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VANADIUM DEPOSITS IN THE CARRIZO MOUNTAINS DISTRICT, NAVAJO INDIAN RESERVATION, NORTHEASTERN ARIZONA AND NORTHWESTERN NEW MEXICO

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Illustrations

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Vanadium deposits in the Carrizo Mountains district, Navajo Indian Reservation, northeastern Arizona and northwestern New Mexico.

By D. C. Duncan and W. L. Stokes

Abstract

The Carrizo Mountains vanadium district is in the Navajo Indian Reservation, northeastern Arizona and northwestern New Mexico. From May through October, 1942, two mining companies, operating under lease agreements with the Navajo Service, opened several mines in the district and produced a total of about 6,000 tons of ore, averaging approximately 2.2 percent V_2O_5.

The central igneous rock mass of the Carrizo Mountains is surrounded by gently folded sedimentary rocks of Mesozic age. The vanadium deposits are sporadically distributed in a sandstone zone in the lower part of the Morrison formation of Jurassic age.

The ore is sandstone impregnated with vanadium- and uranium- bearing minerals, and it ranges in grade from 1 to 10 percent V_2O_5, averaging about 2 percent V_2O_5. The ore bodies are irregularly tabular masses that lie nearly parallel to the enclosing sandstone beds. They range from a few inches to 6 feet in thickness and from a few feet to as much as 300 feet long and contain from a few tons to as much as a thousand tons of ore.

The vanadium is believed to have been deposited from circulating ground waters before consolidation of the enclosing sediments. As the controls that localized ore bodies within the ore-bearing zone have not been determined, the exact geographic distribution of concealed deposits cannot be predicted.

Estimated reserves of indicated ore in the district total about 17,000 tons, containing about 2 percent V_2O_5, and are adequate to maintain the

present production rate of about 1,200 tons per month for about one year. Estimated reserves of inferred ore in the known mineralized areas total about 70,000 tons, containing about 2 percent V_2O_5. Much of this inferred ore will probably be located and mined by the operators as existing indicated reserves are depleted. Additional inferred reserves on the order of 12 million tons of ore are believed to underlie about 350 square miles of the district, but the cost of searching for and mining this ore with present techniques would be much greater than the present value of the ore.

Introduction

Deposits of vanadium ore are spordically distributed in sandstone of the Morrison formation in the vicinity of the Carrizo Mountains, the Navajo Indian Reservation, northeastern Arizona and northwestern New Mexico. The district is an area of about 800 square miles. [1] The Carrizo Mountains

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[1] Figure 1. Index map showing location of Carrizo Mountains vanadium district, Navajo Indian Reservation, northeastern Arizona and northwestern New Mexico.

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are in the central part of the district and are bounded on the west, north, and east by extensive flats that are cut on sandstone and shale and partly covered by thin mantles of gravel and dune sand. Scattered buttes and mesas rise above, and deep washes cut below the flats. The mountains reach an altitude of 9,400 feet but most of the known deposits are in the flats and along the base of the mountains at altitudes between 5,000 and 6,000 feet. Although the climate of the region is semi-arid, sufficient water is available from springs for normal mining requirements. Weather permits surface mining throughout most of the year. Gravelled and dirt roads lead from most of the important deposits to Shiprock, New Mexico, the nearest supply point, 38 to 60 miles distant. The nearest processing plants for vanadium ore are the Metals Reserve mills at Durango, Colorado and at Monticello, Utah. Ore is trucked from the deposits to the Monticello mill, a haul of about 150 miles, or to Farmington, New Mexico, a haul of about [illegible] miles, from which point it is shipped 50 miles by rail to Durango.

As part of the U. S. Geological Survey's investigations of critical [illegible]ar minerals, the deposits in the district were examined during October and November, 1942, by Duncan and Stokes, under the immediate supervision of [illegible]

R. P. Fischer. The accompanying geologic map (Pl. 1) was compiled from

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Plate 1. Geologic map of Carrizo Mountains district, Navajo Indian Reservation, northeastern Arizona and northwestern New Mexico, showing location of vanadium mines and prospects.

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aerial photographs. Outcrops of the ore-bearing beds in the area total about 150 miles in length. Of this, about 50 miles of outcrop, mostly in the general vicinity of vanadium mines and prospects, were examined in detail. The ore-bearing zone in the northern part of the map area, where sand dunes conceal most of the bedrock, and in the western and southwestern parts of the map area, much of which is comparatively inaccessible, was mapped in reconnaissance. Three small areas that are being intensively mined were mapped in detail with planetable (Plates 2, 3, and 4).

Thanks are due to the staff of the Vanadium Corporation of America, particularly Messers D. W. Viles and A. A. Spraul of the Monticello office, for the many courtesies and aid in the field work. Messers. John Wade and T. F. V. Curran, owners of the Wade and Curran Company, kindly supplied much valuable information.

History and Production

Vanadium ore was discovered in the district in 1919, and by 1922 approximately 40 claims were leased from the Navajo Indian Service. Ore production during this period was small, and only a few tons were shipped to processing plants. Prospecting activity in the district ceased in 1922, with the general decline of uranium, radium, and vanadium mining in Colorado and Utah. During the 1930's, special lease regulations governing vanadium mining in the district were established whereby prospecting or mining leases of variable size could be obtained by bid at public auction. Successful bidders contracted to pay royalty on the contained V_2O_5 in ore mined, plus a bonus

to operate each lease and also to employ Indians for unskilled and semi-skilled labor.

Mining in the district was resumed in 1942. Vanadium Corporation of America began operations on two prospecting leases that covered extensive areas within the district, and began shipment of ore to the Monticello mill in May. Wade and Curran Company, which holds 5 claims, started shipping ore to the Durango mill in July. About 6,000 tons of ore containing approximately 2.2 percent V_2O_5 were mined from the district during the period May through October, 1942.

Geology

The central mass of the Carrizo Mountains consists of intrusive igneous rocks of Tertiary age, and complexly deformed older sediments. Gently inclined and flat-lying Mesozoic rocks are exposed around the flanks of the mountains and are in part domed and in part cut by the intrusive mass. Scattered dikes and plugs of basic igneous rock intrude the comparatively undisturbed sediments surrounding the mountains.

The age, thickness, lithologic character, and topographic expression of the sedimentary rocks exposed in the district are shown in the following table.

Generalized section of sedimentary rocks exposed in the Carrizo Mountains district.

System	Series	Group	Formation	Thickness (feet)	Lithologic character and topographic expression
Cretaceous	Upper Cretaceous		Dakota (?) sandstone	30-40	Brown-weathering, cliff-forming, conglomeratic sandstone. Caps scattered buttes and mesas.
Jurassic	Upper Jurassic		Morrison formation	190-210	Bentonitic shale; gray, pink, green, white, tan, and yellow bands. Unit weathers to smooth varicolored slopes.
				210-280	Sandy shale; gray and bluish-green, with lenses of white, friable sandstone which weathers to tan. Unit weathers to low cliffs and slopes.
				210	Chocolate-brown, sandy shale and white sandstone which weathers to salmon-pink. Unit weathers to low cliffs and slopes.
				180-200	Lenticular sandstone, weathering to light gray and light brown, interbedded with minor red, green, and gray shale. Vanadium deposited scattered in lower 120 feet. Unit weathers to discontinuous cliffs and benches.
		San Rafael	Undifferentiated [1]	100-150	White, red, and brown massive sandstone and red thin and crinkly bedded mudstone and sandstone. At top is a white sandstone 1 to 5 feet thick containing scattered coarse grains. Unit forms slopes and distinctively banded cliffs.
Jurassic(?)		Glen Canyon	Undifferentiated [2]	400±	White and red tangentially-bedded, massive sandstone. Weathers to smooth vertical cliffs and bare rock hummocks and domes.
Triassic			Undifferentiated [3]	1,200±	Varicolored shale; thin bedded sandstone; gray limestone; conglomerate.

1 Beds in the Carrizo Mountain district, which were formerly assigned to the lower part of the McElmo formation by Gregory (U.S. Geol. Survey Prof. Paper 93, pp. 59-71, 1917) were assigned to the Carmel and Entrada formations of the San Rafael group by Baker, Dane, and Reeside (U. S. Geol. Survey Prof. Paper 183, pl. 23A and p. 17, 1936). In addition to beds formerly assigned to the San Rafael group, the writers include beds that Baker, Dane, and Reeside assigned to the basal part of the Morrison formation.

2 The Glen Canyon group includes essentially the same rocks as the "LaPlata group" of Gregory. (See Gregory, H. E., op. cit., pp. 52-59; and Baker, Dane, and Reeside, op. cit., figs. 8, 9, 10, and p. 37 and 44.)

3 Triassic rocks are exposed in isolated areas flanking the Carrizo Mountains and over most of the southwest corner of the district; but were not studied during the investigation. The Chinle formation is believed to be the only Triassic formation exposed. (See Gregory, H. E., op. cit., pp. 35-50.)

The Morrison formation which contains the vanadium ore consists mainly of sandstone and shale. It can conveniently be divided into four distinct units, each about 200 feet thick. (See table p. 10.) The vanadium ore is restricted to a zone about 70 feet thick in the lower part of the basal unit, which consists of lenticular gray and brown sandstones 5 to 30 feet thick interbedded with gray, green, and red shales, 1 to 10 feet thick. (See fig. 2 __/.) Clay

__/ Figure 2. Columnar sections through vanadium-bearing beds.

nodules, petrified logs, carbonaceous seams and impressions of reed-like plants are locally abundant in the sandstones. The sandstone lenses of the lower unit are comparatively resistant beds which weather to low cliffs separated by narrow shale benches, the whole cropping out as an irregular slope (see pl. 6, C __/) above the San Rafael beds. The unit ~~is comparatively resistant and~~ underlies extensive flats and caps wide benches and mesas in

__/ Plate 6, C. Martin mine, Sah Tah canyon.

the district (pl. 5, A __/ and pl. 6, A __/ and 6, B __/.

__/ Plate 5, A. View looking south along east side of Carrizo Mountains.

__/ Plate 6, A. Panoramic view looking northwesterly from the northwest flank of the Carrizo Mountains.

__/ Plate 6, B. Typical exposure of lower Morrison and San Rafael beds west of Carrizo Mountains.

Underlying the Morrison and locally unconformable with it is a series of white and brown, thick-bedded sandstones and red, thin-bedded mudstones assigned to the San Rafael group. These beds are locally much crinkled and are generally exposed in conspicuous cliffs protected by sandstones of the ore-bearing zone. (See pl. 6, B.) Massive sandstones of the Glen Canyon

group and shales of Triassic age underlie the San Rafael beds, and they cover wide areas in the south and west parts of the district.

The Dakota (?) sandstone of Cretaceous age overlies the Morrison formation, and caps a few small mesas and buttes in the northern and eastern parts of the area.

Ore deposits

The ore is mostly sandstone impregnated with vanadium- and uranium-bearing minerals. As mined, it averages about 2 percent V_2O_5. The ore bodies are irregular tabular masses that contain from a few tons to about one thousand tons of ore. They are sporadically distributed in a stratigraphic zone 50 to 70 feet thick, which occurs near the base of the Morrison formation.

