask why the tuff, which also contains a similar amount of vanadium, does not precipitate the uranium in a similar manner. Perhaps the answer lies in the fact that the vanadium in the unweathered tuff is present predominantly in the lower oxidation states, V^{+3} and V^{+4} , which are not effective precipitants for uranium, whereas the vanadium in the limestone is probably present as the vanadate, VO_4^{+3} , which may readily precipitate the uranium.

It had been intended to examine the material around the telephone and power line pole holes for mineralization because this debris would furnish a sample of the gravel to a depth of several feet. However, checking of material from holes very close to the carnotite showings failed to disclose any uranium mineralization whatsoever and showed no radioactive anomalies. This observation is almost expected in view of the general sparseness of the mineralization. In view of such negative results in an area where carnotite is known to occur, it was decided that further examination of the power and telephone pole holes would be of little value and the plan was abandoned.

Locality 15 consists of several railroad and highway cuts about two miles southwest of Erie. Carnotite occurs in extremely small amounts in gravels which contain crystalline rock and Erie tuff pebbles in addition to the usual limestone fragments. The gravel is therefore later than this tuff, but the depth to the tuff is unknown.

Locality 16 is the series of excavations in the pre-tuff gravel at Jean Underpass. Carnotite is found sporadically as films and specks on pebbles of crystalline rock and limestone as well as in the caliche.

Localities 17 and 18 are railroad cuts into the Erie tuff just south of Jean Underpass. At Locality 17 the carnotite occurs with caliche of fine grained calcite and small gypsum crystals as coatings and films in joints associated with low temperature quartz and chalcedony. The chalcedony and some of the quartz fluoresce greenish-yellow. There are all gradations between terminated quartz crystals 1 mm in length and drusy quartz in which the individual crystals are barely distinguishable under high magnification. The quartz in which the crystal forms are well developed is not fluorescent. The silica is probably the product of some former thermal spring activity, and perhaps the fluorescence is caused by a trace of uranium which could have been derived from the tuff. The carnotite exhibits the same relation to the quartz as does the caliche and it is therefore concluded that the carnotite is genetically related to the caliche rather than to the silica.

Localities 18, 19, 20 and 21 are in small prospect pits in the Supai formation north of Jean Underpass. Red sandy shale carries carnotite and manganese dioxide as specks along fractures at Locality 18. This is probably the lower unit of the Supai, but the exposure is insufficient to make this certain. At Locality 19 the carnotite is found with manganese dioxide along the bedding planes of a buff argillaceous sandstone in what is probably the upper member of the Supai. Locality 20 shows traces of carnotite along joints and sliksided minor faults about 70 feet below the top of the massive sandstone middle member.

The best showing of any in the Paleozoic sedimentary rocks is at Locality 21 which is in fractures in buff, calcareous sandstone immediately below the base of the Toroweap limestone. The maximum scintillometer count is 45 cps compared to a background of 15 cps showing that the total amount of radioactive material is very small. The uranium mineralization is closely associated with manganese dioxide in joints filled with gypsum and calcite caliche. A few irregular veinlets about 1 mm wide of limonite after pyrite are present but not closely associated with the carnotite. In all four of these localities there is no alteration or bleaching of the country rock, nor is there any mineralization other than the carnotite and the traces of limonite. The radioactivity of this general area will be discussed following the description of the occurrences in the Toroweap formation.

Localities 22, 23, 24, 25 and 26 are found in prospect pits dug into the sandy horizon at the top of the Toroweap formation near the

southern end of a low ridge north of Jean Underpass. Table 4 shows the distribution of carnotite according to lithology.

Table 4

	Country Rock		Total
	Buff sandstone	Red silty shale	
Carnotite present	4 pits	1 pit	5 pits
Carnotite not observed	1	4	5
Total	5	5	10

The carnotite occurs as small patches and films on fractures in sandstone and limestone. Most of it is on buff sandstone and interbedded gray limestone, though red sandstone in places carries yellow specks. Dendritic manganese dioxide is locally found with the carnotite. A chip sample 4 feet along across the face of the best of these showings (Locality 26) gave 0.003% c U_3O_8 . By comparison, red shale which appears free of carnotite gave 0.006% c U_3O_8 , and buff sandstone also free of visible carnotite gave 0.008% c U_3O_8 . These values are too close to the analytical limit to be given great significance, but they do serve to indicate that the amount of uranium present is extremely low.

The area in which the carnotite is found is cut by several small, steeply dipping, normal faults which generally strike a little west of north. Three of the occurrences are associated with the faults, but the faults themselves are not radioactive. This area is not faulted to a greater degree than the rest of the ridge, and there seems no reason to imply a genetic relation between the uranium and the faults.

Visible carnotite does not seem to be sufficiently abundant to greatly affect the radioactivity of the area. The background on the limestone which is not known to contain uranium minerals is about 15 cps at the southern end of the ridge; the red shales give about 25 cps; and the buff sandstone gives about 30 cps. These readings seem to be nearly independent of visible carnotite. Conceivably, the greater radioactivity of the shale and sandstone could be ascribed to a primary concentration such as heavy minerals or as adsorbed ions on clay minerals; however, further measurements refute this. As the sandy horizon is traced northward (and upward) along the ridge, the differences between the scintillometer readings over the limestone and over the sandy beds decrease. Eventually, about four miles north of the last observed carnotite, the sandy beds show no increase above background (10 cps). Therefore, it is suspected that the radioactivity is derived from finely dispersed uranium minerals, probably carnotite, in the sandstones and shales.

At two places in sections 1 and 2, T.24 S., R. 59 E. the massive sandstone of the Supai formation is strongly stained by iron oxide along

minor north trending faults. Except for small amounts of silicification, no mineralization is associated with the iron staining, nor is there any anomalous radioactivity.

Several small patches of the upper Kaibab limestone are entirely replaced by chert in section 24, T. 24 S., R. 59 E. These are not aligned with any known structure nor are they associated with abnormal radioactivity.

Locality 27 is in the low hills two miles north of Goodsprings in the center of section 24, T. 24 S., R. 58 E. where a small amount of carnotite is present in a prospect pit about five feet deep. The uranium mineral is found as small specks on fractures in soft, buff sandstone of the Toroweap formation in a manner very similar to the occurrences at Localities 22 through 26. A chip sample containing carnotite gave a value of 0.006% c U_3O_8 . Manganese dioxide occurs independently of the carnotite. Examination of two other pits a few hundred feet to the south failed to uncover any uranium minerals; but in view of the sparseness of the mineralization, it is possible that some is present.

The entire outcrop of the sandy horizon of the Toroweap formation in Goodsprings Valley was checked with the scintillometer. The radioactivity in the vicinity of all the pits and of the sandy horizon as a whole is similar to that described in the other Toroweap occurrences except that here there is no discernible trend in the radioactivity along the outcrop.

Genesis of the Carnotite in the Tuffs and Sediments

Experience in searching for uranium minerals in this area has shown that what at first glance seems to be only barren rock often carries minor amounts of carnotite. The region in which carnotite is found is quite large, and in no place is there more than a small amount of mineralization. These two facts suggest that the source of the uranium and vanadium was both widespread and of relatively weak concentration. Such a source is present in the form of the Erie tuff which surely once covered all of the area where carnotite is now found. A possible exception is the deposit north of Goodsprings. This occurrence may be explained by calling on the tuffs of Table Mountain which are several hundred feet thick three miles south of Goodsprings.

There are two ways to account for the previously mentioned decrease in radioactivity of the sandy part of the Toroweap formation northward along the ridge near Jean Underpass. The first and more probable is that the tuff thinned in that direction; the alternative is that erosion has removed the mineralized outcrop.

The idea that volcanic material could be an effective source of uranium has been emphasized by Waters and Granger (1953) for the Colorado

Plateau deposits. They also refer to volcanic debris associated with radioactive lignites in North Dakota and New Mexico. In southern California D. F. Hewett (personal communication) has observed widespread uranium mineralization intimately associated with fine grained clastic sediments derived from volcanic debris. T. G. Lovering (1954) has suggested that volcanic rocks may be the source of the uranium in the opal deposits of Virgin Valley, Nevada (Staatz and Bauer, 1951) and in the radioactive lignites in Churchill Co., Nevada.

In order to evaluate the Erie tuff as a potential source for the uranium, extensive sampling was undertaken. The first analyses were by wet chemical methods; but because these yielded extraordinarily high uranium values, fluorimetric analyses of composite samples were also obtained. The results are summarized in Table 5, and the complete data are given in Appendix B.

The chemical determinations are believed to be of little significance so far as the volcanic rocks are concerned, and the fluorimetric values are taken to be reliable. There are two reasons for the unsatisfactory results of the chemical analyses: (1) According to the analyst, whose procedure is quoted in Appendix B, the titration used has a precision of 0.003% U_3O_8 . Because the quantity of uranium reported averaged only about 3 times that amount, the significance of the results is questionable. (2) In addition to the usual interfering elements such as Fe, V, Mn, Co, etc., found in uranium ores, the volcanic rocks contain relatively large amounts of the rare earth elements. Incomplete removal of these elements would tend to give high results.

The fluorimetric method has a sensitivity which greatly exceeds the uranium content of most igneous rocks. The results recorded are reproducible within $\pm 10\%$ of the reported values.

The fact that the radiometric values are high and are seemingly in agreement with the chemical determinations definitely does not prove that the uranium concentration is also high because thorium and potassium certainly contribute important amounts of radiation. In samples other than the igneous rocks, the amount of thorium is probably negligible, and except in the case of the shale samples the amount of potassium is probably very small also. In the oxidized base metal ores from the mines of the Goodsprings district (see Part 2) the chemical uranium determinations are probably valid because: (1) The amount of uranium present is usually significantly higher than the analytical limit. (2) Possible interfering elements are probably limited to Fe, V, Mo, Mn, Co, Ti, Cr, As, Sb, and Cu; these may be satisfactorily removed, whereas in the case of the tuff there are many other possible interfering elements.

In all of the samples taken for analysis the outer surface of the rock was chipped away and discarded so as to provide fresh rock which was free from caliche. In all cases the tuff appeared fresh. There

Table 5

Uranium Content of the Volcanic Rocks

Fluorimetric Method (probably reliable) (Analysed at Lamont Geological Observatory)	% U_3O_8
Upper Member of the Erie Tuff (composite of 10)	0.0012%
Lower Member of the Erie Tuff (composite of 10)	0.0012%
Table Mountain Tuffs (composite of 7)	0.00085%
Flows (composite of 8)	0.00079%
Chemical Method (probably much too high)	
Erie Tuff	
Subdivided according to member	
Upper Member (avg. of 22)	0.0097%
Lower Member (avg. of 21)	0.0097%
Subdivided according to color	
Lavender and maroon (avg. of 21)	0.0098%
Gray (avg. of 12)	0.0084%
Brown and buff (avg. of 6)	0.0136%
Yellow (avg. of 4)	0.0075%
Subdivided according to location	
East of Sloan (avg. of 4)	0.0087%
Near carnotite localities 5 through 9 (avg. of 6)	0.0075%
Near carnotite localities 6 through 10 (avg. of 15)	0.0094%
Near Jean Underpass (avg. of 10)	0.0135%
West of Erie (avg. of 8)	0.0079%
Other igneous rocks from the Geodspings area (avg. of 25)	0.0064%

seems no alternative to the conclusion that the uranium was present as an original constituent of the tuff at the time of its deposition.

Because of the reducing environment the predominant form of uranium in magmas is U^{+4} . This ion is too large to substitute for Si^{+4} , Al^{+3} , Fe^{+3} , Fe^{+2} , Ti^{+4} or Mg^{+2} in the opaque ores and rock forming silicates, and the charge is too high for substitution in place of Ca^{+2} , Na^{+1} or K^{+1} in the feldspars. Minor amounts of uranium may be found in accessory minerals such as zircon and apatite where it may substitute for Zr^{+4} and Ca^{+2} respectively. It is concluded therefore that the greater part of the uranium is concentrated in the glass phase of the tuff.

Leaching and precipitation of the Uranium and Vanadium

In the fresh and presumably unoxidized tuff the uranium should be present in the quadrivalent state. On weathering the uranium is oxidized by ground water to U^{+6} and is probably transported as the uranyl carbonate complex, $UO_2(CO_3)_3^{-4}$, which according to Leo J. Miller (personal communication) is soluble in the range of pH from 5 to 12. Miller also finds that the uranyl ion, UO_2^{+2} , precipitates as uranyl hydroxide or as an alkali diuranate, such as $Na_2U_2O_7$, in the absence of carbonate if the pH is much greater than 5. It seems certain that nearly neutral conditions are necessary in order to develop the abundant caliche with which the carnotite is so intimately associated.

According to Rankama and Sahama (1950, p. 595) the vanadium may be present as V^{+3} , V^{+4} or V^{+5} in igneous rocks. In the weathering processes in an arid, oxidizing climate it would be expected that the vanadium would become oxidized predominantly to the pentavalent state which, due to its small size and high charge, complexes readily, forming vanadate, VO_4^{-3} . It is well known that vanadate is an effective precipitant for hexavalent uranium, forming rather insoluble compounds such as carnotite and tyuyumunite. A problem therefore arises as to how the uranium and vanadium managed to get out of the tuff at all inasmuch as they tend to precipitate each other from solution.

Two possibilities are presented to circumvent this difficulty. The first is that carnotite may be slightly soluble in the groundwater, and that over a sufficiently long time appreciable amounts of carnotite could be transferred to the surrounding rocks where it could be deposited by the evaporation of the solvent. It is also possible that the uranyl carbonate ion is not precipitated immediately by dilute vanadate solutions and therefore the mineralization may be widespread.

An alternative and wholly hypothetical process, which should be amenable to laboratory study, is that the vanadium is leached from the tuff in the quadrivalent state in which case it may not act as a precipitant for the uranyl carbonate ion. It is known that such compounds

as vanadyl sulfate, VOSO_4 , are quite soluble (Hodgeman, 1953), and perhaps they coexist in quantity in the same solution with uranyl carbonate. Garrels (1953) mentions that the rate of oxidation from V^{+4} to V^{+5} is probably slow. If this proposed mechanism is valid it would be possible for carnotite to precipitate at any point merely by the oxidation of the vanadium.

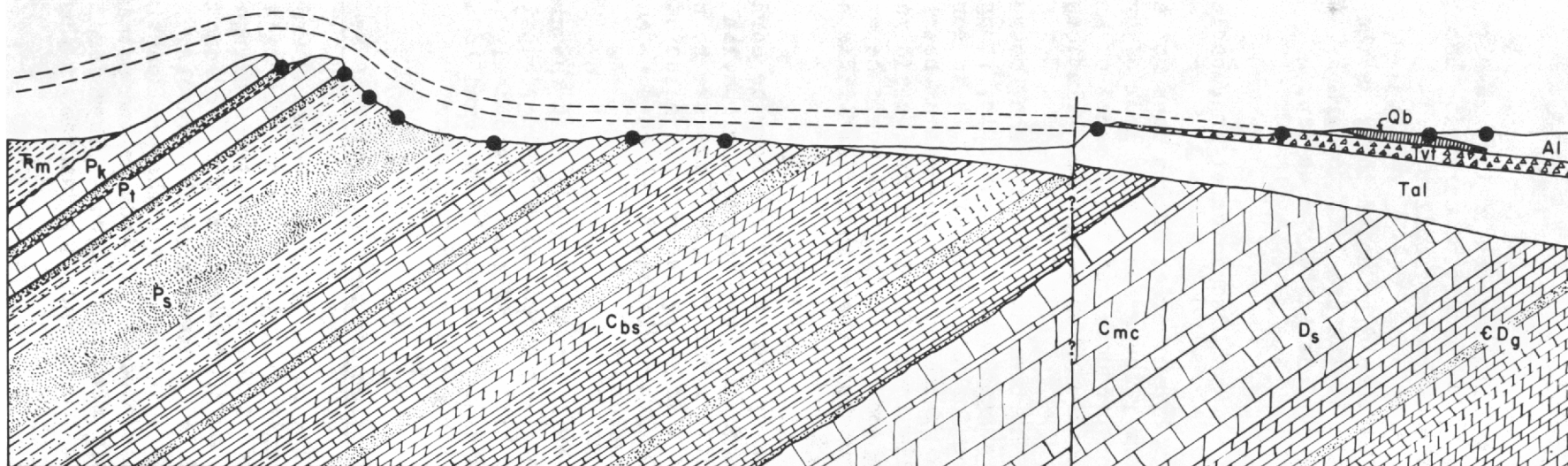
Figure 3 shows a schematic diagram of the relations between the Erie tuff and the various localities of carnotite mineralization. The mineralization took place (and probably is still taking place) by the leaching and reprecipitation of uranium and vanadium from the tuffs through the action of groundwater above the water table. The position of the water table in the areas where the carnotite occurs is not known; but it must be at a very considerable depth, probably some hundreds of feet. Rainwater from brief, infrequent storms rapidly soaks into the ground where it takes into solution various substances, including uranium and vanadium if present. The water may then either continue downward or return upward by capillary attraction as the surface dries. These solutions deposit calcite, gypsum and other less common minerals (including carnotite) as caliche. Thus the carnotite is part of the caliche. The result is that the uranium is dispersed vertically but locally concentrated along channelways which are commonly vertical. Joints and faults naturally are favorable for the accumulation of carnotite for these provide the channelways for the groundwater.

The concentration in the sandy beds at the top of the Toroweap and Supai formations may be explained by considering the channels available to descending solutions. Generally the limestones, and to a lesser extent the sandstones, are massive and therefore tend to break in continuous fractures on deformation. On the other hand, the shaley beds yield along many closely spaced fractures which are not necessarily of great extent; thus the shales remain relatively impermeable. The uranium mineralization should be concentrated just above the shaley beds in the Toroweap and Supai formations because this is a region in which the descending solutions are temporarily dammed. This hypothesis is notably supported by the fact that the best showings in the sediments are in the two horizons mentioned above.

Except for the occurrences above the Erie tuff, none of the other types of carnotite mineralization illustrated in Figure 3 need explanation. Carnotite Localities 11, 14 and 15 are in sands and gravels which are at least 30 feet, and possibly several times that, above the top of the Erie tuff. Capillary rise alone cannot possibly explain this mineralization because Meinzer (1923) has shown that the maximum capillary lift is probably less than ten feet. One possibility which cannot be eliminated is that there was another tuff higher in the section which has now been completely removed by erosion. However, a second tuff need not be called on when it is realized that due to the southeast dip of the tuff it is readily possible for solutions to flow out into the gravels which overlie the volcanics. The lateral movement of groundwater is also

Figure 3 SCHEMATIC CROSS SECTION SHOWING RELATIONSHIP BETWEEN THE ERIE TUFF AND THE CARNOTITE OCCURRENCES

- Carnotite Occurrences
- Al Undifferentiated Alluvium
- Qb Quaternary Basalt
- Tvt Erie Tuff
- Tal Tertiary Alluvium
- Rm Moenkopi Fm.
- Pk Kaibab Fm.
- Pt Toroweap Fm.
- Ps Supai Fm.
- Cbs Bird Spring Fm.
- Cmc Monte Cristo Fm.
- Ds Sultan Fm.
- CDg Goodsprings Fm.



avored by the presence of impermeable dense caliche horizons in the gravels. The basalt of carnotite Locality 11 may also have formed the base for a temporary aquifer.

It should be noted that, as the source of the uranium and vanadium is related to the pre-tuff topography, the carnotite should not be expected to continue indefinitely down dip.

Discussion of Improbable Modes of Origin

A hydrothermal origin does not explain the widespread deposits of uniformly low grade. The lack of hydrothermal minerals or their oxidation products and the absence of any alteration argues against mineralization from deepseated solutions.

The presence of the fresh, coarse feldspar crystals in the gravels suggests another possible, though equally improbable, mode of formation for the carnotite. It is conceivable that the alteration of detrital grains of primary uranium-bearing minerals, such as are occasionally found in pegmatites, could result in the carnotite. If this were the source, the gravels would be expected to show most of the mineralization whereas there should be little or none in the consolidated sediments or tuff.

A syngenetic origin for the carnotite in the Permian sediment fails to explain why the mineralization is only along fractures and does not penetrate the rock. There are no plant fragments or old stream channels like those so commonly associated with the carnotite deposits of the Colorado Plateau to which some authors attribute a syngenetic concentration.

No indication exists that the uranium might have been leached from the older rocks (Bird Spring, Supai, Toroweap and Kaibab) which form the hills. If such a hypothesis were valid, appreciable concentrations of uranium should be found in the dry lakes of the region rather than in the gravels and volcanics.

Evaluation of the Possibility of Producing Uranium Commercially

The possibility of producing uranium ore from any of these deposits is extremely slight. From a comparison of the uranium abundances, as indicated by the scintillometer readings given in Table 3, it is apparent that the tuff contains far more radioactive material than either the consolidated sediments or the gravels. The fluorimetric uranium determinations show that the higher radioactivity of the tuff is not entirely due to the presence of thorium and potassium, but that the Erie tuff is definitely rich in uranium. Therefore, unless the tuff is of importance, all of the known showings outside of the tuff may be eliminated from consideration.