Most of the ore is sandstone that contains a fine-grained, clay-like vanadium-bearing material which fills pore space between sand grains. This material imparts to the ore a gray or greenish-gray color, and the intensity of the color can be used as a rough measure of the vanadium content. Shale and clay pebbles in the mineralized sandstone are particularly rich in vanadium, and fossil plants in and adjacent to ore bodies are in places richly mineralized. The principal ore mineral is thought to be a vanadium-bearing member of the hydrous mica group of clay minerals, but its precise chemical composition is uncertain. Carnotite (approximately $K_2O.2UO_3.V_2O_5.2H_2O$) and tyuyamunite (approximately $CaO.2UO_3.V_2O_5.4H_2O$) are yellow minerals that are widely disseminated in the ore and, in places, they form small high grade bodies. Vanoxite, a black hydrous vanadium oxide ($2V_2O_4.V_2O_5.8H_2O$); corvusite, a purplish blue-black hydrous vanadium oxide ($V_2O_4.6V_2O_5.XH_2O$); hewettite and metahewettite, red, hydrous calcium vanadates of the same composition ($CaO.3V_2O_5.9H_2O$), are locally present but are rarely important ore minerals. For a more detailed description of these minerals and their occurrence the reader is referred to the recent report by Fischer __/.

Gangue minerals are

__/ Fischer, R. P., Vandium deposits of Colorado and Utah: U. S. Geol. Survey Bull. 936-P, pp. 376-379, 1942.

chiefly quartz and chert that occur as sand grains; some deposits contain interlocking crystals of calcite, that enclose sand grains and ore minerals. Ore containing more than 2 or 3 percent calcium carbonate is undesirable for milling.

As mined, the ore ranges in grade from 1 to 5 percent V_2O_5, averaging about 2 percent V_2O_5 and from 0.1 to about 1.0 percent U_3O_8, averaging about 0.3 percent U_3O_8. Small pods of high-grade ore may contain as much as 10 percent V_2O_5 and 4 percent U_3O_8, and they were formerly mined principally for the contained uranium and radium, but now are mostly mined along with the associated lower grade vanadium ore.

The ore bodies are irregularly tabular masses that range from a few inches to 6 feet in thickness and a few feet to as much as 300 feet across. They lie nearly parallel to the enclosing sandstone beds but generally do not follow the beds in detail. Locally ore layers curve across the bedding planes to higher or lower stratigraphic positions within individual sandstone lenses. (See figs. 3, 4, and 5) The thicker and more easily mined ore bodies are generally situated along these curved portions of the ore layers. Along the margins of most ore bodies the contact between barren sandstone and ore is sharp and marked by a thin seam of rich ore to which the rock breaks in mining, but some of the ore bodies have indefinite margins, and the ore becomes leaner through a zone several inches thick. Some of the ore bodies that lack sharp boundaries consist of thin alternating layers of rich ore and barren rock which follow bedding planes.

On the north and west sides of the Carrizo Mountains the vanadium deposits are in a stratigraphic zone about 60 feet thick, that lies 10 to 70 feet above the base of the Morrison and 130 to 180 feet below the top of the lower sandstone unit. (See fig. 2). Extensive flats, benches, and mesas in ~~the western and northern parts~~ this part of the district (See pl. 6, A and B)

are capped by sandstones of this unit, and the ore-bearing beds are a few feet to as much as 150 feet beneath these surfaces.

On the east side of the Carrizo Mountains the ore-bearing zone is about 70 feet thick. Its lower limit is about 50 feet above the base of the Morrison formation, and its upper limit is about 110 feet below the top of the lower sandstone unit. (See fig. 2.) Several extensive benches and flats (see pl. 1 and pl. 5, A) are cut on beds near the top of the ore-bearing zone.

Most of the known ore bodies were found at the outcrop of the ore-bearing zone, but others have been found by subsurface prospecting. In places they are closely spaced along the outcrop, and elsewhere the outcrop for long distances is barren or shows only a few scattered bodies. The surface and underground distribution of these known bodies indicate that most of them occur clustered in poorly defined areas. On the basis of present knowledge these areas appear to be roughly circular or somewhat elongate in outline. They range from a few hundred feet to 2½ miles in length. The distribution and approximate extent of these more strongly mineralized areas are shown in plate 1 (areas favorable for subsurface prospecting). Within them, perhaps 5 to 20 percent of the ground is underlain by vanadium-bearing sandstone. Plates 2 and 3 show the distribution of the known mineralized ground in two of these areas. Similar areas no doubt occur in places throughout the district where the ore-bearing zone is covered, but no satisfactory geologic guide has been established to aid in finding them. Between mineralized areas perhaps no more than 1 percent of the ground is underlain by ore.

Within the district the deposits are confined to sandstones in the lower 120 feet of the Morrison formation, and in parts of the district they are further restricted to certain sandstone beds in this interval. In addition,

many of the deposits are clustered in poorly defined areas. Recognition of these geologic factors aids in prospecting even though no satisfactory explanation can be offered to explain either the restriction of the deposits stratigraphically or the location of the deposits within the ore-bearing beds. As the ore bodies do not conform to the bedding in detail, the ore minerals in their present form had to be deposited from solutions after the sandstones were deposited. The deposits, however, show no genetic relationship to either structural features, such as joints, faults, or igneous intrusions, or present topography. It is thought, therefore, that the vanadium and uranium were deposited from ground water solutions that perculated through the lower part of the formation, perhaps before consolidation of the sandy beds. Geologic conditions that controlled the movement and variation in composition of these ground waters probably played a part in the localization of the ore bodies, but these conditions are not clearly understood. For a more detailed discussion of the problem of localization and origin of these deposits the reader is referred to a recent report by Fischer —/.

—/ Fischer, R. P., Vanadium deposits of Colorado and Utah: U. S. Geol. Survey Bull. 936, pp. 387-389, 1942.

Ore reserves

For the purposes of this report, reserves are classified as "indicated" or "inferred", and the tonnage estimates of both classes are subject to a wide margin of error. Owing to the spotty distribution, generally small size and irregular shape of the vanadium ore bodies, the companies do not find it practicable to block out reserves in advance of mining. Consequently the tonnage of ore that is sufficiently well developed to be calculated with a small margin of error, and thus can be classified as "measured reserves", is so small as to be negligible. Ore that is projected from natural exposures, mine workings, and drill holes to the probable boundaries of individual bodies as determined by geologic interpretation, is classified as "indicated reserves". Estimates of these reserves total 17,000 tons, containing about 2 percent V_2O_5, as shown in the accompanying table. Ore in undiscovered bodies is classified as "inferred reserves", and tonnage estimates can be made for the unexplored parts of the ore-bearing zone on the basis of expectancy, as calculated from the ratio of the length of mineralized outcrop to the length of barren outcrop. These reserves are estimated to total on the order of 12 million tons and to average between 1 and 2 percent V_2O_5. Only a small part of this ore, however, perhaps about 70,000 tons, can be considered available under present conditions—that is, ore that probably would be found and mined by private enterprise under conditions such as those existing in the latter part of 1942. Estimates of the available inferred ore in the several known mineralized areas is shown in the accompanying table.

Estimates of available ore reserves in the known mineralized areas Carrizo Mountains district

Mineralized area	Indicated ore		Inferred ore	
	(Tons)	V_2O_5(%)	(Tons)	V_2O_5(%)
Rattlesnake mine and vicinity	6,700	1½-2	7,000	1½-2
Hogan mine and vicinity	1,300	1½-2	16,000	1½-2
Eurida mine and vicinity	1,200	2-2½	12,000	2-2½
Syracuse mine	600	2-2½	1,500	2-2½
Eastside mines	5,000	2-2½	25,000	1½-2½
Horse Mesa (undeveloped)	600	2-2½	9,000	1½-2½
Other prospects and exposures	2,000	1-2½	3,500	1-2½
Total (round figures)	17,000	2	70,000	2

Most ore bodies have been found by prospecting the outcrop of the ore-bearing zone, which generally is exposed in several irregular sandstone ledges separated by narrow shale benches. Experience has shown that the most efficient prospecting is accomplished by a party of 2 or 3 men, each traversing a different level of the outcrop.

In some areas the ore-bearing zone is poorly exposed in benches or flats beneath shallow soil cover. In such places the ore-bearing zone may be tested by closely spaced shallow pits which require the removal of only a few inches of soil.

About ½ of the ore-bearing zone in the district is still unprospected for vanadium ore. Continued surface prospecting of the zone in the unexplored areas (see p. 18) could be expected to find additional deposits of commercial importance.

From the experience of the mining companies the most effective method of subsurface exploration is by diamond or pneumatic hammer drilling from the surface, but underground drifting is sometimes used in favorable ground where thin ore seams may lead to ore bodies of workable thickness.

Jackhammers are used to test ground to depths as much as 20 feet below surface. The diamond drill has been successfully used in locating ore at depths as much as 100 feet below surface and in especially favorable areas could be used economically to test ground as much as 150 feet below surface.

The Vanadium Corporation of America has prospected extensively in the favorable areas in the vicinity of the Rattlesnake and Hogan mines, putting down diamond drill holes to depths ranging from 20 to 100 feet. Several of the holes encountered ore (see pl. 2). It is estimated that from 5 to 20 percent of the wildcat drill holes that might be put down in the favorable areas, shown in plate 1, would encounter ore and that holes spaced at 100 foot intervals would encounter, though they would not block out, most of the concealed ore bodies that are large enough to mine.

Outlook

The rate of ore production was about 1200 tons a month during the last half of 1942. Indicated ore reserves, thus, are adequate to maintain this rate for about one year. The 70,000 tons of available inferred reserves are adequate to maintain this rate of production for several more years. Since Indian labor is abundant in the district, with it production could perhaps be doubled for a period of about 2 years. To increase production, however, would require more intensive subsurface prospecting, thus increasing the costs of ore.

Along the unprospected parts of the outcrop of the ore-bearing zone there might be available ore comparable in amount to that in the known mineralized areas. More favorable lease regulations might encourage prospecting in these areas and, thus, result in increased ore production from the district.

Mines and prospects

Rattlesnake mine and vicinity.—The Rattlesnake mine, operated by Vandium Corporation of America, is on the east side of Sah Tah Canyon on the northwest flank of the Carrizo Mountains/ (See pl. 1.) Vandium ore was discovered on the claim in 1919, but the deposits were not worked until 1942, when the present operators obtained a lease and started several open cuts and small underground workings. Between May and November, 1942 the mine produced about 2,000 tons of ore, averaging about 1.8 percent V_2O_5. The known ore bodies in the area are generally tabular masses a few inches to as much as 3 feet thick, and a few feet to as much as 300 feet long. They are distributed through a stratigraphic zone 10 to 50 feet above the base of the Morrison formation and lie nearly parallel to the beds, which dip 4 to 7 degrees northward. (See pl. 2 __/.) An extensive area is

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__/ Plate 2. Geologic map and sections of the Rattlesnake mine and vicinity northwest flank of the Carrizo Mountains, Navajo Indian Reservation, Arizona.

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mineralized, as shown by mine workings and drill holes, but the detailed distribution of ore bodies or the limits of the mineralized area are not completely known.

Extensive flats north of the mine are underlain by the ore-bearing zone at depths varying from 30 to 100 feet below surface. (See pl. 6, A)

The ore-bearing zone crops out in canyons about one mile southeast of the Rattlesnake mine. Many small ore bodies are exposed in shallow prospect pits along these outcrops of the ore-bearing zone. (See pl. 1)

Hogan mine and vicinity.--The Hogan mine, operated by Vanadium Corporation of America, is west of Sah Tah canyon northwest of the Carrizo Mountains. Mine workings consist of open pits along the canyon rims and on flats where the ore-bearing zone crops out. Exposed ore bodies are tabular masses, mostly a few inches to 2 or 3 feet thick and 15 to 30 feet long, but a few are as much as 100 feet long. The deposits and enclosing beds dip 4 to 7 degrees northward. During 1942 the mine yielded a few hundred tons of ore that contained about 1.8 percent V_2O_5. Extensive sand-covered flats north of the mine are favorable for subsurface prospecting. (See pl. 1).

Martin mine.--The Martin mine, leased by Wade and Curran Company, is located on the west side of Sah Tah canyon. (See pl. 1). Mine workings consist of open cuts and short adits along the outcrop of the ore-bearing zone, about 60 feet above the floor of the canyon. (See fig. 3 __/ and pl. 6, C) During the period July through October, 1942, the mine produced

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__/ Figure 3. Martin mine, plan and profile projected to line A-B.

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about 500 tons of ore containing about 2½ percent V_2O_5. Some of the ore contains 2 or 3 percent $CaCO_3$ and thus is difficult to treat at the mill.

Sah Tah claim.--The Sah Tah claim, leased by Wade and Curran Company, is on the west side of Sah Tah canyon about ½ mile south of the Martin mine. Mine workings consist of an open cut about 250 feet long that contours the canyon wall about 30 feet above its base. Five small tabular ore bodies aggregating approximately 80 feet in length and avereging about 1 foot thick are exposed along the cut. The property had produced a few tons of ore but was idle in October and November 1942.

Other deposits in Sah Tah canyon.--Other deposits similar to those at the Martin and Sah Tah claims are exposed on the east side of Sah Tah canyon. (See pl. 1) Some of these have been prospected and mined by Vanadium Corporation of America and have yielded a total of 100 or 200 tons of ore.

Eurida mine and vicinity.--The Eurida mine, operated by Wade and Curran Company, is on the west slope of the Carrizo Mountains and is about 60 miles by road from Shiprock, New Mexico. Mine workings are in a narrow gully and consist of an open cut and shallow underground workings. (See fig. 4 __/.)

__/ Figure 4. Eurida mine, plan and profile projected to line A-B.

The mine was in operation during October and November 1942 and produced about 100 tons of ore containing about 3 percent V_2O_5.

Several deposits north and east of the Eurida mine are held under prospect lease by Vanadium Corporation of America. Ore bodies ranging from 1 to 2 feet thick and 15 to 200 feet long are exposed along the ore-bearing zone, whose outcrop partly outlines an area of approximately ¼ square mile, which is believed to be well mineralized. Overburden ranges from 10 to 150 feet in thickness and is mostly 10 to 80 feet thick. Prospecting and development of the deposits are planned by the company.

Sunnyside mine.--The Sunnyside mine, leased by Wade and Curran Company, is on the southwest side of the Carrizo Mountains (see pl. 1) and is at the top of a cliff face about 200 feet above the floor of Whiterock Wash. Mine workings consist of a short adit and an open cut, and they expose an ore body about 100 feet long. (See fig. 5 __/)/ The mine was idle in October and

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__/ Figure 5. Sunnyside mine, plan and profile projected to line A-B.

November 1942 but a few tons of ore estimated to contain 2½ to 3 percent V_2O_5 had been stockpiled. The ore-bearing zone adjacent to the deposit is mostly inaccessible but the parts of the zone that were examined are barren. Several deposits are reported in the rugged country 1 to 5 miles south of the Sunnyside.

Syracuse mine and nearby prospects.--The Syracuse mine, operated by Wade and Curran Company, is on the east side of the Carrizo Mountain (see pl. 1) and is about 43 miles by road from Shiprock, New Mexico. Mine workings consist of open cuts and several short adits. (See pl. 4 __/ and pl. 5, B __/.) The mine produced about 775 tons of ore containing 2.89 percent V_2O_5 from July through October 1942. Six ore bodies are

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__/ Plate 4. Map of Syracuse mine, east side of Carrizo Mountains, Navajo Indian Reservation, Arizona.

__/ Plate 5, B. Syracuse mine, east side of Carrizo Mountains.

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exposed at the surface and in mine workings. These range from 30 to 150 feet in length and generally average about 1 foot thick, but ore as much as 4 feet thick has been mined. Some of the ore contains as much as 10 percent $CaCO_3$ and is difficult to treat at the mill. Southeast of the

Syracuse mine several deposits are exposed but are too small to encourage prospecting. A few small ore bodies are exposed along the outcrop of the ore-bearing zone northeast of the Syracuse mine. Vanadium Corporation of America worked some of these, but the deposits were too small to mine economically. Farther north in the vicinity of Beclabito dome a few pods of ore are exposed in the ore-bearing zone, but these are small and widely separated.

Eastside mines and vicinity.—The Eastside mines (see pl. 1) are about 38 miles from Shiprock, New Mexico, and are operated by Vanadium Corporation of America. Mining from open pits and shallow underground workings began in August 1942 and by November the deposits had produced about 1,800 tons of ore containing an average of about 2.3 percent V_2O_5. The deposits are in beds 60 to 120 feet above the base of the Morrison formation and are scattered along the rim and margins of a bench which is about one mile long and ½ mile wide. (See pl. 3 __/.) The ore bodies are

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__/ Plate 3. Geologic map and section, Eastside mines, Carrizo Mountains district, Navajo Indian Reservation, New Mexico.

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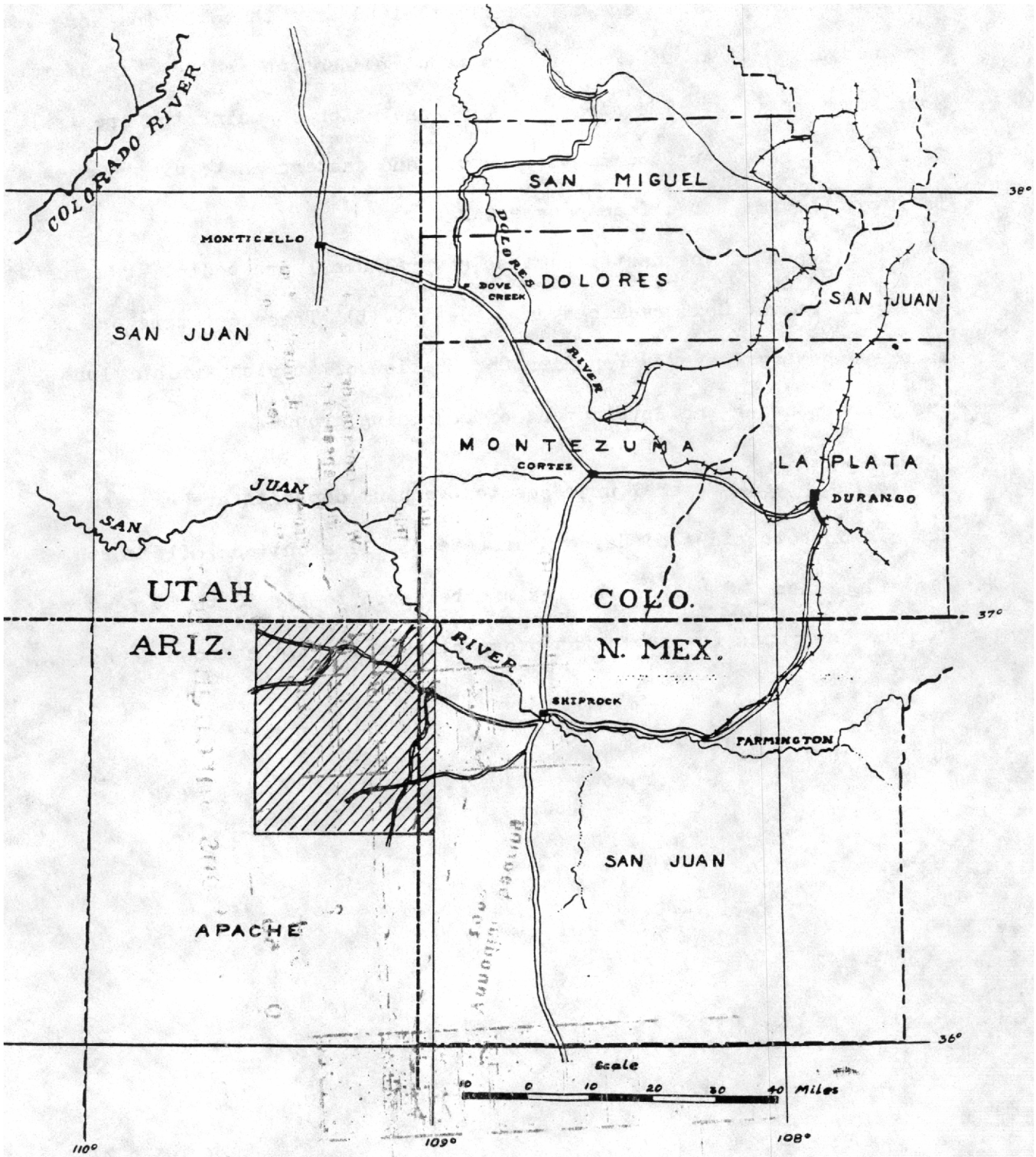
irregularly tabular masses that vary from a few inches to 6 feet in thickness and about 40 to 200 feet in length. Most of the ore consists of the principal vanadium-bearing mineral disseminated in sandstone, but replaced logs in some of the deposits contain high-grade ore, consisting of carnotite, tyuyamunite, hewettite, metahewettite, and other rarer minerals. Small pods may yield 10 to 20 tons of this type of ore, containing as much as 10 percent V_2O_5 and 3 or 4 percent U_3O_8.

Along the western edge of the mineralized area the principal ore-bearing beds crop out in a bench and are about 70 feet above the base of the Morrison formation. The stratigraphic zone which contains the ore is 10 to 125 feet below surface in the central and eastern parts of the area and is favorable for subsurface prospecting.

Northwest of the Eastside mines several small ore bodies are exposed along the rim of Oak Creek canyon. (See pl. 1) These deposits are held under temporary lease by Vanadium Corporation of America, which plans early prospecting and development of adjoining ground.

Horse Mesa.--Several unprospected vanadium deposits are exposed at the rim on both sides of Horse Mesa (see pl. 1) about one mile south of Eastside mines. Other ore bodies are believed to lie 20 to 50 feet below surface in ground favorable for prospecting between the known deposits.