Within the tuff only one showing, the previously mentioned caliche "vein" at carnotite Locality 7, is even near commercial grade; and it is likely that at most only a few tons of such material exist. The tuff itself can probably be ruled out because, despite its large tonnage and its nearness to transportation and electric power, the grade is too low by a factor of 100 or more. Moreover, the extraction of uranium from the glass phase, where most of it is presumably concentrated, would provide serious metallurgical problems.

It is possible that significant concentrations of uranium could be localized by some natural "trap" such as a bed of lignite or bentonite. However, no such horizons were observed in the field.

The only remaining possibility of the occurrence of uranium in economically significant quantities is based on theoretical considerations regarding the origin of the Erie tuff.

Origin of the Erie Tuff

The origin of the Erie tuff is pertinent as a matter of theoretical interest and of possible economic significance. This question is most suitably approached from the viewpoint of its chemical composition in relation to plutonic rocks. Table 6 shows the composition of the Erie tuff compared with Daly's average granite, rhyolite, granodiorite and quartz latite (quoted from Barth, 1952, p. 69). These rocks were chosen because their silica content is comparable to that of the tuff.

The trace element composition is also important in this consideration. Table 7 gives the average results of six semiquantitative spectrographic analyses compared to the trace element composition of granite.

In interpreting data such as these, several factors must be considered. (1) The data for trace elements in rocks varies considerably in its representativeness: some figures are well substantiated whereas others are the result of only a few determinations. (2) Those elements which are abundant in one stage of magmatic processes and markedly rare in other stages (i. e., chromium or potassium, to take extremes) are likely to show wide variation when present only in trace amounts. Similarly, inclusions of mafic rocks may contaminate a sialic rock with more than normal trace amounts of constituents such as nickel or chromium. (3) The Erie tuff is not of granitic composition, but is closer to an alkali-rich intermediate rock. (4) Metallogenic provinces do exist in which certain elements are found in unusual concentrations. In this connection it is of interest to note that a tuff from Table Mountain and a latite flow from the volcanic center east of Erie gave very similar trace element analyses to those from the Erie tuff. This shows that, except for uranium, the Erie tuff is not unique in composition. Concerning the metallogenic province concept, it is noteworthy that, aside from uranium, the main elements concentrated in the tuff are the rare

Table 6
 Comparison of the Major Constituents in
 Erie Tuff and Other Igneous Rocks

	Erie tuff (avg. of 4)	Granite	Rhyolite	Granodior.	Qtz. Latite
SiO_2	66.95	70.18	72.80	65.01	62.43
TiO_2	0.52	0.39	0.33	0.57	0.85
Al_2O_3	15.01	14.47	13.49	15.94	16.15
Fe_2O_3	1.94	1.57	1.45	1.74	4.04
FeO	0.41	1.78	0.88	2.65	1.20
MnO	0.08	0.12	0.08	0.07	0.09
MgO	1.16	0.88	0.38	1.91	1.74
CaO	1.45	1.99	1.20	4.42	4.24
Na_2O	4.04	3.48	3.38	3.70	3.34
K_2O	5.83	4.11	4.46	2.75	3.75
H_2O^+	2.17				
H_2O^-	0.61	0.84	1.47	1.04	1.90
P_2O_5	0.08	0.19	0.08	0.20	0.27

Table 7

Trace Element Comparison between the Erie Tuff and Granite

(Granite data are from Rankama and Sahama, 1950)

Element	Erie Tuff	Granite	Concentration factor (Erie tuff/granite)
U	0.0010%*	0.0004%	2.5
B	.01-.05	.0003	100
Ce	.01-.05	.0025	10
La	.01-.05	.0019	10
Nd	.01-.05	.0018	10
Cr	.001-.005	.0002	10
Sc	.001-.005	.0005	5
Cu	.001-.005	.007	2
Pb	.001-.005	.0016	1
Mo	.001-.005	.001 (?)	1
Ga	.001-.005	.001	1
Be	.0001-.0005	.0002	1
Y	.001-.005	.0017	1
Ni	.005-.01	.008	1
Yb	.0001-.0005	.0003	1
V	.005-.01	.015	0.5
Zr	.005-.01	.022	0.5

The following elements are below sensitivity and the values given are the maximum possible.

Th	< 0.08%	0.0011%	< 7
Li	< .04	.01	< 4
Sn	< .004	.004	< 1
Nb	< .001	.002	< 1.5
W	< .07	.0005	Sensitivity too low for any comparison.
Ta	< .1	.002	
Rb	< 7.0	.03	
Cs	< .8	.0007	

* Fluorimetric determination

earths; and the largest known minable concentration of rare earths occurs only 30 miles away at Mountain Pass, California. (5) It must be emphasized that the spectrographic data presented are only semiquantitative.

The high boron concentration may be due to regional variation since most of the analyses give 0.01-0.05% B; or it may reflect the lack of representativeness of the data on the abundance of boron in granite. With respect to the latter possibility, Wasserstein (1951) notes in his study of South African granites that 0.02% B_2O_3 is not rare.

A significant difference shown in Table 6 is the high potash and soda content of the tuff complemented by low magnesia, lime and iron oxide. As most of the mafic minerals in the tuff are present as inclusions, the contrast becomes more pronounced for uncontaminated material.

In the slow crystallization of a magma at some depth in the crust the fluid phase is believed to become progressively enriched in the alkalis and silica as the more mafic constituents separate as crystals. Also concentrated in the residuum are ions which are insufficiently abundant to form their own minerals and which, because of their size or charge, are not taken into the crystal lattices of the earlier crystallizing substances. In this manner, the magma is enriched in uranium, thorium, rare earths, boron, beryllium, zirconium, hafnium, niobium, tantalum, lithium, rubidium, cesium, yttrium, tin, tungsten, and other ions, assuming that they are present to begin with. Moreover, as the magma is crystallized the percentage of the volatiles, chiefly water, rises greatly and the pressure increases. Under abyssal conditions these residual fluids may form pegmatites with their concentrations of rare elements. This process may also produce hydrothermal solutions which may carry sufficient amounts of metallic elements to form ore deposits. At shallower depths the gas pressure may lead to violent volcanic activity which would tend to extrude material with a composition similar to that of the residual fluid.

In order to place the Erie tuff in this scheme one must consider several facts. (1) The tuff is welded and must have been the product of an extremely violent eruption, i. e., high gas pressure, rapidly released. (2) The rock is rich in uranium, potassium and sodium. (3) Other elements present in concentrations greater than those found in plutonic rocks may reflect only a regional concentration and may not be closely related to the high uranium content. The conclusion reached is that the tuff is the extruded portion of a residual magmatic fluid.

Simple measurements from Plate 1 indicate that the area formerly occupied by the Erie tuff is at least 60 square miles. Assuming that the 100-foot thickness observed was uniform, this gives an original volume of over one cubic mile. If a cubic mile of rock can be ejected in a short period of time, is it not reasonable to assume that a sizable amount of similar material may have remained at depth where it could have crystallized slowly? In such a slow crystallization it is possible that some of the uranium could be removed by means of hydrothermal

solutions. Table 8 gives the results of calculations in which a cubic mile of Erie tuff has water and uranium subtracted until these substances are of approximately the concentrations normally found in a granite or granodiorite. A specific gravity of 2.65 is assumed.

Table 8

	Erie Tuff	Granite or Granodiorite	Difference
H ₂ O% (Table 6)	2.0%	1.0%	1.0%
H ₂ O tons/mile ³	244,000,000	122,000,000	122,000,000
U% (Table 7)	0.0010%	0.0004%	0.0006%
U tons/mile ³	122,000	49,000	73,000

The above illustrates how considerable quantities of uranium conceivably could be derived from a cubic mile of material having the composition of the Erie tuff, and that abundant water would be available for hydrothermal solutions. Admittedly the actual figures in such a calculation are of little value, but there is undoubtedly the possibility that hydrothermal deposits could be associated with the magmatic processes which formed the tuff.

The location of such deposits, if they exist, is at best only an intelligent guess, and probably of theoretical interest at most. Inasmuch as there has been comparatively little erosion since the deposition of the tuff, the depth to the mineralized zone could very well exceed that of practical exploration or mining. If such a deposit were to exist near the surface, it very probably would be concealed by alluvium or more recent volcanic rocks. The use of trace element abundance data from extrusive sialic rocks may provide a method of reconnaissance exploration not only for uranium, but for many materials which are believed to be associated with magmatic activity.

Conclusions

1. Small amounts of uranium mineralization occur in widely scattered localities east of the Goodsprings Quadrangle and in at least one locality two miles north of Goodsprings.
2. The uranium mineral is universally carnotite.
3. All of the deposits are of a common origin. They were deposited from groundwater above the water table in recent geologic time, the mode of deposition being similar to that of caliche.

4. Structural control is effective in the localization of the mineralization because joints and minor faults provide channelways for circulating groundwater.
5. The known deposits are not of sufficient grade to be of economic significance, and there is little possibility that they are related to large undiscovered deposits of the same type.
6. The source of the uranium and much of the vanadium is the Erie tuff which contains a high concentration of uranium. A different tuff, probably related to the tuffs of Table Mountain was the source of the uranium in the occurrence north of Goodsprings.
7. Manganese dioxide and uranium are independent in their occurrence.
8. The Erie tuff is the extruded portion of a residual magmatic fluid in which uranium was concentrated.
9. It is possible that the same magmatic process which produced the tuff gave rise to hydrothermal solutions which could have formed large deposits of uranium. The depth to such deposits, if they do exist, may be excessive for exploration or mining.
10. The vent from which the tuff was erupted is probably located east or southeast of Erie and is probably covered by more recent sediments and volcanic rocks.

Recommendations

1. The caliche "vein" at carnotite Locality 7 should be sampled to verify the suspicion that it too is not of economic significance.
2. If the above sampling proves the lack of material of ore grade no further work should be done on the deposits associated with the weathering of the Erie tuff. More localities certainly can be discovered, but there is no promise that they would be of higher grade.
3. Some type of reconnaissance work such as an airborne scintillometer survey should be conducted to investigate the possibility of near-surface hydrothermal uranium mineralization related to the parent magma of the Erie tuff. Any zones showing hydrothermal alteration or bleaching, whether radioactive or not, would be worth close investigation. The most promising area for investigation is east and southeast of Erie where it is suspected that the source vent of the Erie tuff is located.

PART II: THE URANIUM OCCURRENCES IN THE MINES

Introduction

Many of the mines of the Goodsprings District contain a radioactive material associated with the ores. The radioactivity is universally assumed to be associated with uranium on the basis of several chemical determinations. In all cases the radiometric determinations agree fairly well with the chemical analyses, suggesting that the uranium is close to equilibrium with its decay products. Therefore it is permissible to use radioactivity as a crude measure of uranium abundance. Table 9 gives a summary of the radioactivity observed in most of the mines and prospects. In general the uranium mineralization is very weak, and only occurrences having counts of over 100 cps or exhibiting some feature of particular interest are described. Plate 2 shows the distribution of the mines.

In order to visit as many mines as possible, detailed work was not carried out unless the occurrence was unusual in some way. Generally, the survey of a mine consisted of making a scintillometer survey of the dumps and workings and collecting radioactive specimens.

In most cases no uranium minerals could be recognized; instead, the various oxidation products of the base metal ores were found to be radioactive. This was noted with limonite, hydrozincite, ferruginous chert, and chrysocolla. In the preliminary report (Behre and Barton, 1954) it was stated that jarosite(?) and malachite are radioactive; but the "jarosite(?)" turned out to be a uranium mineral, and the radioactivity attributed to the malachite is probably from closely associated limonite. The uranium is believed to be fixed in the oxidized ores by adsorption, as demonstrated by experiments to be described on a later page. Secondary uranium minerals are found at the Green Monster and Singer-Tiffin mines and at the Desert Valley prospect. Carnotite has been identified from two of these localities, but so far it has not been possible to confirm the identification by Staatz (1950) of the uranium minerals from the Green Monster mine as kasolite and dumontite(?).

All of the mines are shallow, and oxidation is deep. Commonly galena is the only primary sulfide remaining. No primary uranium minerals have been identified. Some unoxidized, radioactive zinc ore is found at the Potosi mine, but polished sections and autoradiographs show that the radioactivity is from fragments of black shale intimately associated with the sphalerite. This will be further described below.

It is emphasized that no limits of uranium mineralization could be established. The mines farthest north, east, south and west, respectively the Potosi, Ireland, Tam o'Shanter and Desert Valley, all

Table 9

Summary of the Radioactivity in the Mines

Mine or Prospect	Principal Metals	Scintillometer Max. (cps)	B. G. (cps)	Localization of Radioactivity
1. Accident	Pb-Zn	15	10	nil
2. Addison	Pb-Zn	15	10	nil
3. Akron	Pb-Zn	10	10	nil
4. Alice	Pb-Zn	40	10	limonite
5. Alice Fraction	Cu	100	10	siliceous limonite, Ox. Cu minerals
6. Anchor	Pb-Zn	10	10	nil
7. Annex	Pb-Zn	10	10	nil
8. Argentina	Pb-Zn			nil (earlier check by AEC)
9. Azurite	Cu	40	10	limonite
10. Belle	Cu	5	5	nil (dump only)
11. Bico (Volcano)	Pb-Zn	30	10	hydrozincite
12. Bill Nye	Pb-Zn-V	15	10	nil
13. Black Jack	Pb-Zn	10	10	nil
14. Blue Jay	Cu-Co	15	15	nil (dump only)
15. Boss	Cu-Au-Pt	100	10	siliceous limonite, chrysocolla
16. Bullion	Pb-Zn	30	10	Hydrozincite
17. Chaquita	Au			nil (earlier check by AEC)
18. Christmas	Pb-Zn	10	10	nil
19. Clementina	Au			nil (earlier check by AEC)
20. Cobalt King No. 1	Co?			nil (earlier check by AEC)
21. Columbia	Cu	50	20	? possibly due to porphyry sill
22. Contact	Pb-Zn			nil (earlier check by AEC)
23. Copper Flower	Cu	175	15	chrysocolla, limonite
24. Copper Glance	Cu	30	10	limonite, oxidized Cu minerals
25. Copper Chief	Cu-Co	100	10	limonite, oxidized Cu minerals
26. Copperside	Cu	80	10	limonite, oxidized Cu minerals
27. Cosmopolitan	Cu	10	10	nil (dump only)
28. Daniel Boon	Pb-Zn	35	15	? uniformly high throughout
29. Dawn	Pb-Zn	10	10	nil
30. Desert Valley	Cu-Zn	90	10	U minerals, limonite, ox. Cu minerals
31. Doubleup	Cu	10	5	nil
32. Eureka	Cu	50	10	limonite, oxidized Cu minerals
33. Eureka-Silver Gem	Pb-Zn	10	10	nil

Table 9 -- (Continued)

Mine or Prospect	Principal Metals	Scintillometer Max. (cps)	B. G. (cps)	Localization of Radioactivity
34. Fitzhugh Lee	Cu	35	10	limonite, oxidized Cu minerals
35. Frederickson	Pb-Zn	10	10	nil
36. Golden Chariot	Au			nil (earlier check by AEC)
37. Green Copper	Cu	15	10	nil
38. Green Monster	Pb-Zn	high	10	U. minerals, hydrozincite, limonite, oxidized Cu minerals
39. Hansen Vanadium	V ?			nil (earlier check by AEC)
40. Hatchet	Pb-Zn-Cu	80	10	limonite, ox. Cu min., hydrozincite
41. Hermosa	Pb-Zn	50	10	limonite
42. Highline	Cu	60	10	limonite, oxidized Cu minerals
43. Hoodoo	Pb-Zn	15	10	nil
44. Hoosier	Pb-Zn	50	10	hydrozincite
45. Ireland	Pb-Zn-Cu	50	10	sheared shale
46. Iron Gold	Au	10	10	nil
47. Ironside	Cu	60	10	limonite, oxidized Cu minerals
48. Keystone	Au	25	10	limonite (dump only)
49. Kirby	Pb-Zn	10	10	nil (dump only)
50. Lavina	Ag	10	10	nil (dump only)
51. Lincoln	Cu	90	10	Limonite, oxidized Cu minerals
52. Little Betty	Pb-Zn	70	15	hydrozincite, iron-rich chert
53. Lookout	Pb-Zn	10	10	nil
54. Middlesex	Pb-Zn	10	10	nil (dump only)
55. Milford	Pb-Zn	40	10	siliceous limonite
56. Milford No. 2	Pb-Zn	200	10	hydrozincite, limonite
57. Mobile	Pb-Zn	10	10	nil
58. Mohawk No. 7	Cu	200	10	limonite, oxidized Cu minerals
59. Mongolian	Pb-Zn	10	10	nil
60. Monte Cristo	Pb-Zn	10	10	nil
61. Mountain Queen	Pb-Zn	10	10	nil (dump only)
62. Mountain Top	Pb-Zn	15	10	nil
63. Ninty Nine	Cu	10	10	nil (near surface workings only)
64. Oro Amigo	Cu	60	10	limonite, oxidized Cu minerals
65. Over	Pb-Zn	110 ?	50 ?	probably oxidized Cu minerals

Table 9 -- (Continued)

Mine or Prospect	Principal Metals	Scintillometer		Localization of Radioactivity
		Max. (cps)	B.G. (cps)	
66. Palace-Porter	Pb-Zn	10	10	nil
67. Paradise	Cu	50	10	hydrozincite, oxidized Cu minerals
68. Pauline	Pb-Zn			nil (earlier check by AEC)
69. Pilgrim	Pb-Zn	10	10	nil (dump only)
70. Platina	Cu	40	10	limonite, chrysocolla
71. Potesi	Pb-Zn	275	10	not identified, hydrozincite
72. Prairie Flower	Pb-Zn			nil (earlier check by AEC)
73. Puelz	Pb-Zn	10	10	nil
74. Rainbow	Cu	10	10	nil
75. Red Cloud	Au	10	10	nil (dump only)
76. Root	Pb-Zn	100	10	limonite
77. Rose	Cu-Pb	25	10	limonite
78. Rosetta nos. 1 & 2	Cu	250	10	limonite, chrysocolla
79. Royal Blue	Cu	35	10	limonite, oxidized Cu minerals
80. Ruth	Pb	20	10	nil
81. Shenandoah	Pb-Zn	50	10	limonite
82. Singer-Tiffin	Pb-Zn	400	10	limonite, hydrozincite, carnotite, oxidized Cu minerals
83. Smithsonite	Pb-Zn	30	10	probably from abundant limonite
84. Snowstorm	Cu	10	10	nil
85. Spelter	Pb-Zn	90	10	hydrozincite
86. Star	Pb-Zn			nil (earlier check by AEC)
87. Sultan	Pb-Zn	50	10	limonite, hydrozincite
88. Surprise	Pb-Zn	10	10	nil
89. Tam o'Shanter	Pb-Zn	225	10	limonite, oxidized Cu minerals (deep workings only)
90. Tom Thian	Pb-Zn	10	10	nil
91. Valley Forge	Pb-Zn-V	10	10	nil (dump only)
92. Whale	Pb-Zn-V	10	10	nil
93. Yellow Pine	Pb-Zn	200	10	limonite, hydrozincite, ox. Cu minerals
94. unknown	Cu	50	10	limonite, oxidized Cu minerals
95. unknown	Cu	60	30	limonite, oxidized Cu minerals

show at least traces of anomalous radioactivity. The only geographic generalization made is that the better showings are usually in the more western mines.

The association of the uranium with other elements and the significance of this distribution with regard to the source of the uranium will be discussed, following the descriptions of some of the more important occurrences.

Descriptions of the Uranium Occurrences

General descriptions of the mines of the Goodsprings Quadrangle are given by Hewett (1931). None of the mines was operating in 1954. Table 9 lists 95 mines and prospects of which 85 were visited in the course of this study. As most of these exhibit only traces of anomalous radioactivity, only the more significant occurrences are described.

Green Monster Mine

The Green Monster mine is located in section 1, R. 56 E., T. 24 S., near the west end of a rugged ridge. This has the best showing of uranium observed, and is the only deposit in the district from which uranium ore has been shipped. According to Nelson and Rambosek (1952), a small experimental shipment of selected uranium ore was sent to Marysville, Utah, early in 1951. Brokaw (Unpublished report of the U. S. Geological Survey) reports that the mine produced principally zinc with minor lead and a little copper. It is owned by the Hearst Land and Cattle Company of San Francisco, California.