INDEX MAP SHOWING LOCATION OF CARRIZO MOUNTAINS VANADIUM DISTRICT (shaded area)

NAVAJO INDIAN RESERVATION, NORTHEASTERN ARIZONA AND NORTHWESTERN NEW MEXICO

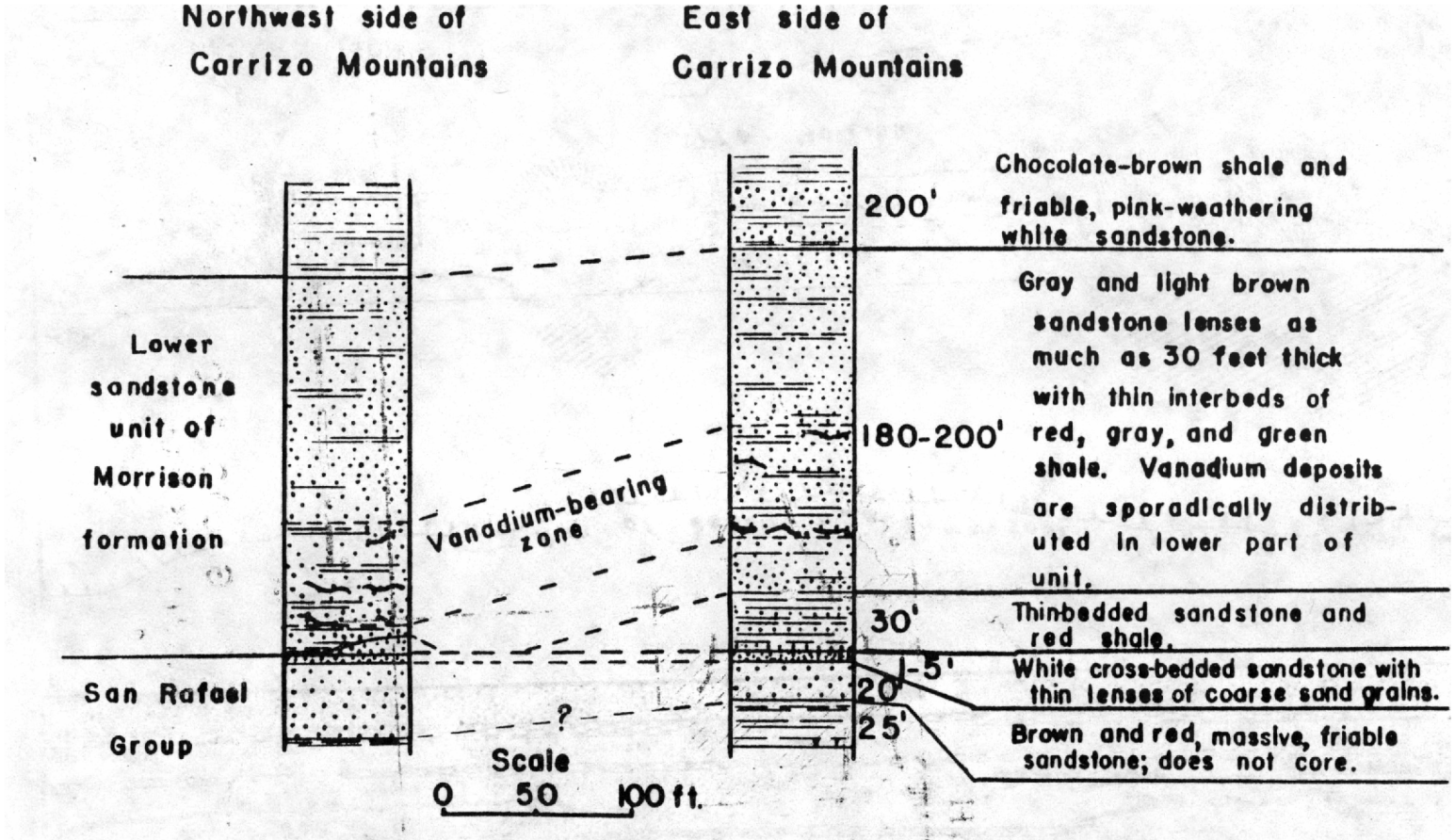


Figure 2 Columnar sections through vanadium-bearing beds

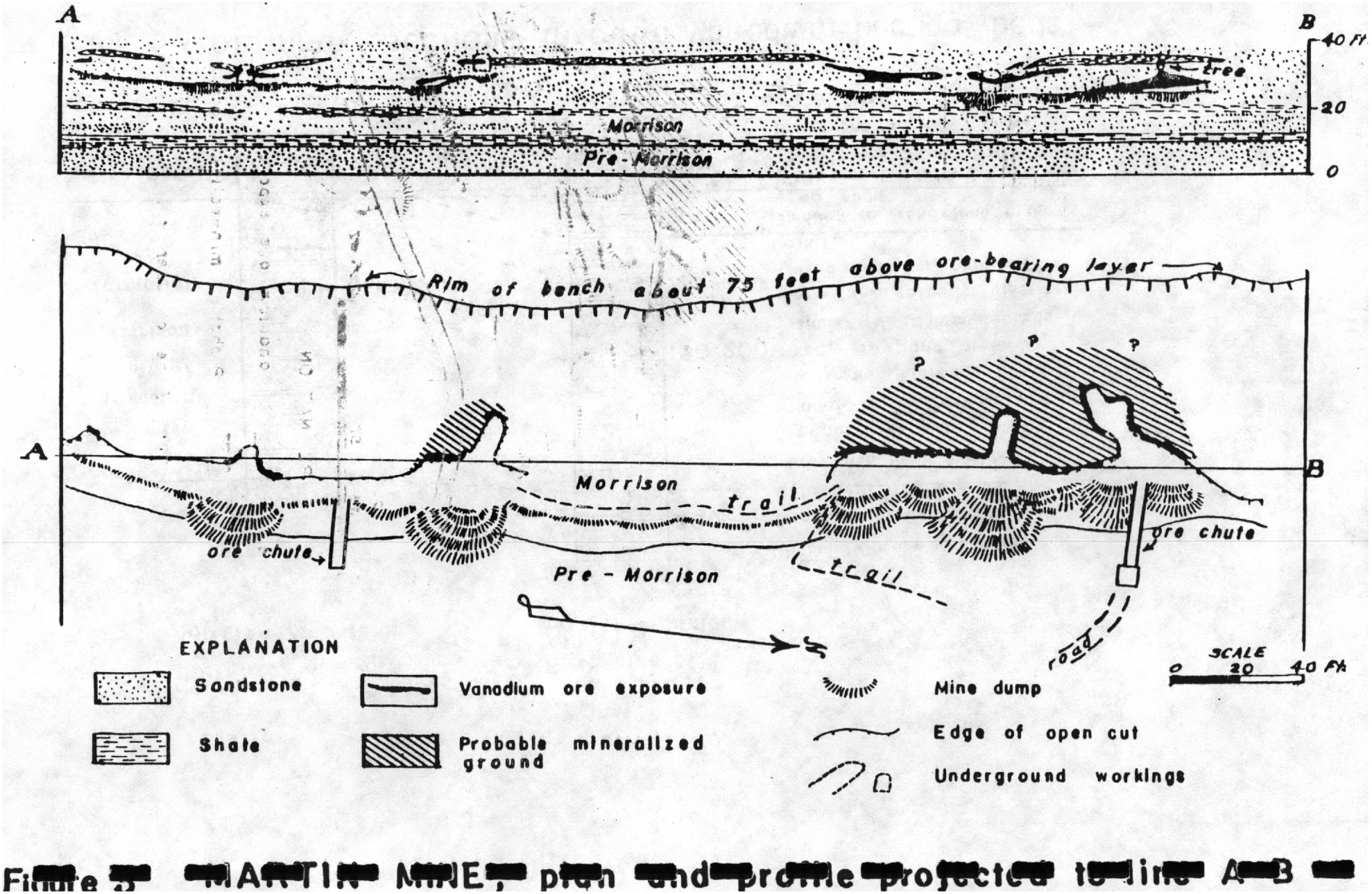


Figure 3 — MARTIN MINE, plan and profile projected to line A–B

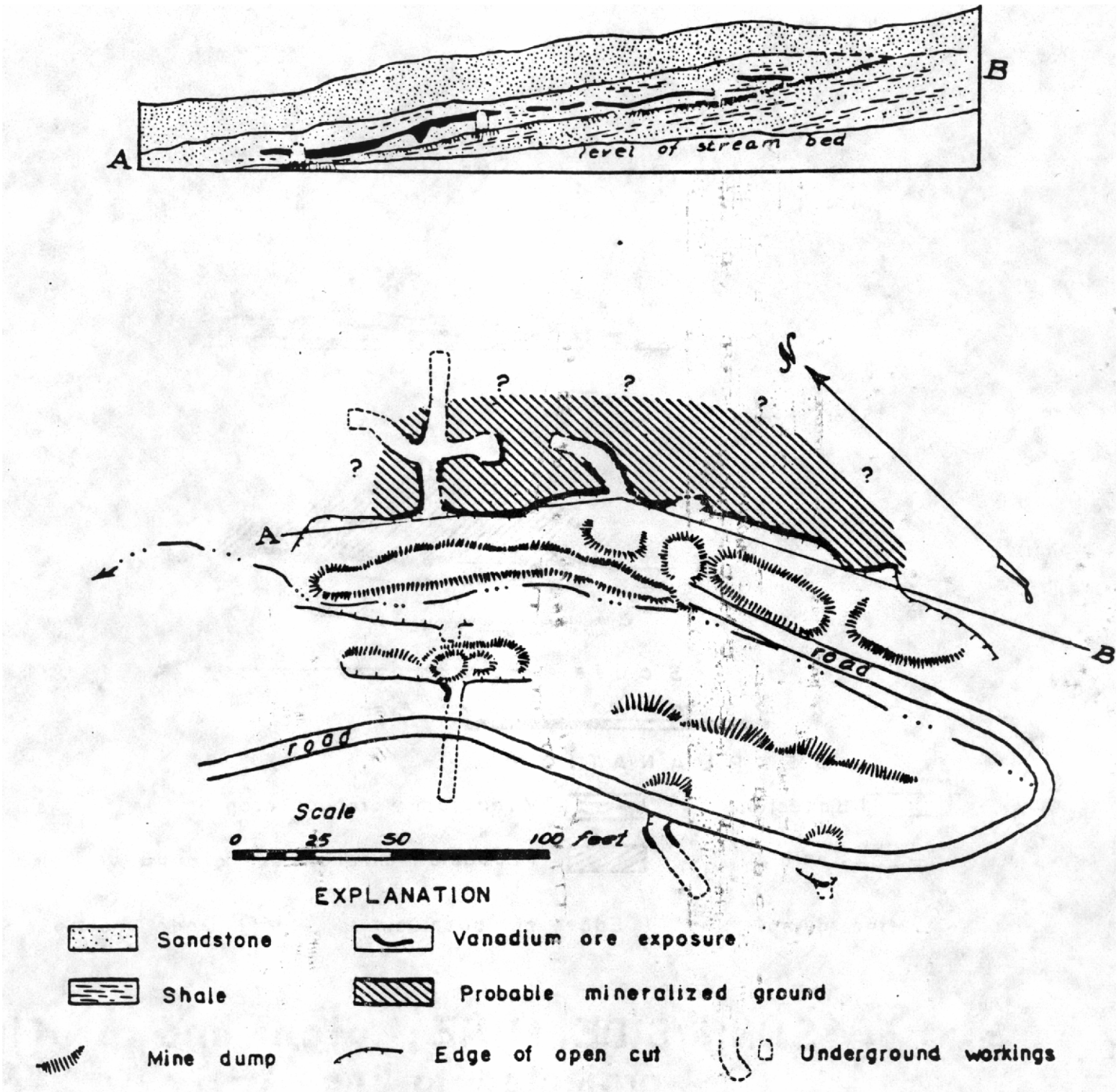


Figure 4 EURIDA MINE, plan and profile projected to line A–B

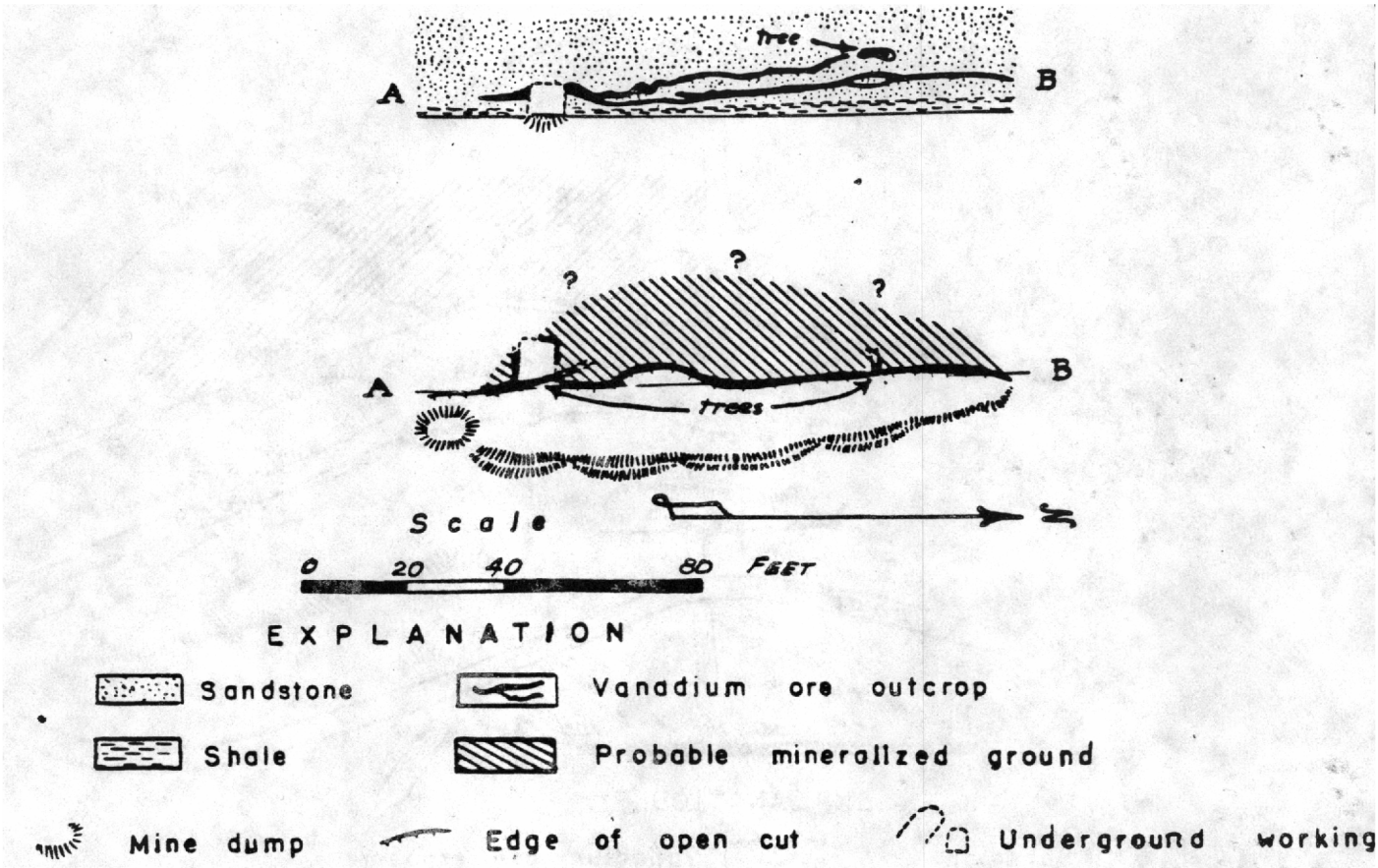


Figure 5 SUNNYSIDE MINE, plan and profile projected to line A-B

109°30'

109°15'

109°00'

37°00'

UTAH | COLO.

ARIZ. | N.MEX.

Four Corners

SAN JUAN RIVER

Red Mesa T.P.

Toh Atin Mesa

Kd

Jum

Jms

JTr

Ti

Arido Creek

HOGAN MINE

RATTLESNAKE MINE

MARTIN MINE

SAH TAH MINE

Wash

Chenlini Wash

Totacon T.P.

Walker Creek

Emmanuel Mission

N. Sah Tah Canyon

S. Sah Tah Canyon

EURIDA MINE

Altar Mesa

SUNNYSIDE MINE

Whiterock Wash

Sigi Ho Cho Mesa

CARRIZO MOUNTAINS

Tes Nos Pas T.P.

APACHE CO.

SAN JUAN CO.

Beclabito T.P.

Beclabito Dome

SYRACUSE MINE

Cottonwood Wash

Oak Creek Canyon

EASTSIDE MINES

36°45'

RMO 28 pl. 1

PLATE I

GEOLOGIC MAP OF CARRIZO MOUNTAINS DISTRICT

NAVAJO INDIAN RESERVATION, NORTHEASTERN ARIZONA AND NORTHWESTERN NEW MEXICO, SHOWING LOCATION OF VANADIUM MINES AND PROSPECTS

BY

D.C. DUNCAN & W.L. STOKES

UNITED STATES GEOLOGICAL SURVEY

1943

BASE FROM AERIAL PHOTOGRAPHS

SCALE 0 1 2 3 4 MILES

≈ 1:120,000

36°45'

36°30'

109°30'

109°15'

109°00'

Creek

Altar Mesa

SUNNYSIDE MINE

Whiterock Wash

Sigi Ha Cho Mesa

Kinusta Mesa

Cove Mesa

MOUNTAINS

SYRACUSE MINE

Cottonwood Wash

Oak Creek Canyon

EASTSIDE MINES

Horse Mesa

Red Rock Wash

Red Rock T.P.

The Thumb

EXPLANATION

Sedimentary rocks

UPPER CRETACEOUS — Kd — Dakota (?) sandstone

UPPER JURASSIC — Jum, Jms — Morrison formation. Jum, upper part of formation; Jms, lower sandstone unit, contains vanadium deposits.

JURASSIC and TRIASSIC — JTr — Pre-Morrison sedimentary rocks, undifferentiated. Includes the San Rafael group of Jurassic age, Glen Canyon group of Jurassic (?) age and Chinle formation of Triassic age.

Igneous rocks

TERTIARY — Ti — Large intrusive masses in Carrizo mountains. Include some older, complexly deformed sedimentary rocks.

Ti — Dike

Ti — Plug

Geologic boundary (exposed).

Geologic boundary (concealed).

Approximate boundary of Carrizo Mountains igneous-sedimentary complex.

Strike and dip of beds; (?) approximate.

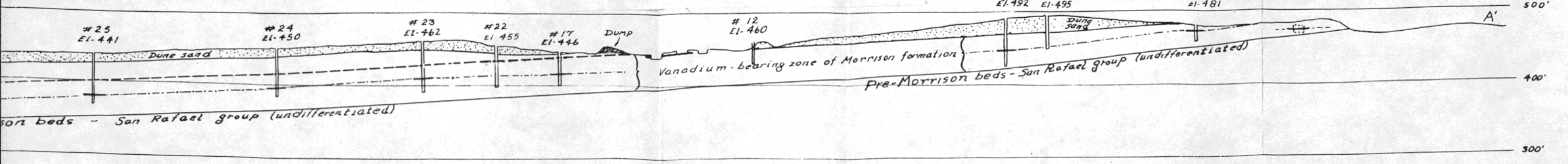
Horizontal beds

Area underlain by inferred mineralized ground, favorable for subsurface prospecting.

Vanadium mine

Vanadium prospect or undeveloped exposure of ore.

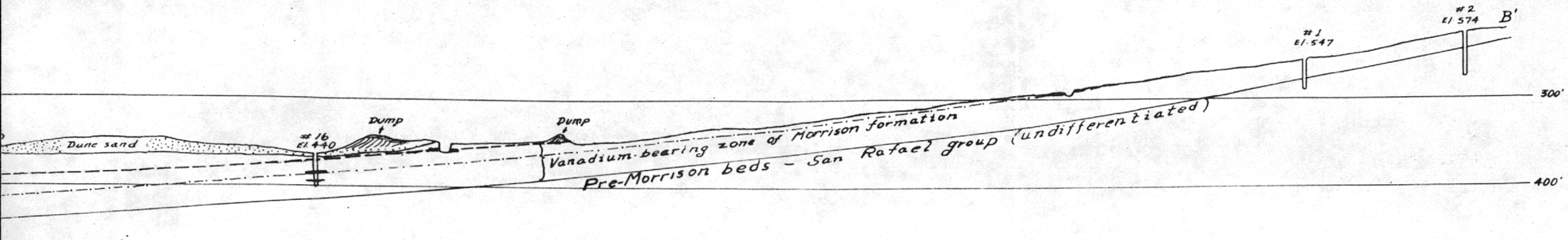
Union Mines' lease



SECTION ALONG A-A', RATTLESNAKE MINE

SCALE

1 inch = 100 feet

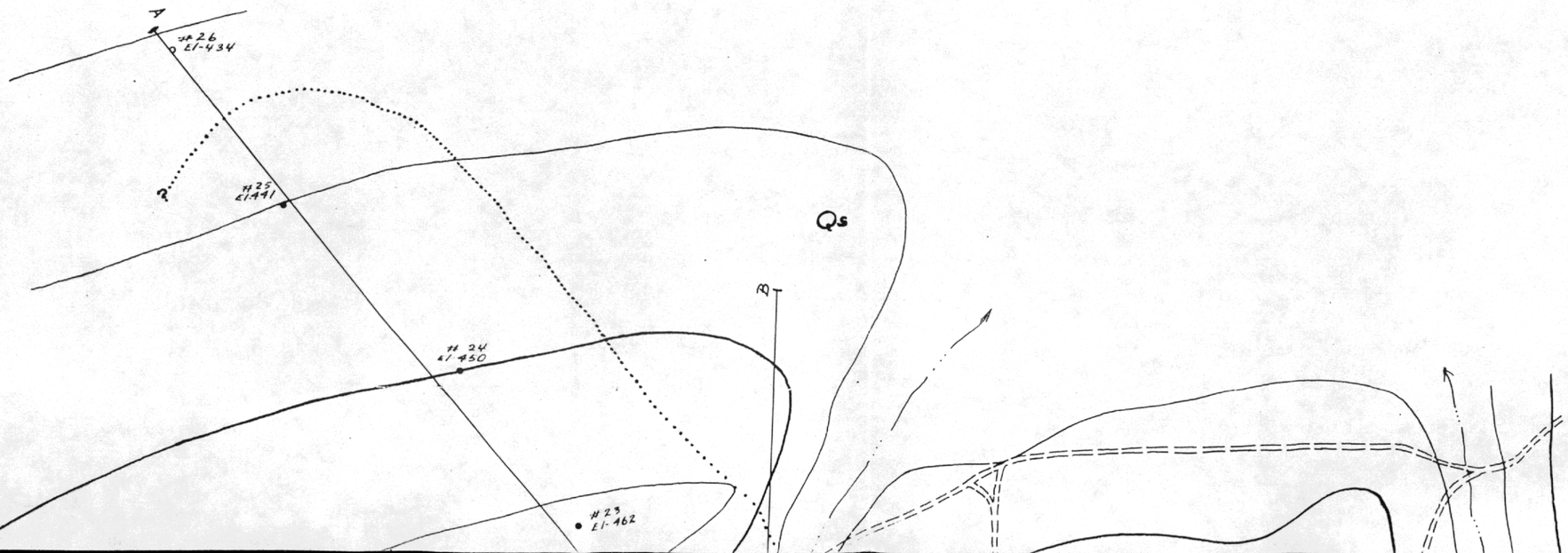


EXPLANATION

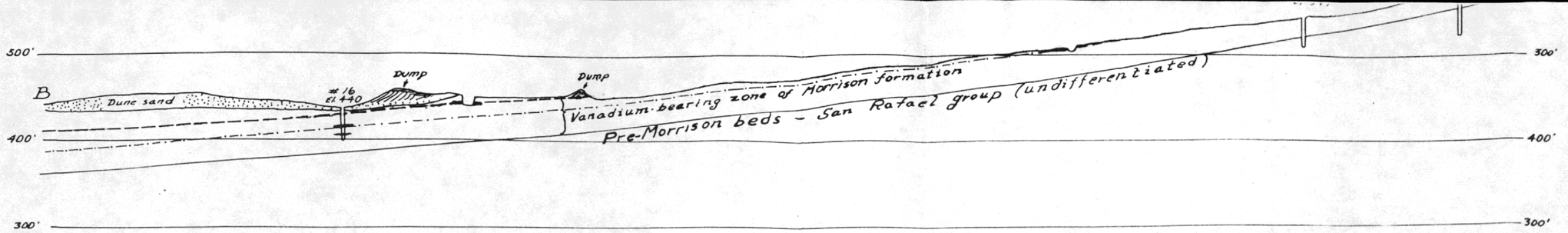
- Diamond drill holes projected on plane of section, barren (right); encountering ore (left).
- Top of vanadium-bearing zone of Morrison formation
- Projection of main vanadium-ore layer
- Underground working with ore
- Surface working with ore

300'

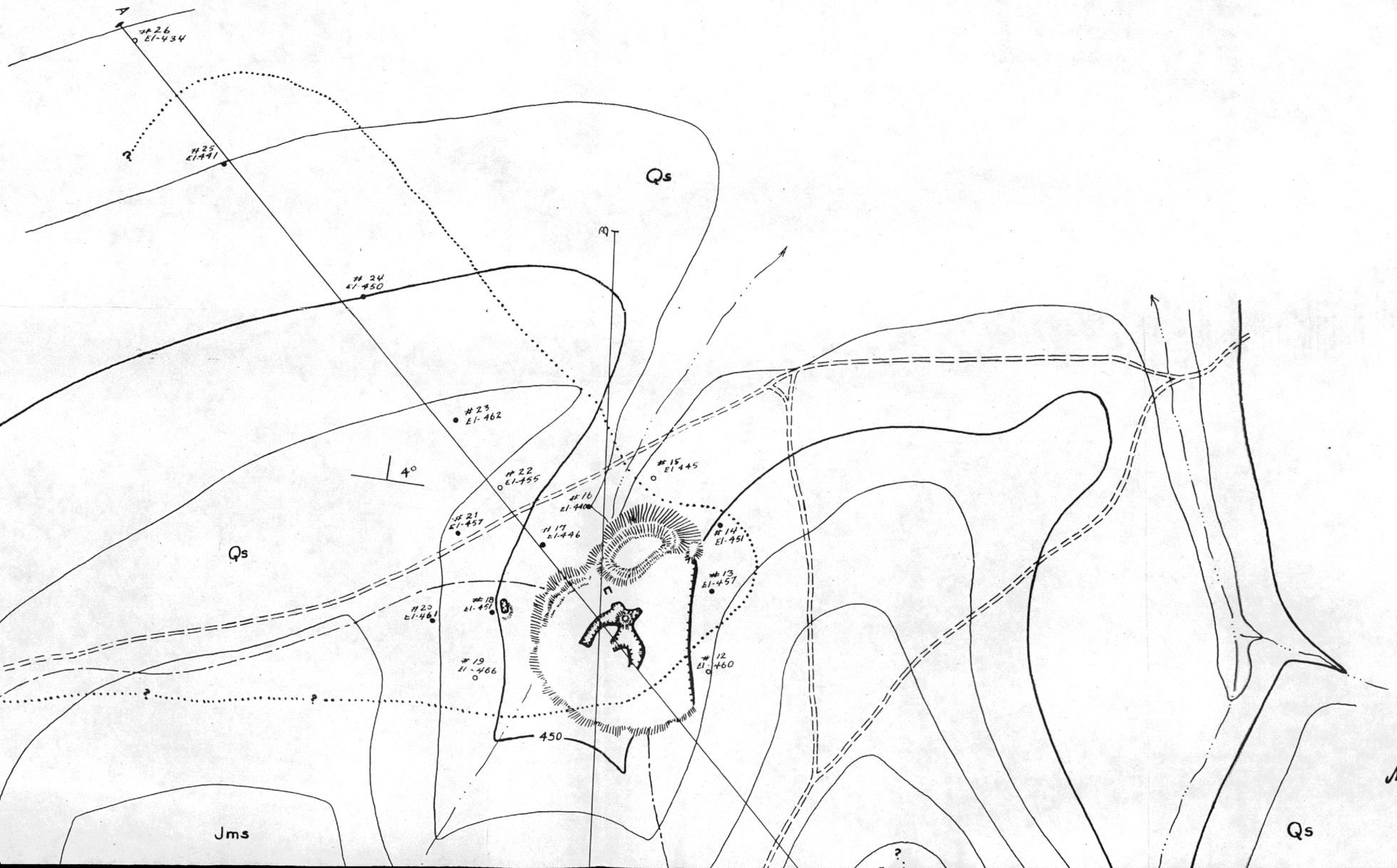
SECTION ALONG B-B', RATTLESNAKE MINE



RMD 28 pl. 2



SECTION ALONG B-B', RATTLESNAKE MINE



RMO 28 pl. 2

EXPLANATION

Jms — Vanadium-bearing zone of the Morrison formation (lower 70 feet of unit).

Jsr — Pre-Morrison Jurassic sediments. Red and brown-weathering beds with white, friable sandstone layer at top.

Qs — Recent sand dunes which mantle bedrock

Geologic boundary.

Boundary of sand-covered area.

Open pit mine working.

Underground mine working.

Mine dump.

Strike and dip of beds

Diamond drill hole, barren

Diamond drill hole encountering ore.

Vanadium ore exposure.

Mineralized area, boundary inferred.