General Geology

A reconnaissance geologic map of the area near the Green Monster mine was prepared in order to tie in the major structural features with those of the Goodsprings Quadrangle. The map is shown in Plate 3. The structure between the mine and the Goodsprings Quadrangle is basically a syncline plunging northwestward which preserves a little Supai red sandstone as the youngest rock. This structure has been overridden from the west by a thrust block which exposes beds well below the middle of the Goodsprings formation. The trace of the thrust continues southeastward and may be the northward extension of the Sultan thrust (Hewett, 1931, p. 48), but it is here called the Green Monster thrust (Hewett, personal communication). Another thrust fault crops out immediately to the west of the Green Monster mine. This is a bedding plane thrust in contrast to the Green Monster fault which is a fore-limb thrust.

The northeast limb of the syncline is gently dipping and comparatively undisturbed. It would offer an excellent locality for study of a single, almost unbroken exposure of the Bird Spring formation. On the other hand, the southwestern limb is much disturbed the beds vary

from horizontal to almost completely inverted. The overall dip of this limb is vertical; but near the base of the Bird Spring formation there are many shaley beds interbedded with the limestone, and in these drag folds up to several hundreds of feet in amplitude are developed. An excellent example of this is shown in the ridge above the Black Jack prospect. Because of minor structural irregularities, the exact position of the synclinal axis is unknown.

The Green Monster thrust is offset south of the Black Jack prospect by two tear faults. These tears are similar to the Ironside fault of the Goodsprings Quadrangle (Hewett, 1931, p. 49) in that they were formed during the period of thrusting and do not offset the beds below the thrust.

The thrust to the south of the Green Monster mine crops out as a band of breccia about 1000 feet wide. Many areas within this zone contain small disconnected segments of folds believed to represent less disturbed regions between zones of more active thrusting. Although the fault is approximately parallel to bedding, Yellowpine limestone is thrust upon Bird Springs within the breccia. The breccia is unmineralized and generally free from dolomitization.

Geology at the mine

Figure 4 shows the surface features in the immediate vicinity of the mine. The stratigraphic column is as follows:

Bird Spring formation

Thin to thick-bedded limestone, a few cherty beds, some sandy limestone locally cross-bedded with an amplitude of as much as 20', some thin shaley horizons, dark clastic limestone near the base 1000' plus

Thin-bedded quartzite and limestone conglomerate; thickness varies above unconformity 07-40'

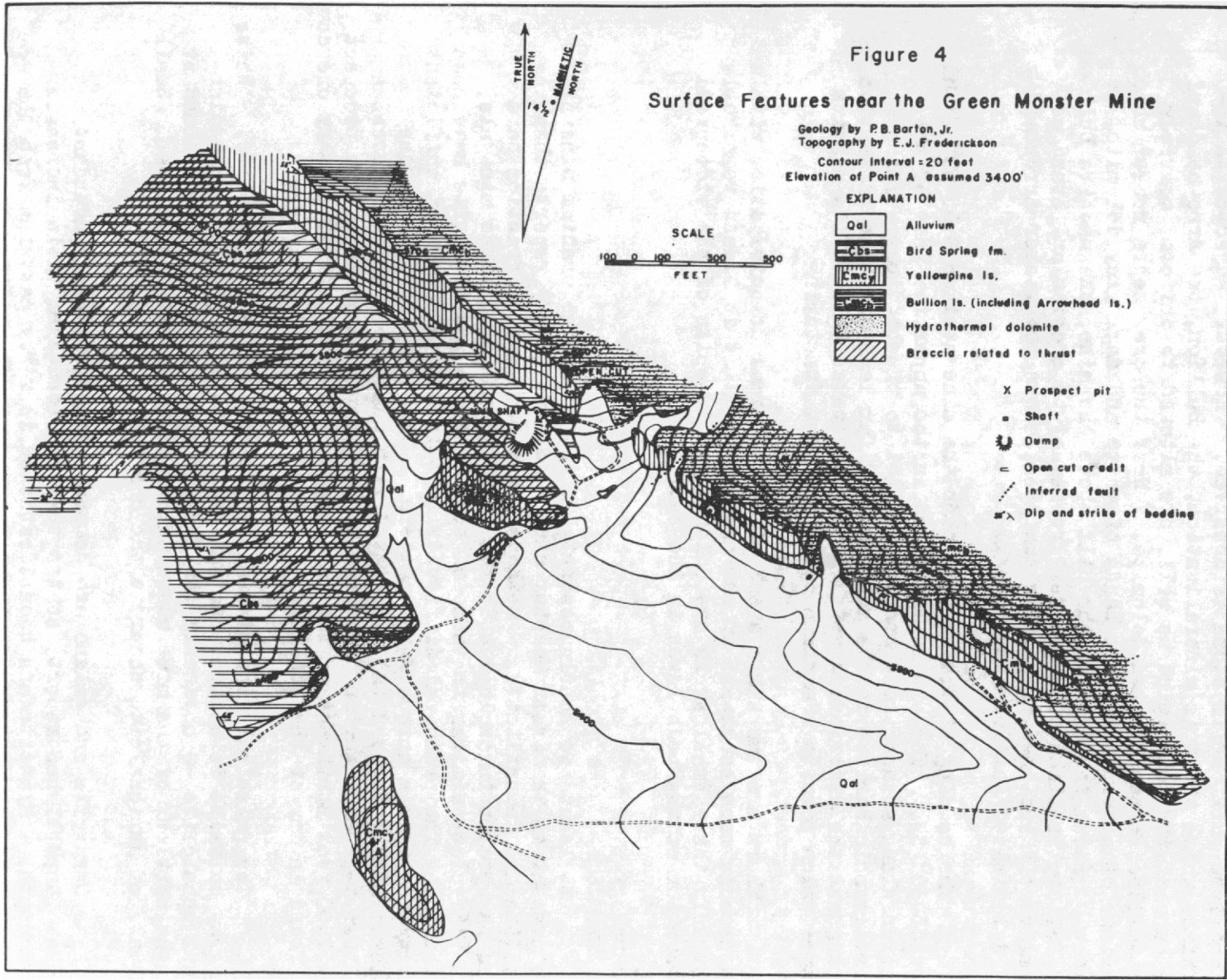
Unconformity

Monte Cristo formation

Yellowpine limestone member; massive dark limestone with many large Zaphrentis corals. 80-90'

Arrowhead limestone member: thin-bedded, fossiliferous limestone and gray shale 10-12'

Bullion member: massive, dark, coarse grained limestone, almost everywhere altered to massive, coarsely crystalline, cream colored dolomite 100' plus



This area is one of few in the Goodsprings region where the undolomitized Bullion limestone is observed. However, adjacent to the workings where there is mineralization, the Bullion, the Arrowhead and the base of the Yellowpine as well, are altered to uniform, coarsely crystalline, cream colored dolomite. Near the ore "zebra rock," which consists of alternating thin bands of white and dark gray dolomite, is common. Along the base of the hill above the mine, the massive Bullion and Yellowpine limestones are very resistant to erosion and stand as "flatirons," inclined triangular surfaces, above the weaker Arrowhead and dolomitized Bullion limestones.

The bedding at the surface near the mine strikes N 55-60° W and dips 55-60° SW. The ore is localized in the upper few feet of the Bullion along a shear zone nearly parallel to the bedding. This stratigraphic horizon is the most favored for lead-zinc mineralization throughout the district; Hewett (1931) attributes this to its massive nature which permits a maximum development of fracturing.

There are two small areas of hydrothermal dolomitization within the breccia zone southwest of the main shaft. It is indeed remarkable that only these small areas are dolomitized in spite of the widespread alteration of the beds lower in the section.

Mineralogy

At least two nonfluorescent, yellow or orange uranium minerals are present in the Green Monster mine. Staats (1950) reports these as kasolite and dumontite(?). Methods based on X-ray diffraction have thus far proven inconclusive in the identification of these minerals, but "d" values similar to those of both kasolite and dumontite have been obtained. The principal difficulty is obtaining a sample of sufficient purity to yield a unique X-ray pattern. Traces of carnotite (see Appendix A for X-ray data) associated with chalcedony which fluoresces yellowish-green occur on fractures in Bird Spring limestone in a prospect pit 1500 feet northwest of the main shaft. No radioactive primary ore could be found in any of the workings.

The principal zinc mineral is brown to white hydrozincite. White to gray calamine is common, and smithsonite is also present. Reddish-brown sphalerite -- obviously the primary zinc ore -- is fairly abundant in the portions of the mine where oxidation is as yet incomplete. Small amounts of aurichalcite occur in the ore bodies.

Cerussite and galena are common but not extremely abundant. Brokaw (unpublished report) states that the lead-zinc ratio increases with depth. Mimetite has been identified in X-ray patterns from the uranium ores.

In the upper workings malachite and chrysocolla are common as halos bordering limonite lenses and veins. It is very likely that these represent oxidized stringers of chalcopryite, though no primary copper sulfides remain as proof.

Goethite and hematite occur commonly with the oxidized copper minerals and as pseudomorphs after pyrite, but otherwise there is little iron. Presumably the brown color of the hydrozincite is due to disseminated limonite formed in situ from extremely fine grains of pyrite observed in the sphalerite. A few crystals of pyrite showing cockade structure were found enclosed by sphalerite.

Study of four polished sections of the unoxidized ore suggests the following paragenetic sequence:

Dolomite	----- - - - - -----
Pyrite	--- ---
Sphalerite	-----
Calcopyrite	-?-
Galena	-?-

The textures of the primary ore show that the mineralization was predominantly open space filling.

Ore Bodies and Uranium Mineralization

The main workings consist of four shafts, an open cut connected with the largest stope and about 2100 feet of drift on three levels. Ore has been mined from four irregular stopes having a vertical range of 380 feet according to Brokaw (unpublished report). The lowest level was inaccessible at the time of the present study.

Brokaw (unpublished report) observes that the ore is localized at the brecciated intersections between bedding plane faults and low angle thrusts which branch from the sheared contact between the Bullion and Arrowhead members of the Monte Cristo formation. This explains the shape of the ore shoots — pipes or lathlike bodies pitching 30° to 60° to the southeast. He also proposes that the steeply dipping tear faults which strike slightly east of north were the conduits through which the mineralizing solutions ascended.

Important uranium mineralization is confined to the uppermost portion of the largest ore shoot, that is, to the region just below the open cut. Significantly, this is the only part of the mine in which copper mineralization is abundant. Maximum scintillometer readings here are slightly over 500 cps compared to a background of 10 cps. The radioactivity decreases rapidly downward and is 50 to 100 cps on the upper level. On the intermediate level the readings are up to 40 cps in the stopes with maxima of about 70 cps near small areas of limonite and oxidized copper minerals. Not all copper staining indicates the presence of uranium, but the absence of copper coloration usually precludes

anomalous radioactivity. No yellow uranium minerals were observed in these studies below the upper level, but Hill (1944) reports minor amounts in lower levels.

The radioactive materials are limonite, chrysocolla and hydrozincite in addition to the uranium minerals. The most common of these is hydrozincite, but in general it is radioactive only near copper staining. Specimens of hydrozincite from the vicinity of the open cut gave $e \text{ U}_3\text{O}_8 = 0.22\%$ and $c \text{ U}_3\text{O}_8 = 0.239\%$. Limonite from the same general area gave $e \text{ U}_3\text{O}_8 = 0.15\%$ and $c \text{ U}_3\text{O}_8 = 0.106\%$. The close agreement between radiometric and chemical analyses strongly suggests that the uranium is approximately in equilibrium with its decay products and that the counts are not from adsorbed radium or thorium without uranium.

Just below the open cut yellow uranium minerals are common as fracture coatings in the footwall dolomite for a distance of five or more feet below a band of limonite and oxidized copper minerals; no uranium minerals could be found in the hanging wall. The fractures are predominantly steeply dipping joints which strike $N 15^\circ E$. The limonite band is up to a foot thick and is surrounded by a halo of malachite and chrysocolla up to three inches wide. Most of the limonite appears to be indigenous and there are no relict structures. The analysis of uranium-bearing limonite mentioned above is from this zone. This is interpreted as representing the oxidized product of a chalcopyrite-pyrite vein containing significant amounts of pitchblende. On oxidation, the uranium in excess of that adsorbed by the limonite, chrysocolla and such hydrozincite as is present was carried in solution into the fractures below the primary ore zone and was precipitated as complex secondary uranium minerals.

Adequate sampling of such a deposit would be very difficult, partly because of the irregular nature of the primary mineralization, partly because of the formation of secondary uranium minerals along fractures of indefinite extent and non-uniform spacing. Material of ore grade appears to be small in quantity, and further extension of the known orebody seems unlikely. The surface workings consist of a few shallow pits and show only very minor radioactivity, usually from ferruginous chert. Except for that near the uranium stope bearing, the dump material is not appreciably radioactive.

A small unnamed mine 1800 feet southeast of the main shaft of the Green Monster in the same structural and stratigraphic position shows only very slight radioactivity from hydrozincite and no copper mineralization. The workings consist of an adit, some short drifts, two small stopes (one of which is open to the surface), and some deeper inaccessible workings of unknown extent. This mine is shown in Figure 4, but because of the lack of radioactivity was neither mapped nor sampled.

The only other occurrence of uranium minerals in the area included in Figure 4 is in a small prospect pit in the saddle 1500 feet northwest of the main shaft of the Green Monster. Here very minor films of carnotite and fluorescent chalcedony coat fragments of dark gray, clastic limestone of the basal portion of the Bird Spring formation. The pit is immediately beneath the thrust breccia. The quartzite beds of the Bird Spring formation do not crop out in the saddle and have probably pinched out between the mine and this point. The radioactivity in the vicinity of the pit is 40 cps with a background of 10 cps. The source of this uranium and the reason for its localization are unknown.

The entire outcrop of the Yellow pine, Arrowhead and upper part of the Bullion members was checked with the scintillometer from a point half a mile southeast of the Green Monster mine to the Desert Valley prospect. No additional radioactive anomalies were discovered.

Desert Valley Prospect

A rather large prospect, the Desert Valley, is located about 3000 feet northwest of the Green Monster mine along the same structure and at an identical stratigraphic position. The workings include several small pits and trenches and an inclined shaft about 50 feet deep with short drifts at two levels. These explore a poorly defined shear zone in dolomitized Bullion limestone just below the contact with the Arrowhead limestone. As at the Green Monster, the top 20-25 feet of the Bullion are not dolomitized except for an aureole around the mineralized zone. The sheared zone is almost parallel to the bedding which here strikes N 58° W and dips 65° SW.

Limonite, galena and oxidized copper, zinc and lead minerals are found in minor amounts impregnating wallrock along vertical fractures which strike N 40° E. No significant amount of material that could be classified as ore was seen. Piles of copper minerals on the dump gave maximum scintillometer readings of 90 cps compared to a background of 15 cps.

Several small pieces of a yellow uranium mineral giving an x-ray pattern similar to some of the material from the Green Monster mine were found on the dump closely associated with goethite and hematite. Traces of this mineral were found in place underground, but the total observed would be measured in ounces. Here the uranium mineral was not closely associated with copper staining.

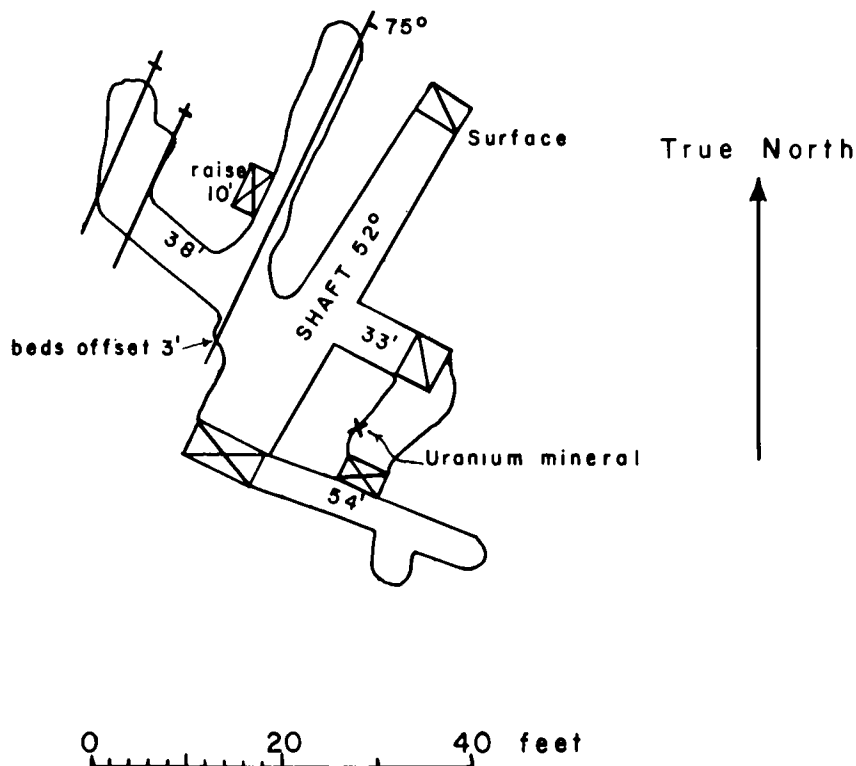


Figure 5. MAP OF DESERT VALLEY PROSPECT

Mohawk No. 7 Prospect

Just west of the Goodsprings Quadrangle, on the south side of the ridge which extends westward to Green Monster mine (see Plate 3) is the Mohawk No. 7 prospect. The country rock is dolomitized Bullion limestone which strikes $N 30^{\circ} W$ and dips $40^{\circ} SW$. A sheared zone nearly parallel to bedding and about 20 feet below the base of the Arrowhead limestone shows a narrow but fairly continuous band of limonite and oxidized copper minerals about 150 feet long, which becomes increasingly radioactive toward the northern end. Scintillometer readings up to 200 cps are given from small surface exposures of goethite surrounded by halos of malachite with some chrysocolla. No zinc minerals were seen. The total mineralization cropping out is small.

A few hundred feet to the south the Rainbow prospect has much better showings of oxidized copper minerals, but there is no anomalous radioactivity. This area is especially interesting because the structural and stratigraphic situation is very similar to that at the Green Monster mine. The contact between the Arrowhead limestone and the Bullion dolomite was examined northward for more than a mile but neither radioactive anomalies nor mineralization were found.

Singer-Tiffin Mine

This mine is located in the northwest 1/4 of section 18, T. 25 S., R. 58 E. The first recorded uranium occurrence in the mines of the Goodsprings district is mentioned by J. M. Hill (1912) from the Beck mine near the Singer-Tiffin. He notes that yellow crystals of pyromorphite were supposed to contain uranium.

Except for the Green Monster mine, the Singer-Tiffin has the best uranium showing observed in the Goodsprings area. The property consists of two mines about 300 feet apart which explore the base of the hill just north of Singer Wash. In addition, the hill above the mines is explored by many pits and smaller tunnels. Lead and zinc were the chief metals produced.

The ore minerals are principally the oxidation products of zinc and lead sulfides, though there is some unoxidized galena. Malachite aurichalcite, limonite and ferruginous chert are common.

According to Hewett (1931), the mines are in the fractured zone just above the sole of the Sultan thrust which here places Anchor and Bullion dolomitized limestones above Bird Spring limestones. The rock is much broken and the lower workings are in what is practically a breccia. Almost all of the limestone is dolomitized and the structural configuration is difficult to interpret.

The Singer mine consists of about 450 feet of drifting and several small stopes on the main level. A winze inclined at 50° and 240 feet deep along the slope leads to a lower level where there are perhaps 400 feet of wandering tunnel without any visible ore. The lowest ore observed is in a small stope about half-way down the winze. The Tiffin has many hundreds of feet of irregular drifting and several small stopes near the adit.

Both mines explore highly broken dolomite which is cut by many faults that seem to be pre-ore as well as post-ore. The ore forms erratic shoots related to faults which cut the breccia. At the Singer mine, irregular lenses of ore occur along what may be a bedding plane shear zone that strikes about N 30° E and dips 25-50° SE.

The major radioactive parts of this property are found near the end of the southwest branch of the Singer and in a short prospect tunnel

almost directly above the lower radioactive region; at both points the scintillometer maximum readings were 400 cps compared to a background of 10-20 cps.

The near-surface activity is associated with a lens of limonite 8 inches thick. The limonite is surrounded by a halo of oxidized copper minerals 1/4 to 1 inch wide. The approximate trend of the lens is N 70° W., 55° SW. The fractures in this material are coated with a fine grained, yellow to orange mineral identified as mimetite by x-ray methods. The sample tested contained only mimetite, but it is possible that yellow uranium minerals are present in other specimens. Hill (1944) quotes Mr. C. Beck, the mine owner, that yellow crystals were identified by the Mining Bureau of California as a uranium phosphate. Thin stringers of galena are found nearby but are not radioactive.

Inside the Singer a prominent fault trends N 30° E., dips 25° S., and forms the back at the end of the southeast branch of the workings. This fault shows a thin, red, clay-like gouge which gives the maximum radioactivity. Below the fault a few grains of galena and cerussite are found in friable dolomite and the radioactivity is much lower. Above the fault for a distance of about 18 inches nodules of ferruginous chert are surrounded by halos of copper staining which give counts up to 300 cps. Black specks of stannierite are common in this area, but their occurrence seems to be independent of the radioactivity. An 18-inch chip sample across the most radioactive zone gave $e U_3O_8 = 0.05\%$ and $e U_3O_8 = 0.033\%$. Hydrozincite not associated with the fault gives counts as high as 250 cps.

Elsewhere underground in the Singer and Tiffin and in the surface workings as far as the hilltop, counts up to 100 cps are noted from limonite, hydrozincite and oxidized copper minerals. Yellow to yellowish green carnotite (See Appendix A for x-ray data) is found sparingly along two prominent postmineral faults, one of which forms the contact between the dolomite and a Tertiary andesite flow. An assay from the andesite gave $e U_3O_8 = 0.01\%$ and $c U_3O_8 = 0.01\%$. The deepest workings of the Singer have a uniform radioactivity of about 40 cps compared to a background of 10-20 cps. As no ore is seen, it is possible that this is due to radon gas from the workings above or from an unknown source.

A dike of lamprophyre about 10 feet thick is found at the top of the hill; it strikes about N 80° E and is vertical. One of the tunnels in the Tiffin also exposes material resembling an altered igneous rock. Neither of these rocks seem related to mineralization or radioactivity.

Paradise Prospect

The Paradise prospect is in the southeast 1/4 section 35, T. 23 S., R. 57 E., and is at present controlled by R. E. MacDonald and D. W. Lowe of Goodsprings. This claim consists of several small pits and short

tunnels into steeply dipping beds of dolomitized Monte Cristo limestone, upturned under the Keystone thrust.

The mineralization consists of minor replacements along fractures by oxidized copper minerals, mainly malachite. The copper minerals are slightly radioactive, but the best count, 50 cps compared to a background of 10 cps, is from an earthy white material which is at least in part hydrozincite.

About 2000 feet to the southeast there are several similar prospects two of which have comparable radioactivity associated with small lenses of ferruginous chert, limonite and copper staining.

Copper Flower Mine

The Copper Flower mine, also known as the Vanadium Wedge and Last Chance, is in the center of the eastern 1/3 of section 11, T. 25 S., R. 57 E. The workings consist of a short drift and two very small stopes. They explore a steeply dipping fracture zone near the base of the dolomitized Anchor limestone close to the Sultan thrust which here dips to the east (Hewett, 1931). A small amount of radioactive chrysocolla and limonite was found in fault breccia, but there is very little additional ore in sight. Piles of oxidized copper minerals from the dump gave maximum scintillometer readings of 175 cps compared to a background of 15 cps. Specimens of chrysocolla from the dump assay $e U_3O_8 = 0.08\%$, $c U_3O_8 = 0.116\%$. Hill (1944) reports that 1 car of 20% copper ore had been shipped.

Yellow Pine Mine

This mine is located 4 miles northwest of Goodsprings. It is by far the largest in the district. The property is well described by Hewett (1931), and only a brief discussion will be given here.

Zinc is the principal metal produced although considerable quantities of lead and some copper have been mined. Hydrozincite is the chief ore mineral though most of the common oxidation products of zinc, lead, copper and iron ores have been identified. Except for very minor pyrite, stibnite and cinnabar on the 900 level, no primary ore other than galena was observed. The orebodies are confined to the dolomitized Yellowpine limestone which is overlain by a thick sill of granite porphyry that intrudes the base of the Bird Spring formation. There are extensive underground workings on 10 levels and several large stopes. The orebodies are localized by sheared zones whose attitude is nearly parallel to the bedding.

As at the Green Monster mine, radioactivity is very closely associated with copper mineralization. The maximum scintillometer

reading of 200 cps was observed in a prospect pit at the side of a wash near the southeast end of the property. The radioactive material is porous, massive, siliceous limonite with small amounts of malachite and chrysocolla. The following is the analysis from a selected radioactive sample; $e U_3O_8 = 0.02\%$ and $e U_3O_8 = 0.017\%$. Small outcrops of similar, but less radioactive, siliceous limonite are found northeastward. These may represent the up-dip extension of the copper bearing zinc bodies mined on the 100 and 200 levels.

In the stope on the 100 level limonite and oxidized copper minerals are abundant. These are radioactive, but the maximum activity of 95 cps is from hydrozincite closely associated with copper mineralization. Zinc ore without noticeable amounts of copper or iron gives 40 or less cps. The porphyry uniformly gives 30 cps; the background is 20 cps. On the lower levels copper staining is less abundant; but almost without exception, the highest counts are in the vicinity of limonite or oxidized copper minerals. One notable contradiction to the above rule is found on the 900 level where pure white hydrozincite without any visible trace of copper gives a scintillometer reading of 75 cps. However, this hydrozincite has been deposited in a fracture by descending waters from oxidizing ores above, and therefore the uranium may have migrated with the zinc.

Alice Fraction Prospect

On the hilltop about 200 yards southeast of the Yellowpine mine there are a few small pits and trenches in Bullion dolomite which expose a 2 foot vein of limonitic chert containing oxidized copper minerals. The vein strikes N 25° E and dips nearly vertically. The maximum scintillometer reading is 100 cps compared to a background of 10 cps.

Copper Chief Mine

This mine is located in the northwest 1/4 of section 35, R. 57 E., T. 24 S. The workings are all shallow shafts, tunnels and pits which follow irregular mineralized fractures in the Bullion dolomite. Several parts of the workings give scintillometer readings of 100 cps with a background of 10 cps. The radioactivity is associated with siliceous limonite and to a lesser extent with chrysocolla. Malachite and stainierite are also common. According to Hewett (1931) this property has shipped small amounts of cobalt and copper ores.

Boss Mine

This property is located near the boundary between sections 27 and 34, R. 57 E., T. 24 S. The country rock is dolomite of the Monte Cristo formation which is cut by several faults. This mine is of particular interest because of the assembly of metals occurring in it.

Hewett (1931) records the production of copper, gold, silver, platinum, palladium, and lead. The amounts produced were not large, but the presence of platinum and palladium was certainly not expected.

Most of the workings are nonradioactive, but slightly higher scintillometer readings were observed near limonite lenses surrounded by halos of chrysocolla. Near the portal on the 100 level one such mass, an irregular lens of siliceous limonite 1 foot thick with a half-inch margin of chrysocolla, gave a count of 100 cps.

Rosetta 1 and 2

This property is located near the bottom of the canyon in the southern 1/2 of section 26, R. 57 E., T. 24 S. Several pits and a short drift have been cut into brecciated dolomite of the lower part of the Monte Cristo formation. The maximum scintillometer reading is 250 cps at the best copper showing which consists of irregular lenses of siliceous limonite surrounded by halos of chrysocolla with minor malachite up to 3 inches thick. Stainierite is present as irregularly distributed specks on fractures. A nearby pit exposing only a large mass of limonite without copper minerals or stainierite gives a count of 60 cps compared to a background of 10 cps.

Milford No. 2 Mine

This property is located high on the north side of a prominent ridge in section 5, T. 26 S., R. 58 E. The main workings consist of a tunnel several hundred feet long with three small stopes which produced lead and zinc ore. There are several other small openings in this area. The maximum radioactivity is found in a small mine whose opening is in the face of a cliff about 700 feet southeast of the main workings. This mine explores a small irregular zinc-lead orebody near the base of the dolomitized Yellowpine limestone. Counts up to 200 cps were obtained from hydrozincite associated with minor limonite; similar values were given by limonite with little hydrozincite. No copper minerals whatsoever were observed. Other workings on the hill gave readings up to 60 cps from limonite and hydrozincite; the background was 15 cps.

Tam o'Shanter Mine

This mine is located in the southwest 1/4 section 4, T. 26 S., R. 58 E., just south of the border of the Goodsprings Quadrangle. The workings consist of several hundred feet of drift on a single level, an inclined winze about 200 feet deep and a stope open to the surface above the drift. These explore a sheared zone parallel to bedding near the base of the Bird Spring formation which here trends N 10° E, and dips 50° W. The stope, which produced oxidized lead ore with some zinc, was

not investigated during this study. The winze follows the brecciated zone that contains much limonite and a little ferruginous chert. There are a few irregularly distributed areas where oxidized copper minerals are common; and it is near these that the maximum scintillometer readings, up to 225 cps, are obtained. All of the underground workings examined give counts greater than 40 cps, and some areas of limonite without visible copper staining give 100 cps. The background reading at the surface is 10 cps.

Potosi Mine

This mine is high on the west side of Potosi Mountain in section 12, T. 23 S., R. 57 E. In 1856 the property yielded the first ore from the Goodsprings District (Hewett, 1931). The Potosi is the only mine in the area which has produced quantities of sulfides, the chief ore present being dark brown sphalerite. The orebodies lie in nearly horizontal, dolomitized Yellowpine limestone. Hewett points out that the mineralization is closely related to two sets of early faults. Sphalerite and galena are the principal sulfides, though a little pyrite is found as very small crystals. Oxidized zinc, lead and copper minerals formed the bulk of the first ore mined, and these are still common in the stopes near the surface. For a detailed description and map the reader is referred to Hewett, 1931, pp. 123-126.

Anomalous radioactivity with readings as high as 275 cps, compared to a background of 10 cps, was recorded in two places on the "three plus thirty" level (intermediate between the second and third levels). One of these is near a prominent, nearly vertical, fault striking north; the other is about 50 feet farther west and is not associated with a major structure. The fault was examined on other levels but no further radioactivity could be found; however, the mine workings are extensive and much ground remains unstudied.

The radioactivity occurs in association with dark brown sphalerite, gray dolomite, white calcite and fragments of black carbonaceous shale. Galena and copper minerals are very uncommon in this area. The relations observed in the field and laboratory examinations suggests that the sphalerite was precipitated in a breccia of gray dolomite and shale fragments and that white calcite and small additional amounts of black shale (presumably as a mud) were deposited after the sphalerite. Study of polished sections of this material indicates the following paragenetic sequence:

Dolomite	- - - - -
Black shale fragments	---
Sphalerite	-----
Black shale mud	-----
Calcite	--?-----
Pyrite	-?--?--?-
Uranium (mineral ?)	-?- ?
Galena	-?-

Autoradiographic techniques have shown that the uranium is concentrated in the areas of black shale and is definitely not in the dolomite, calcite, sphalerite, galena or pyrite. A few small terminated quartz crystals occur in some of the shale. By using high magnification with oil immersion, extremely fine masses of an unidentified mineral are observed as irregularly curving subparallel threads in the shale. All areas in which this mineral is found are marked by exposed patches on the film used for autoradiographs. The material is similar to sphalerite in its appearance under reflected light. Isotropism and the presence or absence of internal reflection could not be established. The amount present is too small to apply the usual physical and chemical tests for pitchblende, and therefore the identity of the mineral remains unknown. Pyrite occurs as small cubic crystals in the black shale and in the calcite.

The black shale occurs above the ore bodies and is apparently from the base of the Bird Spring formation, although Hewett's map (1931) does not show this formation present at the mine. Elsewhere in the part of the mine checked the shale showed no radioactive anomalies even where it was mineralized with sphalerite. An analysis of nonradioactive shale gives $e \text{ U}_3\text{O}_8 = 0.01\%$ and $e \text{ U}_3\text{O}_8 = 0.013\%$, an admittedly high value which should be verified. Black shale at the base of the Bird Spring formation is mentioned by Hewett (1931, p. 128) from the vicinity of the Yellow Pine mine, but such shale certainly is not widespread in the Goodsprings area as a whole. Possibly the lack of oxidation at the Potosi mine may be attributed to the comparatively impermeable capping provided by the black shale. The radioactive materials are generally quite fresh and free from alteration and there is no reason to believe that any of the uranium was carried in by groundwater. To judge by scintillometer readings in the mine, the black shale is far too low in uranium to account for the radioactivity of the two areas mentioned above merely by the inclusion of fragments of shale in the ore. It is possible that an unknown stratigraphic horizon supplied radioactive shale, but it is much more reasonable

to conclude that the uranium was brought in by ascending solutions similar to those which carried the base metals and that some property of the carbonaceous shale facilitated the precipitation of the uranium in these areas. It is not the purpose of this report to discuss the mechanisms of such a precipitation, but the association of uranium mineralization with carbonaceous materials is well known, particularly from the Colorado Plateau.

Summary

In the Goodsprings district mineralization of all types is very much dispersed, a great number of small deposits being scattered over a large area. There have been no very large mines, though undoubtedly many of the ventures have been profitable. The uranium is no exception to this dispersed pattern, but none of the deposits are known to be of economic importance.

Hewett (1931) emphasizes that the lead-zinc deposits are concentrated in the stratigraphic zone near the top of the massive dolomitized Monte Cristo limestone and near the base of the thin-bedded Bird Spring formation. Copper bearing lead-zinc ores are common, but the deposits containing principally copper tend to be slightly lower in the section. The gold and silver mines are localized near the prophyry intrusions. Almost without exception, the ore bodies are in dolomitized limestone; and therefore the absence of dolomitization usually precludes the presence of ore.

Some areas, such as the west side of Shenandoah Mountain in the southeast corner of R. 57 E., T. 24 S., exhibit a concentration of copper deposits; other regions, such as Porter Wash in the east central part of R. 56 E., T. 25 S., have mainly lead and zinc mineralization. As seen in Plate 3, the more western mines tend to be more radioactive, though there are many exceptions.

As shown in Table 9 and summarized in Table 10, the uranium occurrences are closely associated with copper-iron mineralization. Not all of the copper showings carry uranium; but wherever radioactivity is observed, whether in a copper or a lead-zinc mine, it is usually in the vicinity of copper mineralization. This relation is well illustrated in the previously described Green Monster and Yellow Pine mines.

Cobalt as stannierite, $\text{CoO}(\text{OH})$, is present as traces in many of the copper deposits, but there does not seem to be a correlation between cobalt and uranium mineralization. The Copper Chief mine is an example of a radioactive deposit which has shipped cobalt ore, but other cobalt producers such as the Blue Jay and Columbia mines show little anomalous radioactivity.

Nickel, as annabergite, has been reported only from the ore bins of the Yellow Pine mine (Hewett, 1931).

Table 10

Summary of Data on the Distribution of
Uranium in the Goodsprings District

Number of mines and prospects examined	85
Number showing anomalous radioactivity	46
Per cent radioactive	54%
Number which have radioactive limonite or ferruginous chert	36
Number which have radioactive oxidized copper minerals	25 *
Number which have radioactive hydrozincite	12 *
Number which have recognizable uranium minerals	3 *
Number in which source of radioactivity is undefined	4 *
Number having radioactive oxidized copper or iron minerals without associated zinc	23
Per cent of total radioactive mines	50%
Number having radioactive oxidized zinc minerals without associated copper	7
Per cent of total radioactive mines	15%

* Many of the mines show radioactivity from several sources.
Therefore, one mine may be counted in more than one category.

Vanadium is seldom found in any quantity with uranium. Minor amounts of carnotite occur at the Singer-Tiffin and near the Green Monster mines; but the best showings of vanadate are at the Whale, Bill Nye and Mountain Top mines, all of which are not radioactive.

Gold and silver do not appear to occur in quantity in association with uranium; and of the mines which have produced principally gold, only the Keystone gave even small radioactive anomalies. Some of the radioactive copper deposits, such as the Boss mine, have produced small amounts of gold and silver.

Molybdenum as wulfenite is present in some of the lead-zinc mines, but it is not associated with radioactivity.

Zinc and/or lead mines may or may not contain radioactive elements. The majority of the most radioactive showings, i. e. the Green Monster, Singer-Tiffin, Yellowpine, Potosi, Milford No. 2 and Tam o'Shanter mines, are in deposits which have produced principally lead and zinc; but the localization is nearly always near copper mineralization.

Significance of the Distribution of Uranium

Inasmuch as the known uranium deposits are of insufficient grade and quantity to be of economic importance, this study has been directed toward the understanding of the origin and localization of the uranium mineralization so that the principles brought to light may be applied in the search for and evaluation of uranium deposits in this and other districts.

There are two problems of particular interest. The first is to explain the mechanism of the fixation of uranium in the oxidized base metal ores. This is attributed to adsorption and is discussed in detail in a later portion of this report. The second problem is to define the source or sources of the uranium found in these deposits. This is discussed below.

Origin of the Uranium

Two possible sources of uranium are available. The first is a uranium-bearing stratum such as a tuff or black shale from which the radioactive element may have been leached. Part I of this report illustrates that this type of source is effective in producing small scale, widespread uranium mineralization. The alternative possibility is that the primary ore contained a uranium mineral such as pitchblende.

Tuffs similar to those of Table Mountain very probably once covered the entire southern half of the Goodsprings Quadrangle, and their weathering would release enough uranium to account for the traces of radioactivity in many of the mines. However, it is difficult to imagine how the larger amounts of uranium found in the Green Monster and Singer-Tiffin mines could be concentrated by such a process. The black shale present in the Yellow Pine and Potosi mines is definitely not widespread and therefore must be ruled out as a source of uranium for the district as a whole. As pointed out in the description of the Potosi mine, the black shale seems to concentrate rather than supply the uranium.

The time factor is also a consideration. As is shown later in the discussion of adsorption, the degree of crystallization of the adsorbent greatly influences the capacity of the materials to fix the uranium.

Therefore, in order to have optimum conditions for adsorption, the hydrozincite and limonite would have to be formed at approximately the same time as the tuff was furnishing the uranium. This is not impossible, but it does not seem very probable.

Table Mountain is the principal remnant of the tuffs. If the uranium present in the mines was derived from the tuff one would expect the mines surrounding Table Mountain to be among the most radioactive. But of 19 mines in the immediate vicinity, only 6 are at all radioactive, and none of these give readings of over 60 cps.

Perhaps the most decisive argument is the close association of the uranium with copper mineralization. In spite of the fact that many of the mines contain hydrozincite, in the majority of cases the radioactivity is localized by hydrozincite only where near copper mineralization. In many other instances, only the oxidized copper and iron minerals are radioactive. Descending solutions from tuffs or any other source could not be so selective as to by-pass the oxidized zinc minerals; the uranium must have been associated with copper in the primary ore. The absence of primary uranium minerals in the ore is no proof that such minerals did not exist for the deep oxidation would probably have destroyed them.

The conclusion is that most, if not all, of the uranium was initially deposited with the primary base metal sulfide ores as some uranium mineral, presumably pitchblende. On weathering the uranium goes into solution from which the various uranium ions are adsorbed, first by the limonite and chrysocolla in the vicinity of the oxidizing pitchblende, then by hydrozincite nearby. Only when the amount of uranium is large, or when the adsorbent materials are scarce or become crystallized so that they can no longer hold the uranium, do the secondary uranium minerals make their appearance.

Suggestions to Direct the Search for Additional Uranium Deposits

The association of uranium with the other metallic elements indicates that guides in prospecting for these also apply in the search for uranium. Hewett (1931, pp. 102-103) points out that almost without exception the ore bodies are in dolomitized limestone, and therefore the dolomitized areas deserve the most attention. He also emphasizes that sheared zones more or less parallel to the bedding often localize the mineralization. Hewett draws attention to the stratigraphic control shown by the lead-zinc deposits which are found almost entirely in a zone about 600 feet thick including the top of the Monte Cristo and the base of the Bird Spring formations. The copper deposits are usually stratigraphically lower.

The distribution of radioactivity thus far observed indicates that the best chance of finding high uranium values is in the copper-rich portions of lead-zinc mines. Additional copper showings in the area east of the Boss mine may well be radioactive. Even if uranium is not

considered from the viewpoint of producing uranium ore, the radioactive properties might be used to prospect for copper (and lead and zinc where they are associated with copper) in areas where the outcrop is covered by only a few feet of alluvium. Application of this method would not be limited to the Goodsprings district, but could be used in any area where conditions of gossan formation lead to the production of radioactive limonite.

The western side of the district is more promising for uranium than the eastern side. Plate 3 shows that there is an increase in the number of radioactive mines and prospects; also, with few exceptions, the more western deposits give the better scintillometer readings.

No limits of uranium mineralization have been determined in this study, though eastward extension seems unlikely in view of the fact that no hydrothermal mineralization is known for many miles in this direction. There are numerous small carnotite occurrences to the east, but these are related to leaching of uranium from a tuff (see Part I). There are no mines north of the Potosi mine, but Hewett's map (1931) shows several prospects which might be worth investigating located near the contact between the Monte Cristo and Bird Spring formations on the west side of the range. To the west the alluvium of Mesquite Valley covers any ore deposits. No systematic study was made south of the Goodsprings Quadrangle, but there is at least one mine which shows uranium mineralization. The Jeep 1 and 2 claims on the northwest side of Clark Mountain about 23 miles southwest of Goodsprings exhibit radioactivity with limonite and oxidized copper minerals occurring in fractures in Cambrian (?) quartzite. Maximum scintillometer readings are 300 cps with a background of 10 cps. An analysis on limonite gave $e \text{ U}_3\text{O}_8 = 0.05\%$ and $e \text{ U}_3\text{O}_8 = 0.035\%$. This deposit suggests that uranium mineralization may continue to the south. The dumps of a few precious metal mines in the Pre-Cambrian crystalline rocks north of Clark Mountain, however, gave no radioactive anomalies.