Plate 2

GEOLOGIC MAP AND SECTIONS OF RATTLESNAKE MINE AND VICINITY

NORTHWEST FLANK OF THE CARRIZO MOUNTAINS, NAVAJO INDIAN RESERVATION, ARIZONA

by

D. C. Duncan and W. L. Stokes

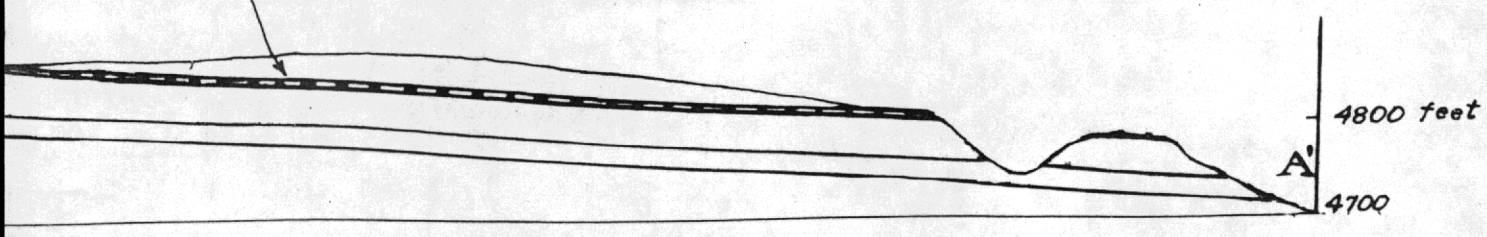
U.S. GEOLOGICAL SURVEY

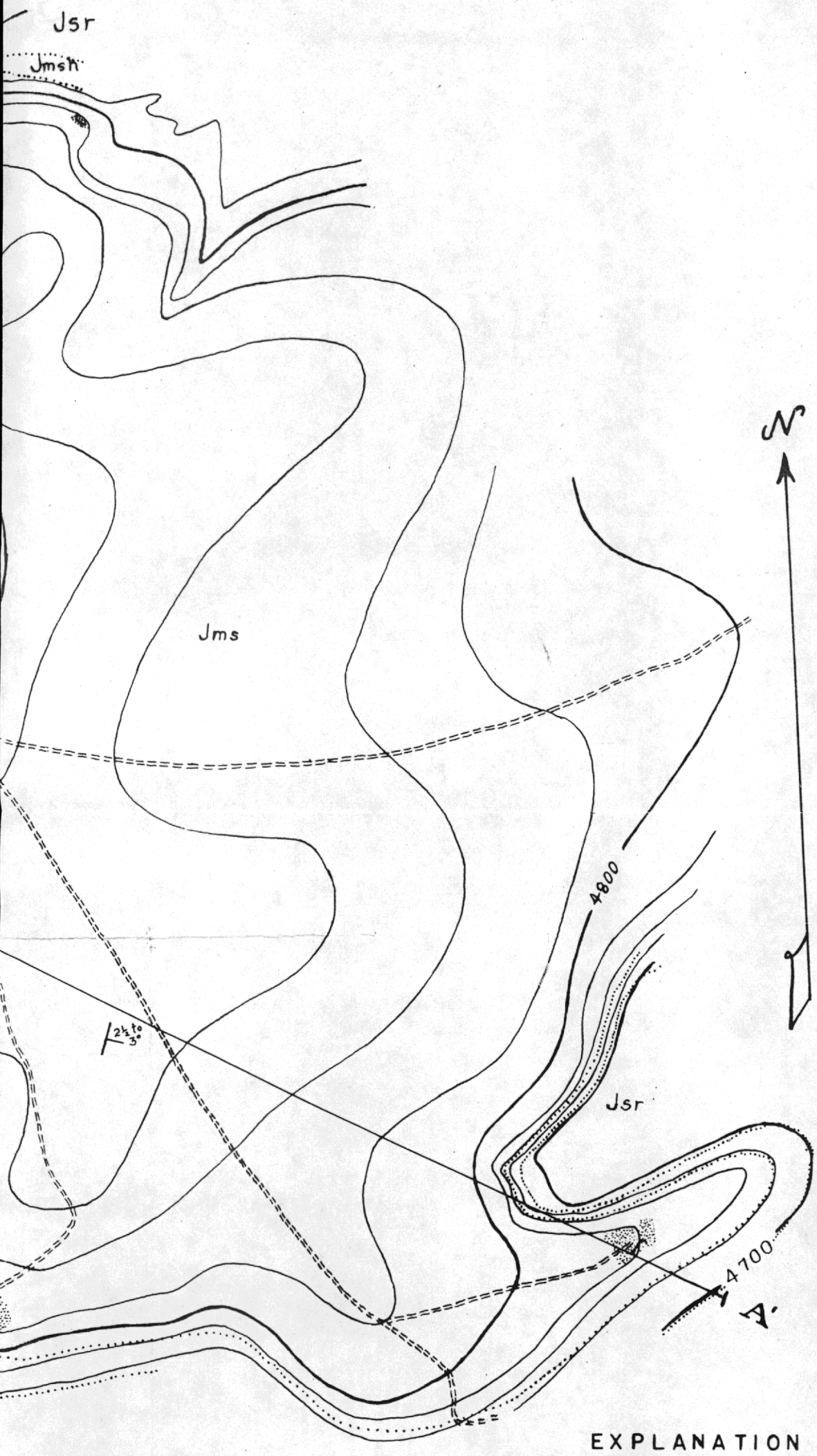
Nov. 1942

CONTOUR INTERVAL 10 feet

DATUM ASSUMED

SCALE 0 50 100 200 FEET





MINES,

ervation,

EXPLANATION

Jms	Sandstone with minor shale, contains vanadium
Jmsh	Shale and thin-bedded sandstone, contains no vanadium
Jsr	Pre-Morrison sandstones and shales, (San Rafael group equivalents ?)
	Geologic boundary
	Vanadium mine or prospect
	Probable mineralized ground
2°	Strike and dip of beds

RMD 28 pl. 3

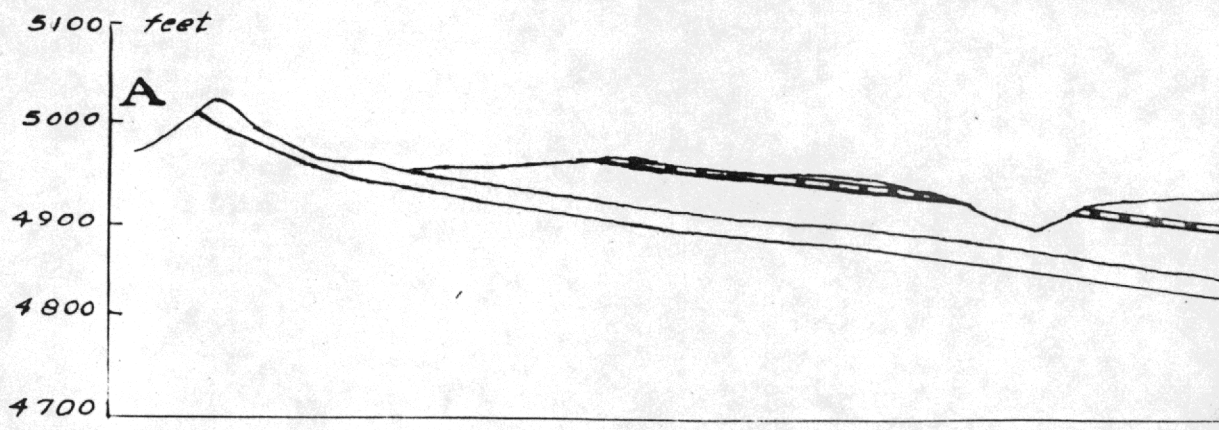


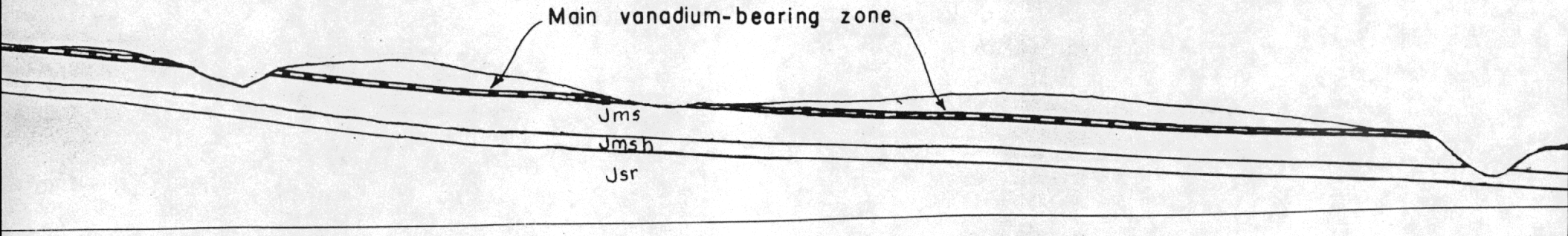
Plate 3

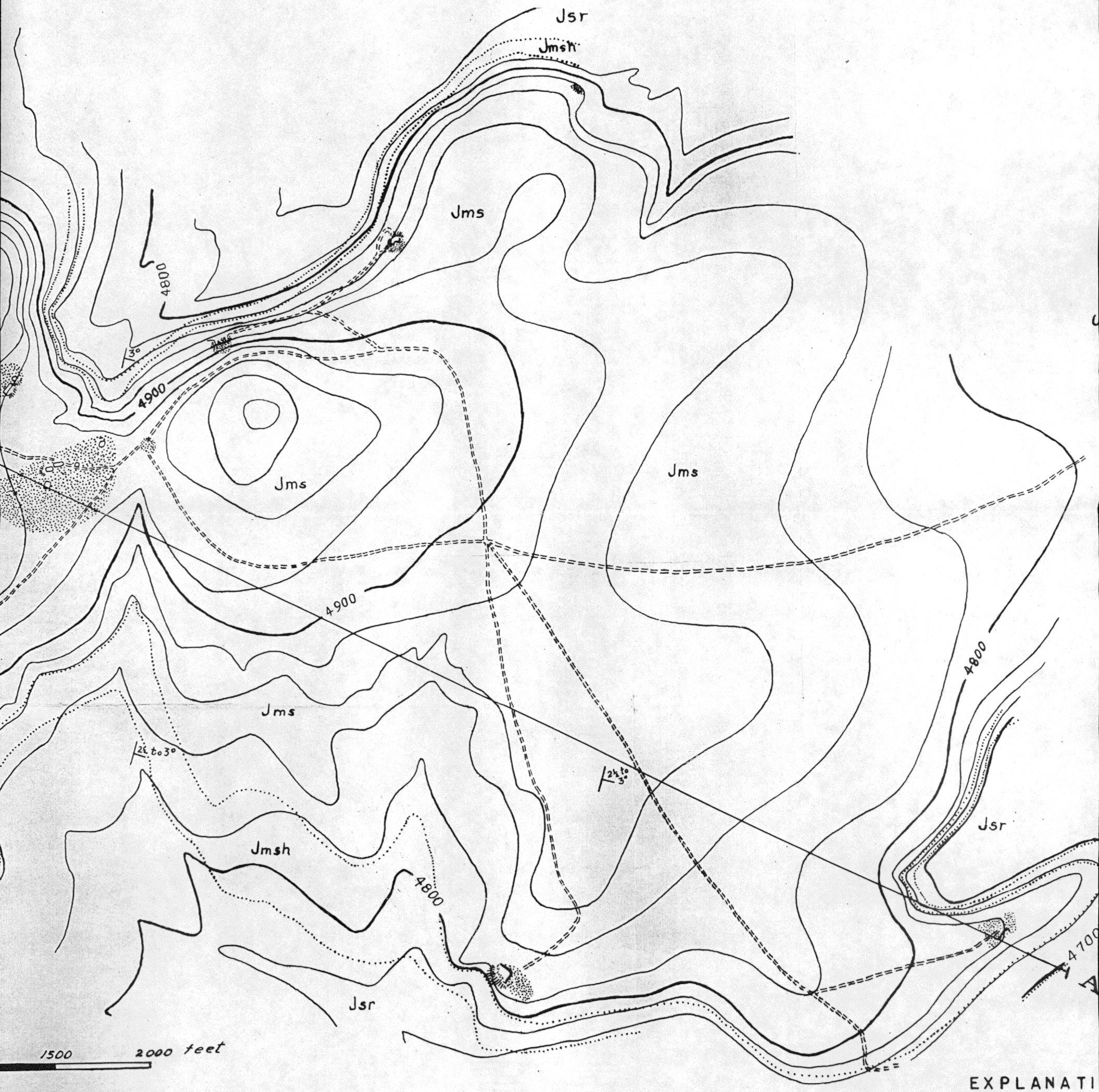
GEOLGIC MAP AND SECT

Carrizo Mountains District, Nav
New Mex

By

D. C. Duncan & W.





C MAP AND SECTION, EASTSIDE MINES,

ntains District, Navajo Indian Reservation, New Mexico

By

D. C. Duncan & W. L. Stokes

eet

EXPLANATI

Jms — Sandstone with mino contains vanadium

Jmsh — Shale and thin-be contains no vana

Jsr — Pre-Morrison san (San Rafael group e

Geologic boundary

Vanadium mine or

RMO 28 pl. 3

Jsr

Jms

Qg

10°

Jms

900

Jms

N

7 8 HUNDRED FEET

USE MINE

VAJO INDIAN RESERVATION, ARIZONA

L. Stokes

SURVEY

RMO 28 pl. 4

Jsr

Jms

1100

Qg

1000

10½°

Jsr

10½°

900

Jms

Contour interval 20 feet
Datum assumed

Scale

0 1 2 3 4 5 6 7 8 HUNDRED FEET

MAP OF SYRACUSE MINE

EAST SIDE OF CARRIZO MOUNTAINS, NAVAJO INDIAN RESERVATION, ARIZONA

by

D. C. Duncan & W. L. Stokes
U.S. GEOLOGICAL SURVEY

Nov. 24, 1942

RMO 28 pl 4

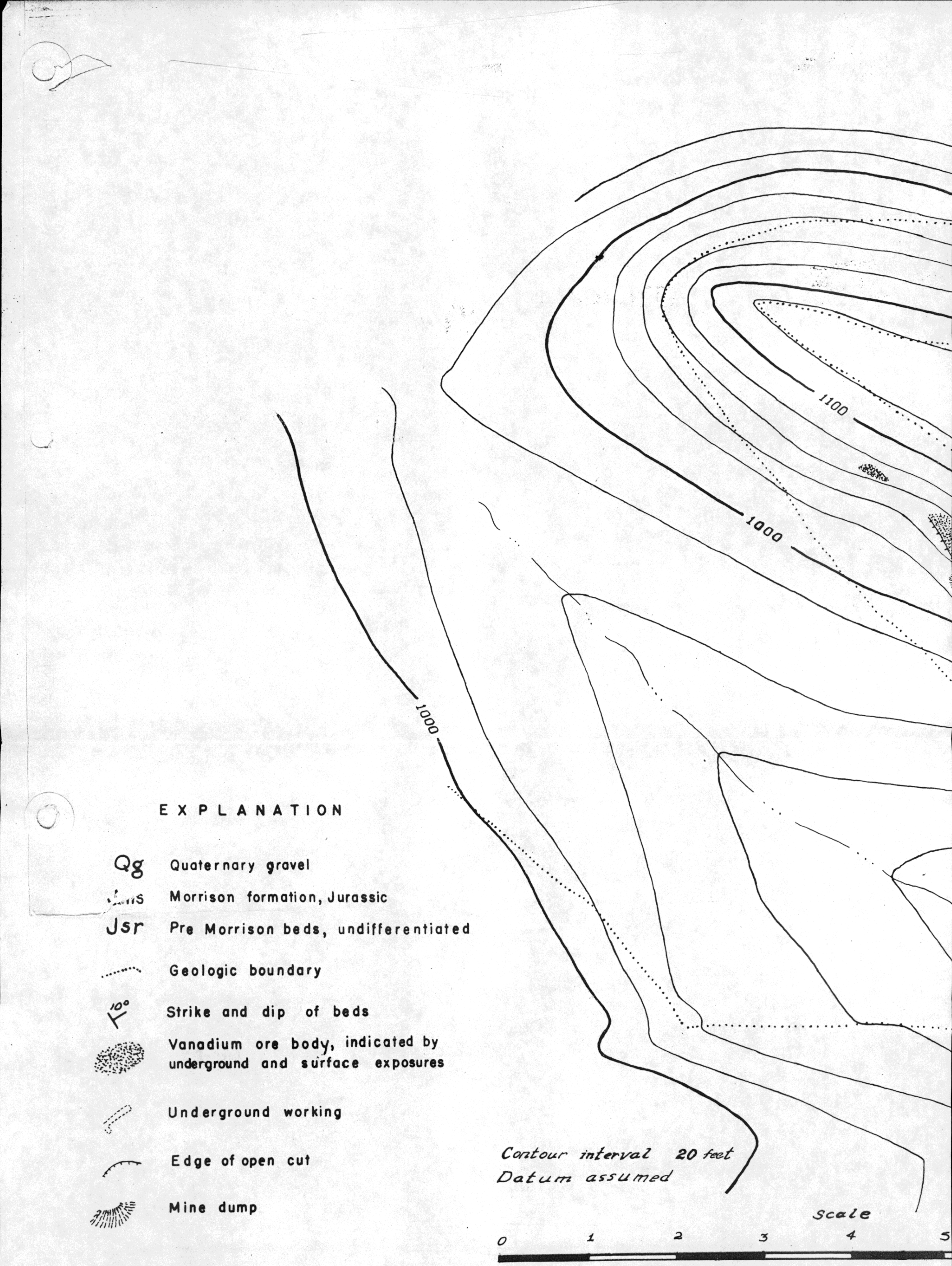


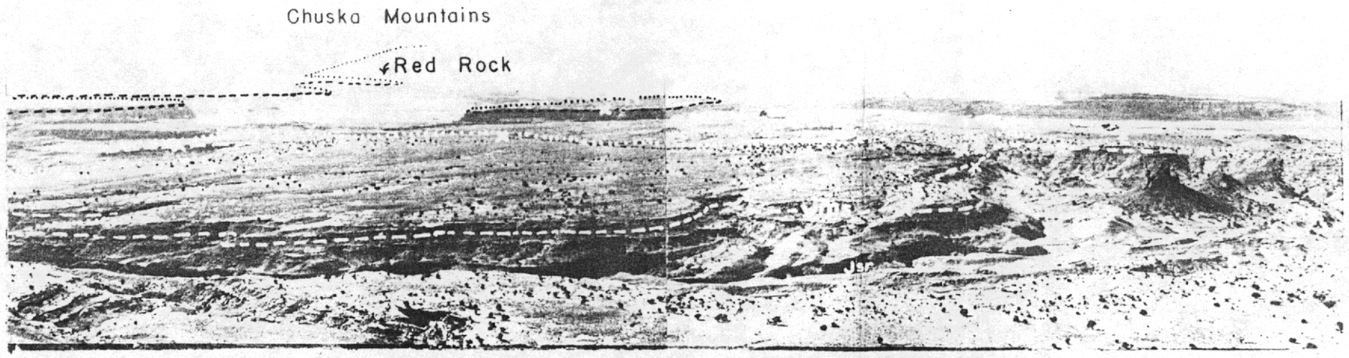
Plate 4

MAP OF

EAST SIDE OF CARRIZO MOUNTA

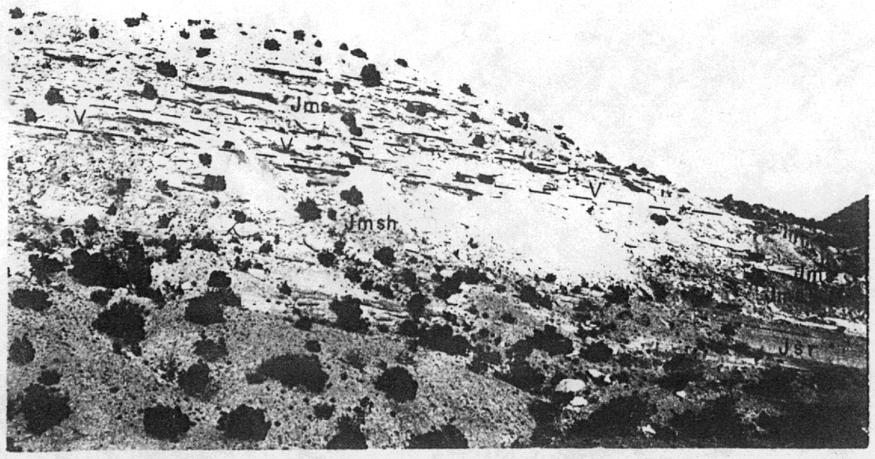
D.C. Dunc

RMO 28 pl. 4



A. VIEW LOOKING SOUTH ALONG EAST SIDE OF CARRIZO MOUNTAINS.