The localization of uranium by carbonaceous shale in the Potosi mine suggests that additional examination of the black shale adjacent to the mineralized areas may uncover significant concentrations of uranium. However, it is probable that unless the shale was highly broken, it would have been too impermeable to localize any large quantity of uranium. This black shale is known only from the Yellow Pine and Potosi mines.

In the search for any substance perhaps the most likely place to look for additional deposits is in the vicinity of the best deposit known — in the case of uranium in the Goodsprings district — this refers to the Green Monster mine. In this area, the upper part of the dolomitized Bullion limestone is sheared and sporadically mineralized along strike for about a mile. The outcrop was checked for radioactivity using the scintillometer without the discovery of any new radioactive anomalies. However, there is some covered area near the Desert Valley prospect which could conceal mineralized ground.

Fixation of Uranium in the Oxidized Zone

The reason for the intimate association of uranium with limonite, hydrozincite, ferruginous chert and chrysocolla is of great interest, especially since radioactivity with limonite is observed in many regions besides Goodsprings. The problem of radioactive limonite has been investigated from the descriptive and theoretical viewpoint by T. G. Lovering whose findings are now in the process of being published. Lovering has examined limonite samples from throughout the western United States and concludes, as did Behre and Barton (1954), that the uranium is fixed by adsorption. The adsorption theory is supported by the fact that all four of the above mentioned materials are precipitated in a colloidal or extremely finegrained state. Rankama and Sahama (1950, p. 636) state that soluble uranium compounds are strongly adsorbed on the hydroxide gels of iron, manganese and aluminum and on silica gel.

It is known that radium is strongly adsorbed by suitable materials (Rankama and Sahama, 1950, p. 784). Adsorption of radium without uranium would produce a limonite which would give high radiometric "uranium" content but low chemical uranium. Such radioactivity would be limited by the comparatively short half-life of the radium. The Goodsprings material gives radiometric and chemical values which agree fairly closely; this suggests either that the uranium is nearly in equilibrium with its decay products, or that fortuitously the amounts of uranium and daughter products are fixed by adsorption in equivalent amounts with respect to radioactivity.

Lovering (manuscript in press) has found up to 0.7% U_3O_8 in limonite. All of the Goodsprings material analysed falls below this value. The following are the highest chemical uranium analyses obtained from Goodsprings:

Limonite	0.106% U_3O_8
Hydrozincite	0.239%
Chrysocolla	0.116%

Possibly there is material having higher uranium content than the above; but to judge from field radioactivity measurements, these are the best specimens.

Oxidation of a Sulfide Ore Body

The details of the processes of oxidation and formation of secondary minerals are too complicated and too little understood for complete discussion here. It is necessary however to consider briefly the weathering in an arid climate of an ore body containing sphalerite, galena, chalcopyrite, pyrite and pitchblende with a carbonate gangue and country rock.

The sulfide ores oxidize to sulfates which, with the exception of lead sulfate, are soluble in slightly acid solutions. The surrounding rock immediately reacts with these solutions to neutralize any acid formed, and this leads to the formation of the various copper and zinc carbonates. Zinc and lead may be transported in the oxidizing zone as the bicarbonates, the former usually traveling farther from the source than the latter. Ferric iron is not soluble except in solutions far more acid than those expected in this environment, and it is precipitated almost in place as a hydrous ferric oxide. Ferrous hydroxide could be precipitated from slightly alkaline solutions, but this would rapidly oxidize to the ferric state (Weiser, 1935), p. 86). The end product in either case is "limonite." Hematite is common with the oxidized copper ores, and the lead-zinc deposits contain limonite that is principally goethite. No lepidocrocite has been identified. This is in agreement with Blanchard (1944) who points out that hematite is rare in lead-zinc gossans and with Kelly (1954) who shows that lepidocrocite is seldom if ever present. Jarosite is common at Goodsprings but has not been identified in the radioactive material.

Phair and Levine (1953) have shown that in order for the pitchblende to be taken into solution the uranium must be oxidized to the hexavalent state.

In the small amounts required the silica necessary to form hemimorphite, chrysocolla and ferruginous chert is available from the gangue or wallrock.

Uranium Ions Present

It has been stated by various writers (Lovering, manuscript; Frederickson, 1948; Tolmachev, 1943) that in an acid, oxidizing environment uranium is present in solution as the uranyl, UO_2^{+2} , ion. Rodden and Warf (1950, pp. 9-13) mention the possibility of forming complex carbonate sulfate, phosphate, chloride, fluoride and sulfite ions; but of these, all except the carbonate complex seem of little significance in consideration of the Goodsprings material. L. J. Miller (personal communication) has recently investigated the stability of various uranium ions, and he finds that as the pH of a solution of UO_2^{+2} ions is increased, the reaction $UO_2^{+2} + (OH)^- = UO_2(OH)^+$ proceeds to the right. Below 3.5 the UO_2^{+2} is the predominant ion; and above 3.5 the $UO_2(OH)^+$ ion is more abundant. In the absence of significant amounts of carbonate, the uranium is precipitated as an alkali diuranate or uranyl hydroxide beginning at a pH of about 4.5. Even in the pH range from 6 to 8 Miller finds that uranium is soluble to the extent of $2-4 \times 10^{-5}$ moles per liter. This concentration is sufficient to provide the amounts of uranium found in radioactive limonites. A simple calculation shows that if 1 gram of a suitable adsorbent removed all of the uranium contained in only 2 liters of a solution whose concentration was 2×10^{-5} moles per liter the U_3O_8 content

of the adsorbent would be 1%. In the presence of sufficient carbonate ion, the soluble uranyl carbonate complex, $UO_2(CO_3)_3^{-4}$, is readily formed and is stable up to a pH of 11.5.

If it is reasonable to assume that previous weathering occurred under similar conditions to those now prevalent, the conclusion is reached that the oxidation took place at a considerable depth beneath the surface, and yet well above the water table. The present water table must be at great depth as water was observed in only 3 of the 85 mines and prospects examined. Since the oxidation is probably carried on by oxygenated descending water, and since this water must pass through several tens or hundreds of feet of dolomite and limestone, the solutions which enter the orebody are undoubtedly saturated with carbonate and may well have a pH above 7. With the continued supply of carbonate by the very water that carries the oxygen and because of the possibility of reaction with a predominantly carbonate gangue, it is very difficult to believe that the solutions present during the oxidation of these relatively small ore bodies could be strongly acid. Granting this, the sulfate complex ion, the uranyl ion and the uranyl hydroxide ion may be eliminated from consideration here. Thus only the uranyl carbonate ion is considered to be important in the oxidizing ore bodies at Goodsprings. In occurrences elsewhere, with massive sulfides or inert country rock, the pH might be lower, and in such cases the other ions are probably significant.

Additional evidence in favor of a relatively high pH during oxidation is the common occurrence of stannierite (Cooke and Doan, 1935). This mineral is a hydrous cobaltic oxide and was referred to by Hewett (1931) as heterogenite. Mason (1952, pp. 144-146) notes that alkaline conditions are necessary for the oxidation of cobalt to the trivalent state. Therefore, although cobalt is not closely associated with uranium at Goodsprings, the presence of stannierite in many of the mines does suggest alkaline conditions.

Possible Methods of Fixation of Uranium in the Oxidized Zone

It may be of value to discuss briefly the possible methods by which an element may be fixed in the oxidized zone. There are four outstanding possibilities: (1) The substance may be insoluble and is retained as a residuum; an example is native gold. (2) The element may form an ion which can be substituted for a different ion in some mineral which is stable in the oxidized zone; an example would be radium substituting for lead in pyromorphite-mimetite (Goldschmidt, 1954, p. 257). (3) The metal may form an insoluble compound with some other substance; for example, the combination of uranium and vanadium to form carnotite. (4) Soluble ions may be adsorbed by suitable materials.

In explaining the fixation of uranium, (1) is eliminated because in the presence of carbonate, hexavalent uranium is very soluble. With

respect to (2), the U^{+6} ion has an ionic radius of 0.80 Å (Green, 1953); but because of the combination of high charge and small radius, U^{+6} readily combines with other atoms to form large complex ions which cannot be taken into the lattices of any of the minerals commonly associated with the oxidized zone. The choice between (3) and (4) can be made on the basis of simple adsorption experiments. One argument against (3) is that there are no known iron-uranium minerals which would form by reaction between a uranium solution and limonite.

Previous Work on Adsorption

Several references in the literature mention that various uranium-bearing ions are adsorbed from solution by suitable materials, but in general the consideration of these possibilities are not applied to geologic situations nor do the authors discuss the behavior of the adsorbed uranium as the adsorbent crystallizes.

Tolmachev (1943) found that UO_2^{+2} is reversibly adsorbed by activated charcoal at room temperature from uranyl nitrate solution according to the Freundlich equation. He noted that schists from central Asia and from Leningrad adsorb uranium irreversibly and concluded that the bonding is at least partly chemical.

Rodden and Warf (1950, p. 30) state that hexavalent uranium is removed from solution down to "1 or 2 parts per 100 million" by coprecipitation of ammonium diuranate and hydrous ferric oxide by the addition of ammonium hydroxide. "The presence of substantial amounts of carbon dioxide, up to 0.01% by weight, did not alter the results measurably." This last statement emphasizes the fact that although ammonium diuranate is not quantitatively precipitated in the presence of carbonate because of the formation of the carbonate complex (Rodden and Warf, 1950, p. 16), the colloidal iron oxide adsorbs practically all of the uranium remaining in solution.

Lovering cites an experiment by Horne (1952) which showed that finely divided goethite and hematite remove radioactive elements from solution.

Adsorption Experiments

General Procedure

Adsorption is the process by which a substance is concentrated on the surface of another material. Colloids possess high adsorptive properties because of their very great surface area. Adsorption should not be confused with absorption, which is the concentration of a substance throughout the body of another material, as a sponge absorbs water.

The experiments described here were performed in order to determine the extent to which various uranium ions are adsorbed by hydrous ferric oxide (limonite) and basic zinc carbonate (hydrozincite). Also of interest is the behavior of the adsorbed uranium upon dilution of the solution and upon crystallization of the adsorbent.

Chemists have developed various equations, some of which are theoretical, others empirical, to define the relations between the quantity of material adsorbed and the concentration of the solution with which it is in equilibrium. (References: Moore, 1950, pp. 497-504; Prutton and Maron, 1951, pp. 226-233). The Freundlich equation is one of these. It is a simple empirical relation which has been found to approximate closely the data given by adsorption of substances from solution provided that the range of data is not extremely large. It assumes the adsorption of a single layer of particles only; but as adsorption from solution generally does not appear to result in multiple layers, this is a valid assumption. The relation is:

$$Y = k P^{1/n}$$

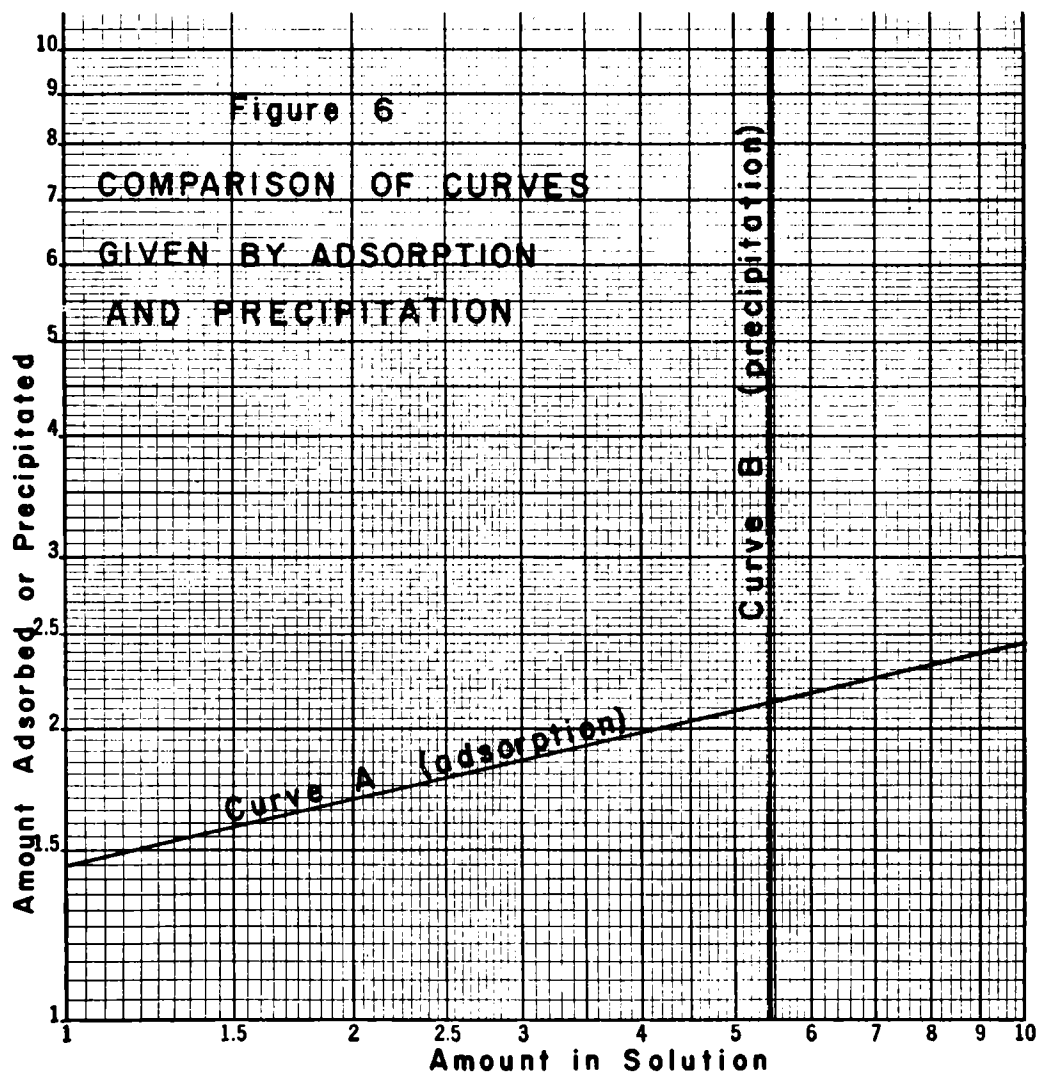
Here Y is the quantity adsorbed; P is the concentration of the solution; and k and n are constants of the system. The Freundlich equation may also be written:

$$\log Y = \log k + 1/n \log P$$

This means that if log Y is plotted against log P, a straight line with a slope of 1/n results. An example is curve A in Figure 6. It predicts that the higher the concentration of the solution, the more material will be adsorbed; but the lower the concentration, the greater the proportion of the material that will be adsorbed.

On the other hand, if an insoluble precipitate forms the amount in solution remains constant (at a value equal to the solubility of the precipitate) while the quantity "adsorbed" (actually precipitated) may have any positive value. Curve B in Figure 6 is an example of this. Therefore, the distinction between adsorption and precipitation can be made on the basis of simple adsorption experiments.

The experimental procedure followed was to prepare a series of several identical samples of synthetic limonite or hydrozincite and to add to each identical volumes of solutions containing different amounts of one of the uranium-bearing ions. After a period of 5 to 10 days had been allowed for equilibrium to be established, a sample of the solution was withdrawn and analysed for uranium. Then, knowing the total initial amount of uranium and the volume of solution, the amount of uranium adsorbed could be determined by difference. All of these experiments were run at room temperature which did not vary more than 2 or 3° from 25° C. The data used in plotting the curves are given in Appendix D.



The analytical procedure employed consisted of the reduction of the uranium to a mixture of U^{+3} and U^{+4} by amalgamated zinc in a Jones reductor. Aeration quantitatively converted the U^{+3} to U^{+4} which was then titrated with standard potassium permanganate to determine uranium (Rodden and Warf, 1950, pp. 54-57, 65-68). In the curves presented here and in the tables in Appendix D the uranium content is recorded in milliequivalents. In this connection 1 millimole is equal to 2 milliequivalents, a relation which reflects the analytical method in which 2 electrons per atom of uranium are exchanged.

In order to determine the time necessary for equilibrium to be established, samples of synthetic hydrozincite and limonite were placed in a large volume of uranyl carbonate solution. Small samples of solution were withdrawn and analysed at various intervals. The concentration of uranium reached a constant value after 5 hours with limonite and after 20 hours with hydrozincite.

The preparation of the adsorbent materials and the uranium solutions is described in Appendix D.

Series 1A

Figure 7 shows the curve given by $\text{UO}_2(\text{OH})^+$ and UO_2^{+2} with hydrous ferric oxide. Since this agrees well with that predicted by the Freundlich equation it is concluded that the uranium is adsorbed. The effects of aging and dilution will be discussed later.

In this experiment the most concentrated uranium solution had the lowest pH which was 2.5 before it was added to the adsorbing medium. At the time of analysis the pH of this sample had risen to 3.54 and the pH of the others increased regularly to 4.90 for the most dilute. As a result, the predominant ion was $\text{UO}_2(\text{OH})^+$. However, the concentration was always sufficiently low at the pH involved that no precipitate formed. One of the reasons for the variation in pH may be the adsorption of SO_4^{-2} ions.

Series 1B and 1C

Figure 8 shows the curves given by $\text{UO}_2(\text{OH})^+$ and $\text{UO}_2(\text{CO}_3)_3^{-4}$ with hydrous ferric oxide. The sharp break in the $\text{UO}_2(\text{OH})^+$ curve shows that adsorption is not the only reaction. Actually, a yellow precipitate formed in the stock solution overnight, and it is assumed that a similar precipitation took place, in addition to adsorption, in the flasks containing the two more concentrated samples. The $\text{UO}_2(\text{CO}_3)_3^{-4}$ curve is a straight line for much of its length, which is good evidence of adsorption.

Series 2

Figure 9 shows the adsorption of $\text{UO}_2(\text{CO}_3)_3^{-4}$ by synthetic hydrozincite. The curve is not quite a straight line, but it is clearly the result of adsorption and not of precipitation.

Effects of Aging and Dilution

In order to test the reversibility of the adsorption half of the solution was removed and replaced by distilled water. As shown in Figures 7, 8 and 9, this gives a new (calculated) point at which the quantity of uranium adsorbed remains constant while the solution is reduced to half of its initial concentration. If the adsorption is reversible, with time the points marking the ratio between uranium adsorbed and in solution should return toward the initial curve. But since some uranium has been

Figure 7

SERIES IA ADSORPTION OF UO_2^{+2} AND $UO_2(OH)^+$
BY HYDROUS FERRIC OXIDE AT 25° C.

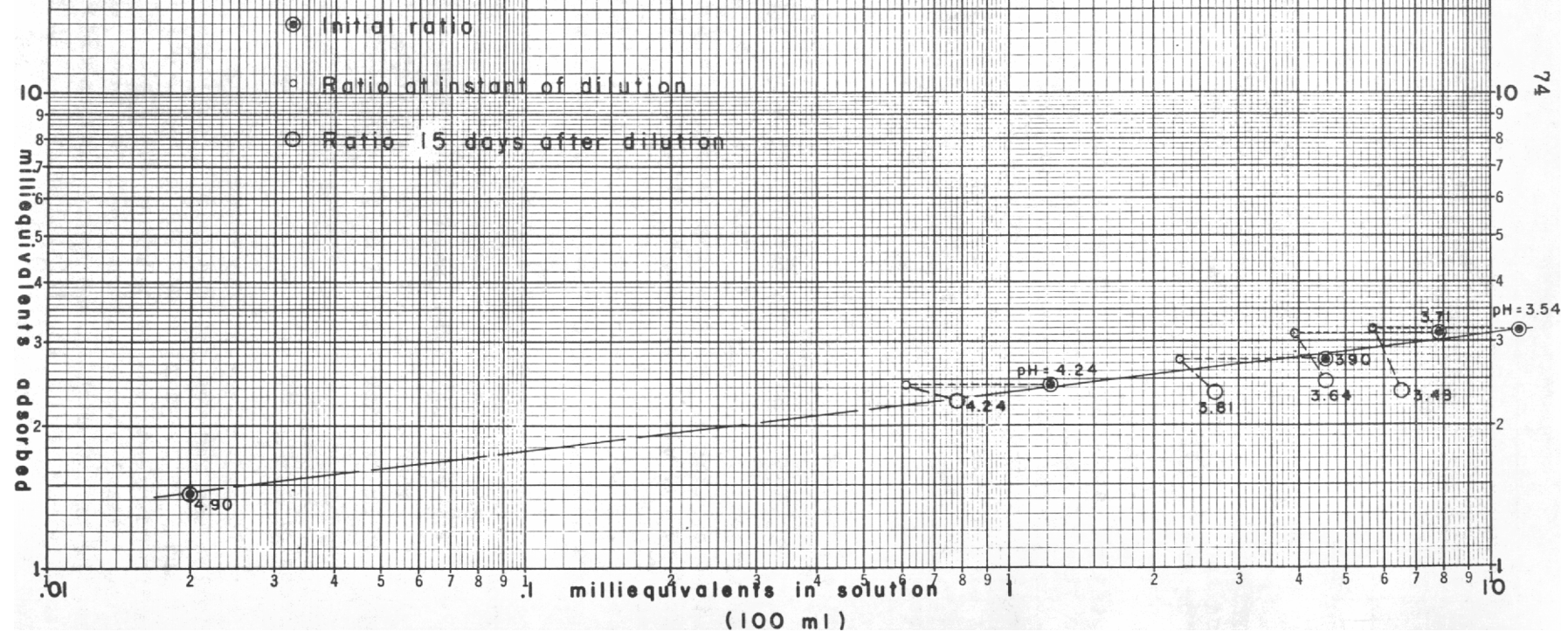


Figure 8

SERIES IB & IC ADSORPTION (AND PRECIPITATION) OF UO_2OH^+ ,
AND ADSORPTION OF $UO_2(CO_3)_3^{4-}$ BY HYDROUS FERRIC OXIDE
AT 25°C.

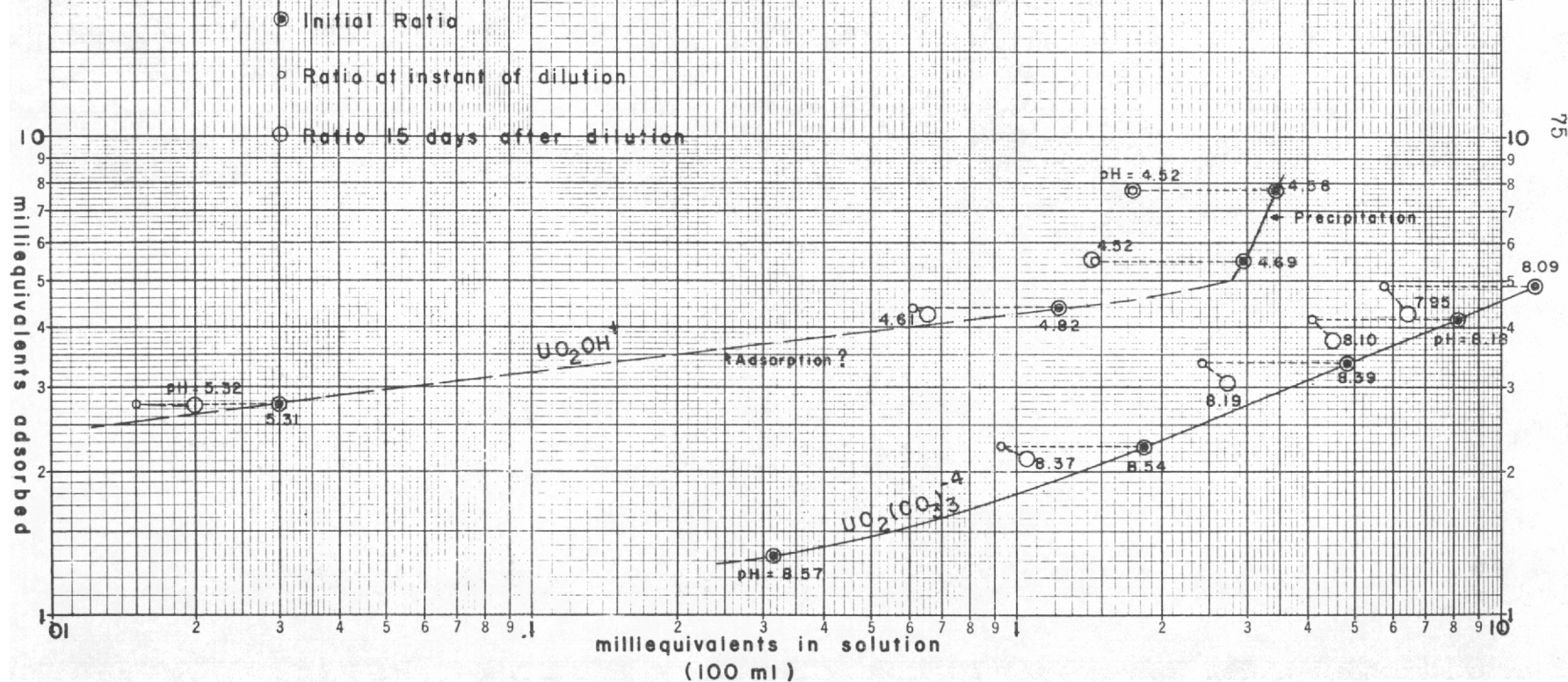
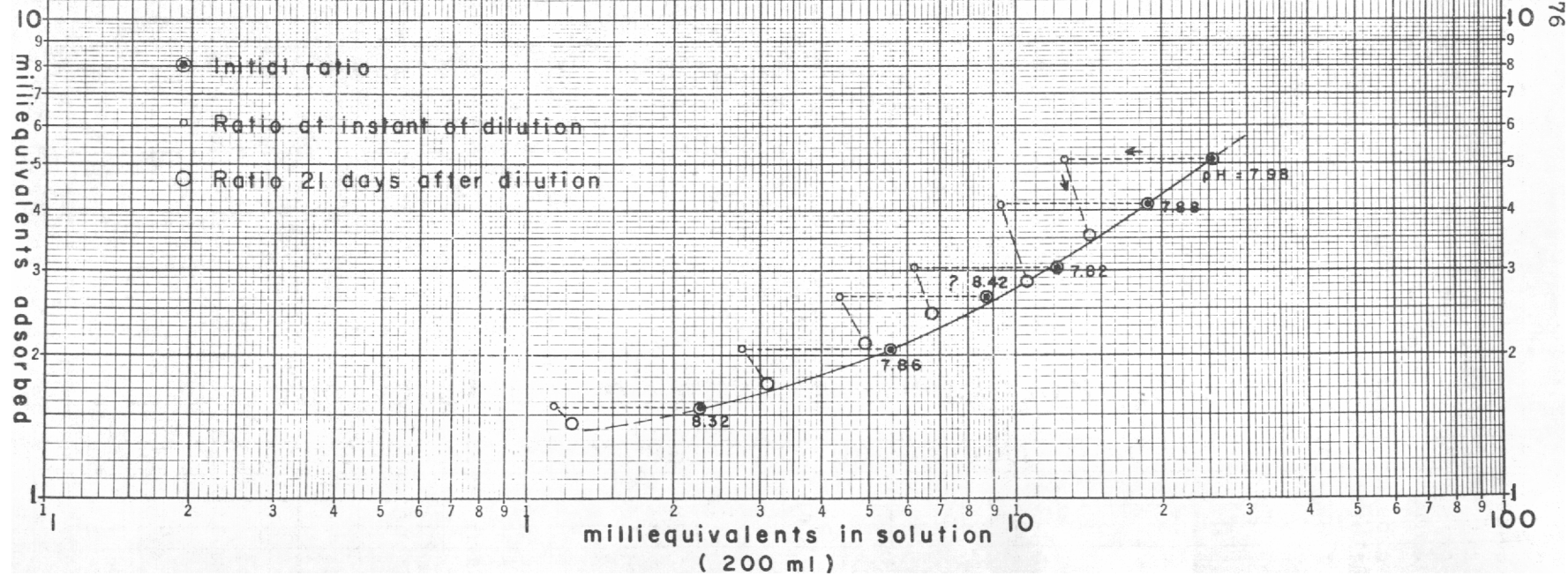


Figure 9

SERIES 2 ADSORPTION OF $UO_2(CO_3)_3^{-4}$
BY SYNTHETIC HYDROZINCITE AT 25°C.



lost (due to removal of half of the solution) the final point, if totally reversible, should fall on the initial curve but lower than (to the left of) the initial point. Sufficient time must be allowed for equilibrium to be attained, and in these experiments 15 to 21 days elapsed between dilution and analysis. From an examination of the curves for $\text{UO}_2(\text{CO}_3)_3^{-4}$, Figures 8 and 9, a logical conclusion would be that the adsorption is reversible. However, in the case of Figure 7, the final points overshoot the initial curve. This should not occur if reversible adsorption were the only reaction.

Thus far crystallization of the adsorbent has not been discussed, but apparently it is an important consideration. The crystallization of a colloid reduces the surface area and therefore decreases the capacity to adsorb, the net result being to return material to solution.

In line with this reasoning is the observation that the amount of crystallization seems to be a function of the hydrogen ion concentration as well as the concentration of the uranium in solution. In Figure 7 the pH for the sample giving the maximum overshoot is 3.48, and in the others it increases regularly to 4.24 for the minimum overshoot. Although ferric hydroxide is precipitated below a pH of 3, the minute quantities remaining in solution play an important role in its crystallization. As proof of this, a synthetic limonite aged "dry" crystallizes much more slowly than one aged under water. At a pH of 3.48 the Fe^{+3} concentration is about 190 times that at a pH of 4.24; and therefore the lower the pH, the more rapid the crystallization. This seems to explain adequately the apparently real differences in rates of crystallization in Series 1A. It may also be true that the rate of desorption is lower where the amount of adsorbed uranium is smaller. It is concluded that both reversible adsorption and crystallization are significant in explaining the observed phenomena, but these experiments do not define their relative importance.

The lack of change with time after dilution of the two most concentrated samples of $\text{UO}_2(\text{OH})^+$ shown in Figure 8 is another strong argument that this represents a precipitation whereas all of the other curves are due to adsorption.

Lovering (manuscript) reports that microscopic study of radioactive limonite thin sections shows that those which contain 0.05% uranium usually exhibit distinct uranium minerals. He attributes this to the expulsion of adsorbed uranium during the crystallization of the iron oxide. The experimental data agree fully with this conclusion. In the absence of abundant solutions to carry away the uranium, the various secondary minerals must form by the reaction of this expelled uranium with any carbonate, phosphate, vanadate, arsenate, silicate, sulfate or the like that is available.

Figure 10 shows that the adsorptive capacity of hydrous ferric oxide definitely decreases with aging, presumably because of crystallization. The data describing this experiment are found in Appendix D.

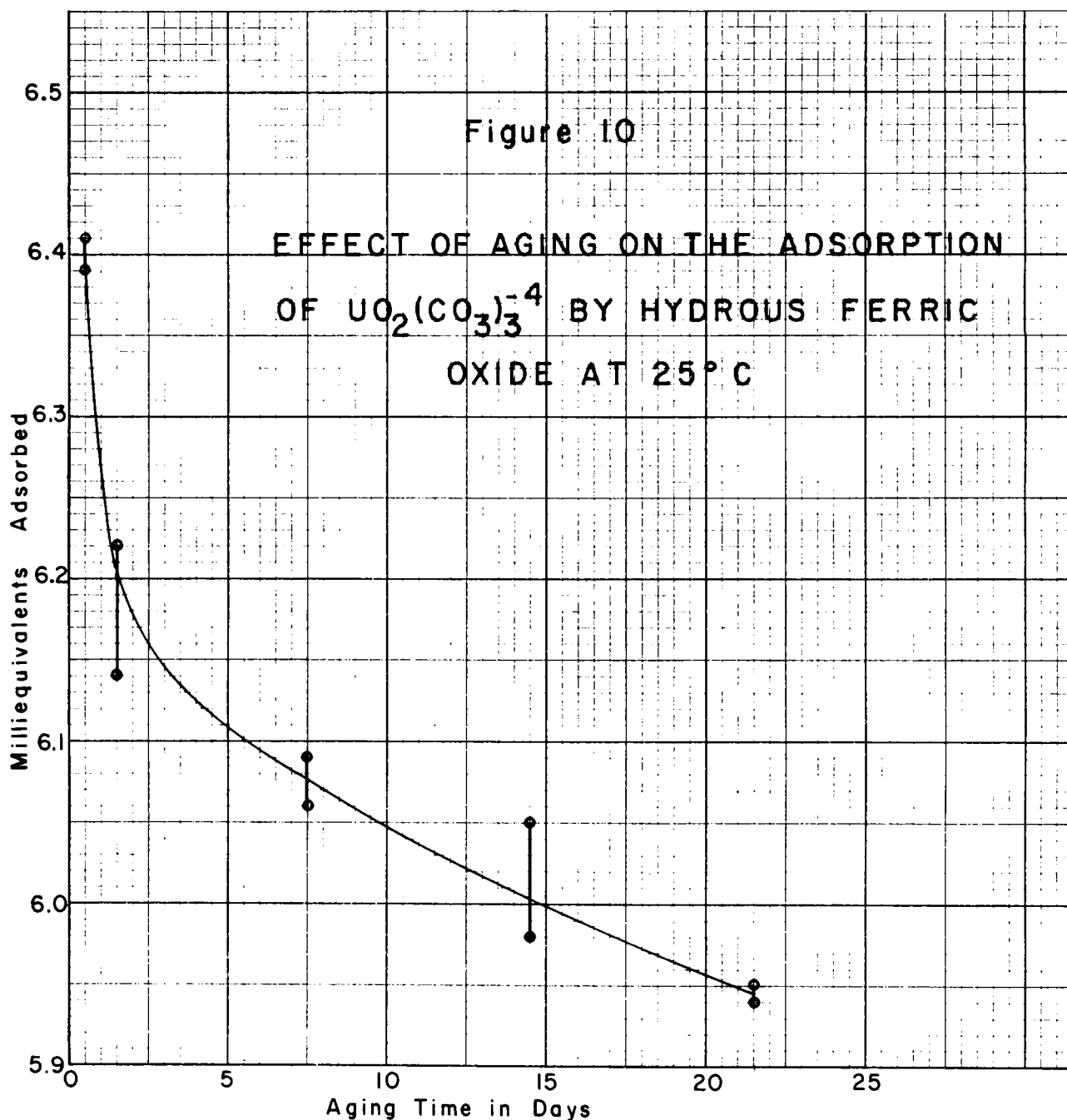


Table 11 gives a comparison of the adsorptive properties of various natural materials. The relative values are significant because the solutions above the different samples were of similar, though not identical, concentration. All of the samples mentioned were from totally oxidized ore bodies, and it is believed that they represent materials which had aged for hundreds of years.

It is seen that chrysocolla has the highest adsorption capacity whereas hematite (limonite form the Tam o'Shanter) has the lowest. The reason for this is believed to be related to the crystal structure. Chrysocolla has a layer lattice structure similar to montmorillonite

Table 11

Adsorption of the Uranyl Carbonate Ion by Natural Materials

	milliequivalents of U adsorbed by 10 grams	% U_3O_8 *
Chrysocolla from Boss Mine	0.54	0.76%
Chrysocolla from Copper Flower Mine	0.64	0.90%
Limonite from Jeep Mine, Clark Mtn., Calif. Yellow, very friable, x-ray pattern shows only goethite.	0.25	0.35%
Limonite from Boss Mine Dark reddish brown, x-ray pattern shows hematite, goethite and quartz.	0.09	0.13%
Limonite from Tam o'Shanter Mine Dark reddish brown, x-ray pattern shows hematite and trace of goethite.	- 0.08	- -
Hydrozincite from Yellow Pine Mine white, trace of MnO_2 present.	0.17	0.24%
Hydrozincite from Sultan Mine buff color (due to finely divided limonite??)	- 0.70	- -

* The % U_3O_8 is calculated assuming that all of the uranium is present as U_3O_8 and that the weight of the pure adsorbent is 10.00 grams.

(Eitel, pp. 93-94, 1954), and thus there a large interlayer surface available for adsorption. Hematite probably does not present a large area for adsorption; apparently hydrozincite and goethite are intermediate.

Several possible explanations may be advanced to account for the increase in uranium concentration of two of the samples. (1) Negative adsorption (the solvent more strongly adsorbed than the solute) is a possibility, but other samples of the same type of material do not show similar effects. Therefore this mechanism is believed to be insignificant. (2) Evaporation of solution during the time of adsorption could give the observed results. This is thought to be the explanation for the sample of hydrozincite from the Sultan mine because it became unstoppered for about 24 hours. The other flasks remained sealed and therefore this cannot be the explanation for the limonite from the Tam o'Shanter mine.

(3) The samples were ground to pass 100 mesh with the result that a great many fine particles were formed, and it was noted that the solutions showed a weak Tyndall effect even after they had remained undisturbed for several days. Fine particles of iron oxide in suspension may have been removed with the sample solution. These particles may then have been dissolved when the solution was acidified prior to reduction. The iron in solution would be reduced in the reductor and oxidized in the titration so as to give apparently high uranium values. This effect apparently accounts for the limonite from the Tam o'Shanter mine.

Synthetic limonite similar to that used in Series 1 was kept under water at 95° C for a few days. This crystallized the material sufficiently to permit its identification as alpha hematite by x-ray methods. As a comparison, synthetic goethite was prepared by boiling a solution of ferric sulfate. The resulting precipitate contained only about 25% water, the remainder being FeO(OH) which gave a goethite x-ray pattern. This material also adsorbed a large amount of uranium (see Table 12). It must be noted that because the solutions in equilibrium with the samples listed below were not identical in concentration; the values mentioned merely give orders of magnitude for adsorption.

Table 12

Maximum Uranium Content of Synthetic
Limonite and Hydrozincite

(Assumes all uncombined water removed
and uranium present as U₃O₈)

	Calculated % U ₃ O ₈
Series 1A limonite (hematite)	22.4%
Series 1C limonite (hematite)	30.8%
Series 2 hydrozincite	17.2%
Synthetic goethite	11.2%

Table 12 shows that very large quantities of uranium may be adsorbed under laboratory conditions. Natural materials are much lower in uranium because: (1) the solutions are not nearly so concentrated; (2) natural materials are probably precipitated much more slowly and are therefore better crystallized and less adsorptive; (3) crystallization tends to return the uranium to solution if water is present.

Discussion of Errors and Corrections

As seen in Appendix D, the duplicate uranium analyses agree very well, and both points usually fall within the circle plotted on the curve. However, those points where the concentration of the solution is extremely low are expected to have larger percentage errors. Other possible sources of error outside of the analytical technique are as follows: (1) The amount of adsorbent in each of the "identical" samples may have varied by ± 0.05 gram; but as the samples were 15 grams or more, this is a second order correction. (2) Small amounts of uranium may have been adsorbed by the glassware; but because the solutions were fairly concentrated, this effect was certainly insignificant. (3) The gelatinous samples of adsorbent contained up to 90% or more water. Certainly some of this water was merely entrapped, and as such it was more or less part of the solution.

Consideration (3) was of significance in calculating the total amount of uranium in solution on the basis of the concentration of a sampled volume, as it was necessary to assume a total volume of solution. This was done by neglecting any and all entrapped water. As the total weight of adsorbent was usually only 15/100 that of the solution, the maximum possible error is less than 15%. This factor can influence the shape and slope of the curves. For example, in Figure 9, Series 2: the adsorption of $UO_2(CO_3)_3^{-4}$ by synthetic hydrozincite, an increase in the volume of water of 10% over that assumed in the plotting of the present curve both flattens and partially straightens it. The conclusion is that this factor aids in explaining deviations from the straight line predicted by the Freundlich equation, but that it in no way invalidates the conclusion that the uranium is fixed by adsorption.

Conclusions

1. Anomalous radioactivity attributable to minor amounts of uranium is widespread in the Goodsprings district, being found in 46 of 85 mines and prospects examined.
2. All known occurrences are of very low grade; and, with the possible exception of the Green Monster mine, there is little possibility of producing uranium ore.
3. It is probable that more trace uranium mineralization can be found throughout the district, but except for the area near the Green Monster mine any additional discoveries are likely to be below ore grade.
4. Uranium minerals in megascopic quantities are rare, being found only at the Green Monster and Singer-Tiffin mines and at the Desert Valley prospect.

5. Radioactivity is concentrated by limonite, hydrozincite, chrysocolla and ferruginous chert. These materials have passed through a very fine grained or colloidal state during their formation.
6. The mechanism for the fixation of the uranium is adsorption.
7. The uranyl carbonate complex ion, $\text{UO}_2(\text{CO}_3)_3^{-4}$, is probably the most important uranium ion so far as the adsorption by the oxidized ores at Goodsprings is concerned. In environments where the pH is low or where carbonate is absent, the uranyl (UO_2^{+2}) and uranyl hydroxide (UO_2OH^+) ions are probably more important.
8. The adsorption is reversible; and upon crystallization of the adsorbent the uranium is forced to return to solution. If no solution is present secondary uranium minerals will crystallize within the former adsorbent.
9. The best uranium showings are in lead-zinc mines, but are generally confined to the immediate vicinity of copper mineralization.
10. Copper showings are often radioactive, especially those on the west slopes of Shenandoah Mountain (near the Boss mine).
11. Uranium is independent of cobalt, vanadium, gold, silver and molybdenum mineralization.
12. The more western mines of the Goodsprings area tend to be more radioactive; but no definite limits to uranium mineralization have been defined.
13. The source of the uranium was in large part traces of some primary uranium mineral, presumably pitchblende, which was more closely associated with the copper-iron primary minerals than with those of lead-zinc, cobalt, vanadium, gold, silver or molybdenum.
14. The only known ore containing what is probably a primary hydrothermal uranium mineral occurs at the Potosi mine where it is localized by black shale. Pyrite, but no copper minerals, accompanies the uranium paragenetically later than the sphalerite.
15. The volcanic rocks which once covered much of the area possibly contributed small amounts of uranium to the oxidized base metal ores, but this effect is probably of minor importance.
16. As in the case of the other metals, there is little likelihood of finding mineralization of value in undolomitized limestone.

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APPENDIX A

X-RAY DIFFRACTION DATA FOR CARNOTITES

"d" values given in Angstrom units. Intensities in ().
Letter identifies sample; see following page.

A	B	C	D	E	F	G	H	I
		8.96 (4)*	8.98 (3)*					
		7.90 (1)*	8.00 (1)*					
		7.53 (1)*						
6.43 (10)	6.45 (10)	6.49 (10)	6.45 (10)	6.32 (10)	6.50 (10)	6.41 (10)	6.43 (10)	6.44 (8)
5.063 (3)	5.077 (1)	5.144 (3)	5.105 (5)		5.120 (2)	5.049 (2)	5.091 (1)	5.097 (2)
		4.633 (2)*	4.716 (2)*	4.741 (1/2)*				4.525 (1)*
	4.218 (2)	4.263 (5)	4.198 (4)	4.168 (3)	4.228 (3)	4.414 (3)	4.228 (4)	4.251 (6)
		3.971 (9)*	3.974 (6)*	3.799 (1)*				
3.493 (6)	3.510 (3)	3.535 (3)	3.511 (4)	3.490 (5)	3.524 (5)	3.497 (5)	3.517 (5)	3.513 (3)
		3.339 (1)*	3.330 (1)*			3.330 (1/2)*	3.379 (1/2)*	3.345 (10)*
3.208 (3)	3.241 (2)	3.228 (2)	3.236 (2)	3.196 (2)	3.270 (1)	3.218 (1)	3.241 (3)	3.224 (1)
3.092 (8)	3.108 (3)	3.116 (8)	3.113 (8)	3.108 (6)	3.113 (9)	3.103 (9)	3.108 (8)	3.027 (4)
2.998 (3)	2.897 (9)*	2.974 (5)	2.976 (4)	3.010 (8)*		2.897 (2)		2.901 (1)
2.822 (1)	2.842 (2)	2.805 (2)	2.807 (1)	2.878 (1/2)		2.807 (1)		
2.742 (2)	2.716 (1/2)	2.717 (1)	2.720 (2)	2.688 (2)	2.708 (2)	2.708 (2)	2.708 (2)	2.704 (1)
				2.583 (1)		2.597 (1)	2.616 (1/2)	2.587 (1)
2.552 (3)	2.554 (1)	2.563 (2)	2.554 (2)	2.529 (2)	2.564 (2)	2.540 (2)	2.543 (2)	2.540 (1)
2.452 (2)	2.473 (1)	2.454 (1)	2.459 (1)	2.476 (2)	2.476 (1)	2.470 (1)	2.469 (1)	2.459 (1)
2.356 (1/2)		2.346 (1/2)		2.437 (1/2)				
2.267 (1)				2.268 (3)*				2.280 (2)*
2.146 (3)		2.163 (2)	2.152 (2)	2.139 (2)	2.152 (2)	2.194 (1)	2.154 (3)	2.137 (1)
2.081 (2)		2.091 (1)	2.106 (1)	2.083 (2)		2.149 (2)		2.088 (1)
2.016 (2)		2.026 (1)	2.025 (1)	2.019 (1)	2.015 (1)	2.021 (1)	2.034 (1)	2.017 (1)
	1.993 (2)			1.983 (1)		1.985 (1)	1.989 (1)	1.977 (1)
1.934 (3)	1.937 (1)		1.937 (1)	1.925 (1)	1.937 (2)	1.937 (2)	1.941 (1)	
1.901 (2)		1.900 (1/2)		1.899 (3)		1.899 (1)	1.901 (1)	1.806 (1)
1.864 (1)				1.864 (3)				1.862 (1)
1.816 (1)		1.821 (1)				1.822 (1)	1.822 (1)	1.818 (2)
1.756 (1)		1.777 (2)	1.779 (1)		1.767 (1)			
		1.697 (1)						1.699 (2)
1.670 (2)		1.671 (1)	1.672 (1)	1.670 (1)	1.670 (1)	1.671 (2)	1.678 (1)	
1.599 (2)		1.591 (1)	1.595 (1)	1.599 (2)		1.608 (1)		1.599 (1)
			1.522 (1)*	1.522 (1)		1.543 (1)*		
1.500 (2)				1.498 (1)	1.503 (2)	1.500 (2)	1.498 (2)	

Appendix A (continued)

Explanation of the X-ray diffraction data for carnotites

The values given in the preceding table were measured from powder patterns which were obtained using copper radiation (nickel filter) in a Debye-Scherrer camera having an effective diameter of 114.59 mm.

The "d" values are given in Angstrom units.

The estimated intensities are shown in parentheses.

The intensities of diffuse lines have been underlined.

Those lines which are wholly or in part due to impurities have been noted by an asterisk. The impurity is listed below.

- A - Standard carnotite from Vaes and Kerr, 1949, Am. Min. 34:109-120.
- B - Greenish yellow carnotite from Locality 5. (The localities are shown in Table 3 and on Plate 1.) Specimen also contains dolomite.
- C - Greenish yellow carnotite from Locality 10. Specimen contains celestite and an unidentified mineral.
- D - Greenish yellow carnotite from Locality 10 (second specimen). Contains celestite and an unidentified mineral.
- E - Yellow-green carnotite from Locality 14. Contains calcite.
- F - Yellow carnotite from the opposite side of the same two inch pebble that produced E.
- G - Yellow carnotite from Locality 27.
- H - Yellow carnotite from fault breccia at Tiffin mine.
- I - Yellow carnotite from prospect 1500' northwest of Green Monster mine. Also contains quartz.

Discussion:

As these X-ray patterns were run only in order to identify the minerals, great pains were not taken to secure complete groups of lines with each sample. Nevertheless, the results make it possible to identify all of these as carnotite with confidence.

Appendix A (continued)

It is noteworthy that the "d" value for a given line may vary considerably from specimen to specimen. However, a few lines, i. e., those with spacings of 1.500, 1.670, 1.900 and 1.937, show very little change. According to Dana's System of Mineralogy, carnotite probably has layer lattice structure in which the water content may vary, as indicated by the formula $K_2(UO_2)_2(VO_4)_2 \cdot nH_2O$. The question raised is this: are the variations in "d" values due to variations in the amount of water between the layers? If so, then the reflections from the planes normal to the plane containing the water should be the ones which maintain constant spacing. Unfortunately the Goodsprings material is neither sufficiently abundant for chemical determinations nor well enough crystallized to provide material for structural investigations.

APPENDIX B

Chemical and Radiometric Uranium Analyses of various
Materials from the Region around Goodsprings, Nevada
(Determinations by W. L. Anderson,
U. S. Bureau of Mines, Salt Lake City, Utah.)

Sample number, description and locality	e U_3O_8	c U_3O_8
<u>PB-31-53</u> Chip sample containing carnotite from Locality 26.	< 0.01	< 0.003
<u>PB-32-53</u> Shaley red sandstone, Toroweap formation, 1 mi. northwest of Jean Underpass; no U mineral seen.	< 0.01	0.006
<u>PB-38-53</u> Buff sandstone, Toroweap formation, 2 mi. northwest of Jean Underpass; no U mineral seen.	< 0.01	0.008
<u>PB-59-53</u> Chip sample containing carnotite from prospect pit 2 mi. north of Goodsprings	< 0.01	0.006
<u>PB-63-53</u> Chip sample of sand containing carnotite from Locality 11.	0.01	0.006
<u>PB-52-53*</u> Yellow tuff, Locality 7.	< 0.01	0.010
<u>PB-53-53</u> Maroon tuff, Locality 7.	0.01	0.012
<u>PB-60-53</u> Maroon tuff, Locality 10.	0.01	0.022 †
<u>PB-64-53</u> Gray tuff, Locality 13.	0.01	0.013
<u>PB-80-53</u> Lavender tuff, 2 mi. west of Erie	0.01	0.003
<u>V-25</u> Basal buff tuff, 1 mi. east of Sloan	0.01	0.006
<u>V-26</u> Top of buff tuff, 1 mi. east of Sloan	0.01	0.006
<u>V-27</u> Lavender tuff, 1 mi. east of Sloan	0.01	0.006
<u>V-28</u> Maroon tuff, 1 mi. southeast of Sloan	0.01	0.017
<u>V-29</u> Maroon tuff from 500 ft. east of Locality 5.	0.01	0.006
<u>V-30</u> Black vitrophyre, Locality 7.	0.01	< 0.003
<u>V-31</u> Yellow tuff, Locality 9.	0.01	0.006

Appendix B (continued)

		e U_3O_8	c U_3O_8
<u>V-32</u>	Maroon tuff, Locality 9.	0.01	0.009
<u>V-33</u>	Brown tuff, 1000 ft. west of Locality 10.	0.01	0.012
<u>V-34</u>	Gray tuff above V-33	0.01	0.009
<u>V-35</u>	Basal maroon tuff above V-34	0.01	<0.003
<u>V-36</u>	Gray tuff, Locality 12.	0.01	0.009
<u>V-37</u>	Brown (yellow) tuff, just northwest of Locality 14.	0.01	0.007
<u>V-38</u>	Gray tuff, Locality 13.	0.01	0.005
<u>V-39</u>	Gray tuff, north end of Locality 13.	0.01	0.012
<u>V-40</u>	Maroon tuff, 1/4 mi. east of Locality 12.	0.01	0.010
<u>V-41</u>	Maroon tuff from 1/2 mi. east of Locality 12.	0.01	0.012
<u>V-43</u>	Lavender tuff east of Jean Underpass	0.01	0.010
<u>V-44</u>	Brown tuff below V-43	<0.01	0.014
<u>V-45</u>	Gray tuff below V-44	0.01	0.003
<u>V-46</u>	Brown tuff from north end of R. R. cut, Jean Underpass. May not be representative.	0.01	0.033 ?
<u>V-47</u>	Maroon tuff overlying V-46	0.01	0.012
<u>V-49</u>	Brown tuff 1 mi. south of Jean Underpass	0.01	0.011
<u>V-50</u>	Lavender tuff above V-49 Duplicate	<0.01 0.01	0.011 0.015
<u>V-51</u>	Gray tuff adjacent to probable fault S.S.W. of Jean Underpass	0.01	0.014
<u>V-52</u>	Maroon tuff, Locality 17.	0.01	0.012
<u>V-53</u>	Maroon tuff from 2 1/2 mi. west of Erie	0.01	0.011
<u>V-54</u>	Gray tuff beneath V-54	0.01	0.005

Appendix B (contimed)

		e U_3O_8	c U_3O_8
<u>V-55</u>	Basal lavender tuff, 2 1/2 mi. west of Erie. (1/4 mi. south of V-54)	0.01	0.009
<u>V-56</u>	White tuff above V-55.	< 0.01	0.010
<u>V-57</u>	Yellow tuff above V-56	0.01	0.007
<u>V-57A</u>	Gray tuff, yellow horizon at V-56. Alteration??	0.01	0.011
<u>V-58</u>	Maroon tuff 2 1/2 mi. northwest of Erie	0.01	0.007
<u>V-60</u>	Maroon tuff south of Erie Duplicate	0.01 0.01	0.008 0.010
<u>V-63</u>	Gray tuff, Locality 10. Duplicate	0.01 0.01	0.003 0.006
<u>PB-41-53</u>	Light gray tuff, north end, Table Mountain.	0.01	0.004
<u>V-1</u>	Agglomerate, base of Table Mountain tuffs.	< 0.01	0.004
<u>V-2</u>	Light brown tuff above V-1.	< 0.01	0.005
<u>V-2A</u>	Light brown tuff 50 ft. above V-2.	< 0.01	0.006
<u>V-2B</u>	White lense in brown tuff, 70 ft. above V-2.	< 0.01	< 0.003
<u>V-3</u>	Gray tuff overlying V-2B.	0.01	0.006
<u>V-4</u>	Light brown tuff above V-3.	< 0.01	0.006
<u>V-5</u>	Gray tuff and agglomerate above V-4.	< 0.01	0.005
<u>V-8</u>	Latite(?) flow, volcanic center east of Erie.	0.01	< 0.003
<u>V-9</u>	Laminated flow of latite(?) from V-8.	0.01	0.007
<u>V-59</u>	Andesite (?) large area south of highway at Erie. Representative ??	< 0.01	0.022 ?
<u>V-11</u>	Waterlain tuff, southwest 1/4 section 2, T. 24 S., R. 57 E. (Goodsprings Quad.)	0.01	0.006
<u>V-12</u>	Waterlain tuff from east 1/2 section 2, T. 24 S., R. 57 E.	0.01	0.003

Appendix B (continued)

		e U_3O_8	c U_3O_8
<u>PB-78-53</u>	Andesite (?) immediately west of Tiffin mine.	0.01	0.010
<u>V-14</u>	Latite (?) plug north of Sultan mine.	< 0.01	0.006
<u>V-16</u>	Tuff and agglomerate near V-14.	< 0.01	< 0.003
<u>V-18</u>	Flow overlying V-16.	0.01	0.010
<u>V-19</u>	Flow from hilltop east of Sultan mine.	< 0.01	0.006
<u>V-20</u>	Agglomerate beneath V-19.	0.01	0.004
<u>V-21</u>	Buff tuff below V-20.	0.01	0.005
<u>V-61</u>	Violet latite (?), small plug 1 mi. west of Sultan mine.	< 0.01	0.010
<u>V-62</u>	Rhyolite, west side of Big Devil plug.	0.01	0.016
<u>V-22</u>	Porphyry, eastern part of Yellow Pine sill.	< 0.01	0.007
<u>V-23</u>	Tuff, hill 4 mi. west of Green Monster mine.	0.01	0.007
<u>V-24</u>	Tuff 1 mi. south of V-23.	0.01	< 0.003
<u>PB-74-53</u>	18 in. chip sample across most radioactive part, main level in Singer mine.	0.05	0.033
<u>PB-18-54</u>	Limonite from prospect at Yellow Pine mine.	0.02	0.017
<u>PB-50-54</u>	Oxidized Zn ore, uranium stope, Green Monster mine.	0.22	0.239
<u>PB-51-54</u>	Limonite from the Uranium stope, Green Monster mine.	0.15	0.106
<u>PB-55-54</u>	Limonite, Jeep mine northwest of Clark Mountain.	0.05	0.035
<u>PB-65-54</u>	Chrysocolla, Copper Flower (Vanadium Wedge or Last Chance) mine.	0.08	0.116
<u>PB-71-54</u>	Black Shale bearing sphalerite, Potosi mine.	0.01	0.013

* In all of the sampling of the volcanic rocks care was taken to secure fresh material free from caliche.

Appendix B (continued)

RESUME OF THE METHODS USED FOR THE DETERMINATION OF URANIUM

Volumetric Method

An appropriate size sample is brought into solution by acids. The hydrogen sulfide group of metals are removed by thioacetamid. Vanadium, iron, titanium, and other elements are removed by a cupferron-chloroform extraction. The separated uranium is oxidized and then reduced in a lead reductor. The reduced uranium is then titrated with a standard ceric sulfate solution using ferroin as the indicator. The method is good to ± 0.003 percent U_3O_8 .

Reference:

"Volumetric Determination of Milligram Quantities of Uranium," by C. W. Sill and H. E. Peterson, Analytical Chemistry, Vol. 24, Page 1175, July 1952.

Radiometric Method

The radiometric determination of uranium is subject to the inherent statistical error due to the random nature of the disintegration of uranium. Also the state of equilibrium of the ore being tested and its association with other radioactive elements can give rise to positive or negative errors. Therefore it is impossible to state the limits of accuracy of the method.

The sample to be counted is placed in a planchet directly under an end window Geiger counter in a lead shield. The sample is counted for five minutes and the pulses are recorded by an automatic scaling unit.

The percent U_3O_8 equivalent of the sample is determined by multiplying the counts per minute by a factor obtained by counting a standard uranium ore of known uranium content.

Appendix B (continued)

Fluorometric Uranium Determinations

In order to evaluate the unusually high uranium values given by the chemical determinations, composite samples were analysed fluorometrically by Mr. James Cobb at the Lamont Geological Observatory. The probable error of this method does not exceed 10% of the recorded value.

Sample 1 Upper Erie Tuff

Composite of: V-29S, V-40, V-47, V-52, V-50,
V-36, V-63, V-58 and V-29.

Average chemical U_3O_8 (Bureau of Mines) = 0.0098%

Fluorometric U_3O_8 (Lamont) = 0.0012%

Sample 2 Lower Erie Tuff

Composite of: V-54, V-44, V-37, V-57, V-33, V-49,
V-54, V-31, V-26 and PB-52-53

Average Chemical U_3O_8 = 0.0081%

Fluorometric U_3O_8 = 0.0012%

Sample 3 Table Mountain Tuffs

Composite of: V-1, V-2, V-2A, V-2B, V-3, V-4 and V-5

Average chemical U_3O_8 = 0.0048%

Fluorometric U_3O_8 = 0.00085%

Sample 4 Flows

Composite of: V-8, V-9, V-18, V-19, V-14, V-61, V-52,
and PB-78-53

Average chemical U_3O_8 = 0.0083%

Fluorometric U_3O_8 = 0.00079%

APPENDIX C

Semiquantitative Spectrographic Analyses
(Determinations by C. S. Ansell, U. S. Geol. Survey)

	<u>PB-2-53</u>	<u>PB-14-53</u>	<u>PB-60-53</u>	<u>V-30</u>	<u>V-31</u>	<u>V-58</u>	<u>PB-49-53</u>	<u>V-9</u>
Over 10%	Si Al	Si Al	Si Al	Si Al	Si Al	Si Al	Ca	Si Al
5-10%	-----	-----	-----	-----	-----	-----	-----	-----
1-5%	K Na Ca Fe	K Na Ca Fe	K Na Ca Fe	K Na Ca Fe	K Na Ca Fe	K Na Ca Fe	Si Al K Na	K Na Ca Fe
.5-1%	-----	-----	-----	-----	-----	-----	Fe	-----
.1-5%	Mg Ti	Mg Ti	Mg Ti	Mg Ti	Mg Ti	Mg	U Mg	Ba Mg
.05-.1%	-----	-----	-----	-----	-----	Ti	Ti	Ti Sr
.01-.05%	Ba Mn V Ce B Sr La Nd	Mn B Ce Sr	Ba Mn B Sr Nd V La	Ce Mn B Sr Nd La	Mn Ce B Sr Nd La	Mn B Sr	Mn Sr V B	Mn Ce B V La Nd
.005-.01%	Zr Co Ni	V Ba Nd La Zr Ni	Co Ni Zr Cr	Zr Ba Ni V	Zr Ba Ni V	Nd La V Zr Ba Ni	Ni La Ba	Zr Ni
.001-.005%	Cr Pb Cu Ga Mo Y Sc	Pb Ga Cu Cr Y Mo	Ga Pb Y Cu Mo Sc	Cr Ga Y Pb Cu Mo Sc	Cr Ga Y Pb Mo Cu Sc	Pb Ga Y Cu Cr Mo	Zr Cr Cu Pb Y	Pb Ga Y Cu Mo Cr Sc
.0005-.001%	-----	-----	-----	-----	-----	-----	-----	-----
.0001-.0005%	Be Yb	Be Yb	Be Yb	Be Yb	Be Yb	Be Yb	Be Yb	Be Yb
.00005-.0001%	-----	-----	-----	-----	-----	-----	Ag	-----
.00001-.00005%	-----	-----	-----	Ag	-----	-----	-----	-----

* Samples identified on page following this table.

Appendix O (continued)

	<u>V-3</u>	<u>PB-68-53</u>	<u>PB-67-54</u>	<u>PB-70-53</u>	<u>PB-50-54</u>	Lower Limit of detection
Over 10%	Si Al	Ca	Zn	Zn	Zn	-----
5-10%	-----	-----	-----	-----	Mg	Rb
1-5%	K Na Ca Fe	-----	Ca	-----	Ca	-----
.5-1%	-----	-----	Cd Si	-----	-----	Ca
.1-.5%	Mg Ti	Si Mg Al Fe	Fe Al Mg	Si Ca Pb Fe Mg	Fe Ni Si Cd Co <u>U</u>	Os Ta K
.05-.1%	-----	-----	Ge Cu	Cd Al	Al Pb Cu As	Hg P Te Th U W
.01-.05%	Ce Mn B Sr Nd La	Na Sr Mn Ti	B Sb Ni Pb Mn	Mn B Ni Ti V	B Ge V Ti Mn	As Ca Ce Hf Ir Pr Sb Tb Tl Re Li Na
.005-.01%	Zr V Ni Co Ba	<u>Y</u>	Ti	Cu	-----	B Bi Cd Co Dy Gd Zn Lu Nd Ni Ru Si Sm
.001-.005%	Pb Ga Cu Y Mo Cr Sc	Pb Cu Cr Ba	V Ag Sr Ga	Mo Sr Sn Ag Ge	Mo Ag Ga Sr	An Ba Eu Er Ga Ge Y Ho La Nb Pb Pd Pt Rh Sc Sn Sr Tm V
.0005-.001%	-----	-----	Cr	Cr	Cr	Cr Fe Mo Mn Ti Zr
.0001-.0005%	Be Yb	-----	-----	-----	-----	Al In Yb
.00005-.0001%	-----	-----	-----	-----	-----	Be Cu
.00001-.00005%	-----	-----	-----	-----	-----	Ag Mg

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* Samples identified on page following this table.

Appendix C (continued)

The samples represented in the preceding table are identified as follows:

- PB-2-53 Maroon welded tuff from carnotite Locality 7.
- PB-14-53 Lavender welded tuff from Jean Underpass.
- PB-60-54 Gray welded tuff from Locality 10.
- V-30 Black vitrophyre (near base of Erie tuff) from Locality 7.
- V-31 Yellow welded tuff from Locality 9.
- V-58 Maroon welded tuff from two miles northwest of Erie.
- PB-49-53 Selected radioactive specimen from breccia zone at Locality 7.
- V-9 Latite flow from post-tuff volcanic center two miles east of Erie.
- V-3 Gray tuff, not welded, north end of Table Mountain.
- PB-68-53 Carnotite free core of carnotite coated pebble from carnotite Locality 14.
- PB-67-54 Radioactive zinc ore from Potosi mine. Contains sphalerite with traces of black shale and calcite.
- PB-70-54 Radioactive hydrozincite from Singer mine.
- PB-50-54 Radioactive oxidized zinc ore from Green Monster mine.

APPENDIX D

Adsorption Data

Series 1 Adsorption of various uranium ions by hydrous ferric oxide

Preparation of the hydrous ferric oxide:

A solution containing 100.0 grams of $\text{Fe}_2(\text{SO}_4)_3 \cdot n\text{H}_2\text{O}$ per liter was neutralized by 1:4 NH_4OH to pH 7. The resulting precipitate was filtered and washed with distilled water until a negative sulfate test with BaCl_2 was obtained. By ignition to Fe_2O_3 it was determined that the hydrous ferric oxide was 10.25% Fe_2O_3 , the rest being water. This material gives an alpha hematite x-ray pattern after being aged for a few days under water at 95° C.

Adsorption procedure:

Portions of 15.0 grams each of the hydrous ferric oxide were placed in 250 ml flasks and 100.0 ml portions of various uranium solutions of varying concentration were introduced. The flasks were shaken daily.

Solutions used:

- 1A 0.0729 M uranyl sulfate, diluted to varying concentrations. UO_2^{+2} ion present initially, but pH after adsorption at time of analysis was high enough that $\text{UO}_2(\text{OH})^+$ must have been present in significant amounts.
- 1B 0.0661 M solution made from uranyl sulfate neutralized to pH of 4.49 by NaOH. According to L. Miller (personal communication) this gives mostly $\text{UO}_2(\text{OH})^+$ ions. After a few hours a yellow precipitate formed and it is assumed that this also occurred in the flasks where adsorption was taking place. These data are presented mainly to illustrate the form of a curve when the precipitation of an insoluble phase occurs. No attempt was made to exclude CO_2 in the air; therefore some $\text{UO}_2(\text{CO}_3)_3^{-4}$ was probably formed, though the amount certainly was small.
- 1C 0.0823 M solution made from uranyl sulfate by adding 1.0 N Na_2CO_3 in slight excess of the stoichiometric amount needed to form $\text{UO}_2(\text{CO}_3)_3^{-4}$; pH equals 8.0

The following results were obtained on analysing the solutions after 5 days.

Appendix D (continued)

Adsorption Data

Series 1A Adsorption of the uranyl ion (UO_2^{+2}) and the uranyl hydroxide ion ($UO_2(OH)^+$) by hydrous ferric oxide

Sample	Total U	Values in milliequivalents	
		U in solution	U adsorbed
1A-1	14.58	11.41	3.17
1A-1	14.58	11.38	3.20
1A-2	10.94	7.76	3.18
1A-2	10.94	7.87	3.07
1A-3	7.29	4.52	2.77
1A-3	7.29	4.59	2.70
1A-4	3.65	1.23	2.43
1A-4	3.65	1.23	2.42
1A-5	1.46	0.02	1.44

Series 1A-R Reversibility of series 1A on dilution

Sample	U in solution at instant of dilution	Total U	Values in milliequivalents	
			U in solution after 15 days	U adsorbed after 15 days
1A-R1	5.70	8.89	6.53	2.36
1A-R1	5.70	8.89	6.54	2.35
1A-R2	3.91	7.03	4.52	2.51
1A-R2	3.91	7.03	4.57	2.46
1A-R3	2.28	5.02	2.68	2.34
1A-R3	2.28	5.02	2.70	2.32
1A-R4	0.61	3.04	0.78	2.26
1A-R5	(too dilute to analyse)			

Appendix D (continued)

Adsorption Data

Series 1B Adsorption (and precipitation) of the uranyl hydroxide ion (UO_2OH^+) by hydrous ferric oxide

Sample	Total U	Values in milliequivalents	
		U in solution	U adsorbed
1B-1	11.22	3.45	7.77
1B-1	11.22	3.46	7.76
1B-2	8.42	2.94	5.48
1B-2	8.42	2.93	5.49
1B-3	5.61	1.20	4.41
1B-3	5.61	1.23	4.38
1B-4	2.81	0.03	2.78
1B-5	1.12	0.01	1.11

Series 1B-R Reversibility of series 1B on dilution

Sample	U in solution at instant of dilution	Total U	Values in milliequivalents	
			U in solution after 15 days	U adsorbed after 15 days
1B-R1	1.73	9.49	1.73	7.76
1B-R1	1.73	9.49	1.74	7.75
1B-R2	1.47	7.95	1.42	6.53
1B-R2	1.47	7.95	1.44	6.51
1B-R3	0.61	5.00	0.67	4.33
1B-R3	0.61	5.00	0.64	4.36
1B-R4	0.015	2.80	0.02	2.78
1B-R5	(too dilute to analyse)			

Appendix D (continued)

Adsorption Data

Series 1C Adsorption of the uranyl carbonate ion ($\text{UO}_2(\text{CO}_3)_3^{-4}$)
by hydrous ferric oxide

Sample	Total U	Values in milliequivalents	
		U in solution	U adsorbed
1C-1	16.46	11.56	4.90
1C-1	16.46	11.62	4.84
1C-2	12.35	8.13	4.22
1C-2	12.35	8.22	4.13
1C-3	8.23	4.83	3.40
1C-3	8.23	4.86	3.37
1C-4	4.12	1.85	2.27
1C-4	4.12	1.86	2.26
1C-5	1.65	0.30	1.35
1C-5	1.65	0.33	1.32

Series 1C-R Reversibility of series 1C on dilution

Sample	U in solution at instant of dilution	Total U	Values in milliequivalents	
			U in solution after 15 days	U adsorbed after 15 days
1C-R1	5.79	10.66	6.43	4.23
1C-R1	5.79	10.66	6.44	4.22
1C-R2	4.09	8.26	4.52	3.74
1C-R2	4.09	8.26	4.51	3.75
1C-R3	2.42	5.80	2.72	3.08
1C-R3	2.42	5.80	2.76	3.04
1C-R4	0.93	3.19	1.06	2.13
1C-R4	0.93	3.19	1.07	2.12
1C-R5	(too dilute to analyse)			

Appendix D (continued)

Adsorption Data

Series 2 Adsorption of the uranyl carbonate ion, $\text{UO}_2(\text{CO}_3)_3^{-4}$, by synthetic hydrozincite.

Preparation of synthetic hydrozincite:

100.0 grams of ZnCO_3 were dissolved in 45 ml of 36 N H_2SO_4 and 455 ml of water. 300 ml of the resulting ZnSO_4 solution were then neutralized by 500 ml of 1 M Na_2CO_3 to a pH of 8. The flocculent white precipitate of basic zinc carbonate was filtered and washed with water. A sample of this material was dried for 10 days at 95° C and then x-rayed. The pattern was diffuse, but it contained over 20 lines, all of which matched those from natural hydrozincite from the Yellow Pine mine. The natural hydrozincite fluoresced an intense blue-white, but the synthetic material apparently did not have the impurities necessary for fluorescence. On ignition, the dried synthetic material gave 73.79% ZnO (average of 3) compared to 74.12% for pure hydrozincite, $\text{Zn}_5(\text{OH})_6(\text{CO}_3)_2$. The adsorbent used had 11.5% by weight of hydrozincite, the remainder being water.

Adsorption procedure:

30.0 gram portions of hydrous basic zinc carbonate were placed in 500 ml flasks and 200.0 ml portions of solutions containing variable amounts of uranyl carbonate ion were introduced. The flasks were shaken daily.

Solution used:

An 0.0763 M solution of uranyl carbonate was made from a uranyl sulfate solution by adding 1.0 N Na_2CO_3 in slight excess of the stoichiometric amount needed to form $\text{UO}_2(\text{CO}_3)_3^{-4}$; the pH equaled 8.2. The solution was diluted with water to obtain the amount of uranium desired for the adsorption experiments.

The following results were obtained on analysing the solutions after 8 days.

Appendix D (continued)

Adsorption Data

Series 2 Adsorption of the uranyl carbonate ion ($\text{UO}_2(\text{CO}_3)_3^{-4}$)
by hydrous synthetic hydrozincite

Sample	Total U	Values in milliequivalents	
		U in solution	U adsorbed
2-1	30.46	25.40	5.06
2-1	30.46	25.30	5.16
2-2	22.85	18.66	4.19
2-2	22.85	18.78	4.07
2-3	15.23	12.15	3.08
2-3	15.23	12.25	2.98
2-4	11.43	8.74	2.69
2-4	11.43	8.79	2.64
2-5	7.62	5.55	2.07
2-5	7.62	5.54	2.08
2-6	3.81	2.24	1.57
2-6	3.81	2.28	1.53

Series 2-R Reversibility of series 2 on dilution

Sample	U in solution at instant of dilution	Total U	Values in milliequivalents	
			U in solution after 21 days	U adsorbed after 21 days
2-R1	12.67	17.78	14.28	3.50
2-R1	12.67	17.78	14.19	3.59
2-R2	9.36	13.49	10.57	2.92
2-R2	9.36	13.49	10.68	2.81
2-R3	6.10	9.13	6.74	2.49
2-R3	6.10	9.13	6.77	2.46
2-R4	4.38	7.04	4.92	2.12
2-R4	4.38	7.04	4.92	2.12
2-R5	2.77	4.84	3.10	1.74
2-R5	2.77	4.84	3.09	1.75
2-R6	1.13	2.68	1.21	1.47
2-R6	1.13	2.68	1.24	1.44

Appendix D (continued)

Variation of adsorptive capacity with degree of aging

Aging time	Total U	Values in milliequivalents	
		U in solution	U adsorbed
1/2 day	17.62	11.21	6.41
		11.23	6.39
1 1/2 days	17.62	11.40	6.22
		11.48	6.14
7 1/2 days	17.62	11.53	6.09
		11.56	6.06
14 1/2 days	17.62	11.57	6.05
		11.64	5.98
21 1/2 days	17.62	11.67	5.95
		11.68	5.94

In this experiment a hydrous ferric oxide gel containing 8.5% Fe_2O_3 was prepared in the manner described for Series 1. Five samples of 20.0 grams each were weighed and placed in 50 ml of water. The pH was 8.4. The samples were aged from 1/2 to 21 1/2 days in stoppered 500 ml flasks. At the end of the desired aging period 200 ml of 0.08808 N $\text{UO}_2(\text{CO}_3)_3^{-4}$ solution were added. After 24 hours 50 ml of solution were withdrawn and stored in a tightly stoppered flask. All of the samples were analysed the same day. The concentration of the solution is believed to have been sufficiently high that the amount of uranium lost through adsorption on the glassware was negligible.

Appendix D (continued)

Adsorption of the uranyl carbonate ion by natural materials

Material (Locality)	Total U	Values in milliequivalents	
		U in solution (per 100 ml)	U adsorbed
Chrysocolla (Boss mine)	8.81	8.27	0.54
		8.27	0.54
Chrysocolla (Copper Flower)	8.81	8.15	0.66
		8.20	0.61
Limonite (Jeep)	8.81	8.57	0.24
		8.56	0.25
Limonite (Boss)	8.81	8.66	0.15
		8.78	0.03
Limonite (Tam o'Shanter)	8.81	8.87	-0.06
		8.92	-0.11
Hydrozincite (Yellow Pine)	8.81	8.62	0.19
		8.65	0.16
Hydrozincite (Sultan)	8.81	9.49	-0.68
		9.52	-0.71

In this experiment all of the materials were dried in air at room temperature and were ground to pass 100 mesh. Samples of 10.0 grams each were weighed and placed in stoppered 250 ml flasks with 100 ml of 0.08808 N $\text{UO}_2(\text{CO}_3)_3^{-4}$ solution. The flasks were shaken daily, and the solutions were analysed at the end of 5 days.

















The sample of hydrozincite from the Sultan mine accidentally became unstoppered for a period of about 24 hours; this may have permitted sufficient evaporation to account for the increase in the uranium concentration.

Plate I

RECONNAISSANCE GEOLOGIC MAP OF THE CARNOTITE LOCALITIES EAST OF THE GOODSPRINGS QUADRANGLE

(This map has been prepared from 1:23,000 aerial photographs. The only control is provided from a map of the railroad right-of-way.)

EXPLANATION

-  Undifferentiated alluvium
-  Basalt
-  Erie tuff
-  Early alluvium
-  Maenkopi fm.
-  Kaibab fm.
-  Toroweap fm.
-  Supai fm.
-  Bird Spring fm.
-  Monte Cristo fm.
-  Sultan fm.
-  Goodsprings fm.
-  Fault, dashed where inferred
-  Contact, dashed where inferred
-  Prospect
-  Quarry

APPROXIMATE SCALE

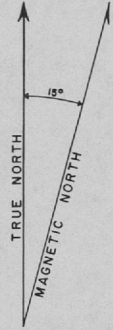
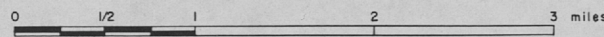


Plate 2

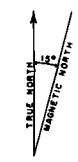
LOCATION OF THE URANIUM OCCURRENCES
OF THE GOODSPRINGS DISTRICT

EXPLANATION

- Mine or Prospect
- ⊛ Uranium minerals
- Radioactive oxidized zinc minerals
- Radioactive limonite and/or oxidized copper minerals
- ⊙ Radioactive source undefined

SCALE

0 1 2 3 4 miles



LIST OF MINES AND PROSPECTS

- | | |
|----------------------|----------------------|
| 1 Accident | 49 Kirby |
| 2 Addison | 50 Lovino |
| 3 Akron | 51 Lincoln |
| 4 Alice | 52 Little Betty |
| 5 Alice Fraction | 53 Lookout |
| 6 Anchor | 54 Middlesex |
| 7 Annes | 55 Milford |
| 8 Argentina | 56 Milford No. 2 |
| 9 Azurite | 57 Mobile |
| 10 Belle | 58 Mahawk No. 7 |
| 11 Bico (Volcano) | 59 Mongallon |
| 12 Bull Eye | 60 Monte Cristo |
| 13 Black Jack | 61 Mountain Queen |
| 14 Blue Jay | 62 Mountain Top |
| 15 Boss | 63 Minty Mine |
| 16 Bullion | 64 Oro Amigo |
| 17 Chaquita | 65 Ovar |
| 18 Christmas | 66 Palace-Porter |
| 19 Clamalina | 67 Paradise |
| 20 Cobalt King No. 1 | 68 Pauline |
| 21 Columa | 69 Pilgrim |
| 22 Contact | 70 Platino |
| 23 Copper Flower | 71 Potosi |
| 24 Copper Glance | 72 Prairie Flower |
| 25 Copperchief | 73 Puetz |
| 26 Copperside | 74 Rainbow |
| 27 Cosmopolitan | 75 Red Cloud |
| 28 Daniel Boone | 76 Root |
| 29 Dawn | 77 Rose |
| 30 Desert Valley | 78 Rosetta Nos 1 & 2 |
| 31 Doubleup | 79 Royal Blue |
| 32 Eureka | 80 Ruth |
| 33 Eureka-Silver Gem | 81 Shenandoah |
| 34 Fitzhugh Lee | 82 Singer-Tiffin |
| 35 Frederickson | 83 Smithsonian |
| 36 Golden Chariot | 84 Snowstorm |
| 37 Green Copper | 85 Spelter |
| 38 Green Monster | 86 Star |
| 39 Honeau Vanadium | 87 Sulfen |
| 40 Matchet | 88 Surprise |
| 41 Hermosa | 89 Tom o' Shanter |
| 42 Highline | 90 Tom Thinn |
| 43 Hoodoo | 91 Valley Forge |
| 44 Hoosier | 92 Whale |
| 45 Ireland | 93 Yellow Pine |
| 46 Iron Gold | 94 unknown |
| 47 Ironside | 95 unknown |
| 48 Keystone | |

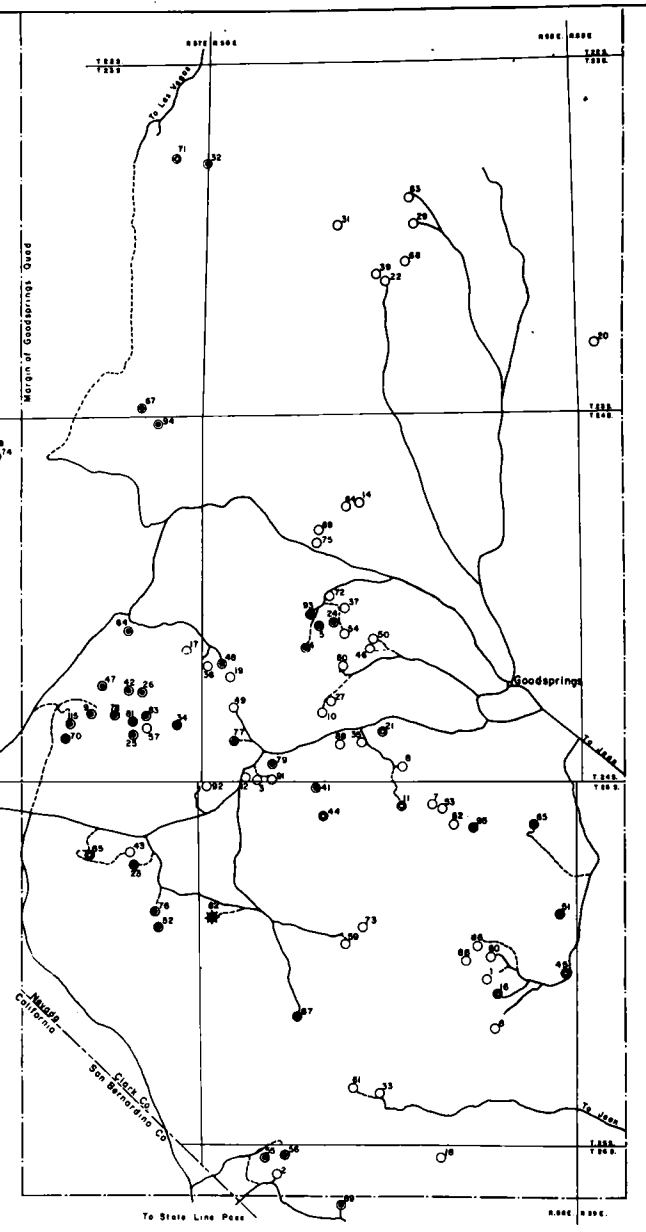


Plate 3 RECONNAISSANCE GEOLOGIC MAP OF THE AREA EAST OF THE GREEN MONSTER MINE

EXPLANATION

- Qal Alluvium
- Ps Supai fm.
- Cbs Bird Spring fm.
- Cmc Monte Cristo fm.
- Ds Sultan fm.
- CDg Goodsprings fm.
- Contact
- Fault
- Thrust fault
- Syncline
- x Mine or Prospect

This map has been prepared from aerial photos.
No correction for distortion has been made.

APPROXIMATE SCALE