Shows San Rafael beds (Jsr), lower sandstone unit of the Morrison formation (Jms), outcrop of ore-bearing zone (dashed line where visible, dotted line where concealed from view), and vanadium mines and prospects (X). E, Eastside mines; H, Horse Mesa.



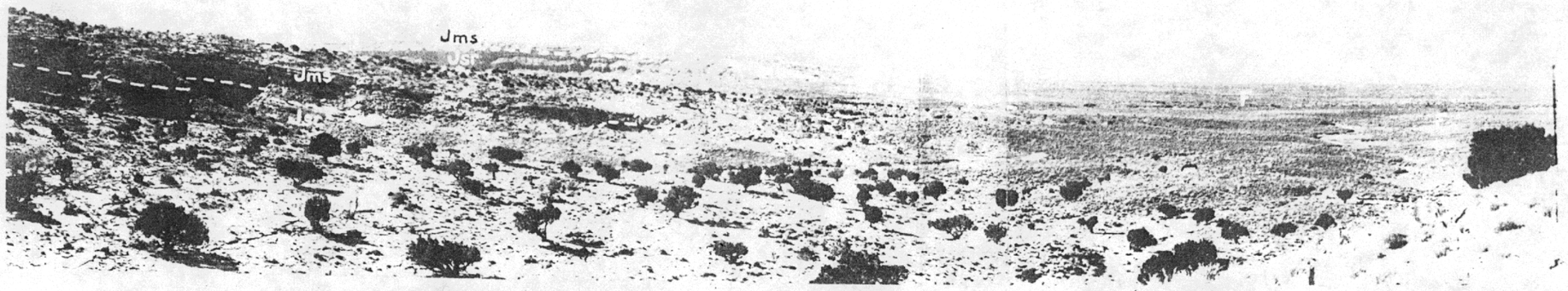
B. SYRACUSE MINE, EAST SIDE OF CARRIZO MOUNTAINS

Mine entries about half way up the hillside enter the ore-bearing zone (v). The lower sandstone unit of the Morrison formation (Jms) is separated from the underlying San Rafael beds (Jsr) by a thin-bedded shale and sandstone unit (Jmsh). (See also pl. 4.)

C. OPEN PIT MINING, EASTSIDE MINES

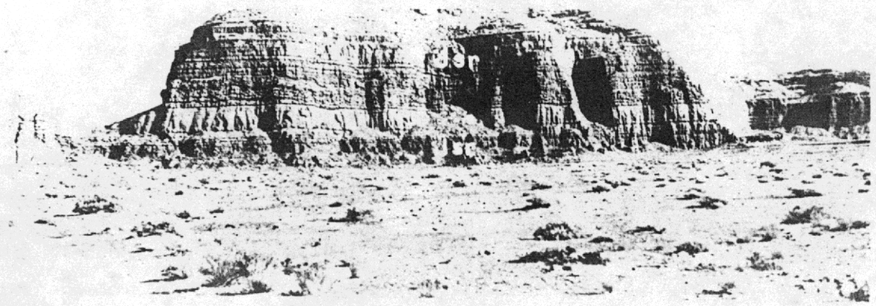
Dark rock in floor of pit is ore. Neat ore piles in background are ready for shipment to mill.

RMO 28 Pl. 5



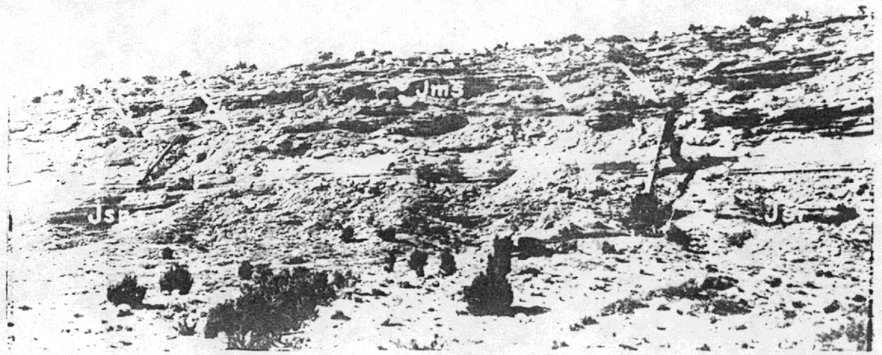
A. PANORAMIC VIEW LOOKING NORTHWESTERLY FROM THE NORTHWEST FLANK OF THE CARRIZO MOUNTAINS.

Shows extensive flats (F) underlain by the ore-bearing zone of the Morrison formation, workings of the Rattlesnake mine (X) and location of the Hogan mine (H). Jms, lower sandstone unit of the Morrison formation; Jsr, San Rafael beds.



B. TYPICAL EXPOSURE OF LOWER MORRISON AND SAN RAFAEL BEDS WEST OF CARRIZO MOUNTAINS.

Butte 1½ miles southeast of Emmanuel Mission. The distinctive bedding and weathering of the San Rafael sediments (Jsr) aid in locating the ore-bearing zone in the lower sandstone unit of the Morrison formation (Jms).



C. MARTIN MINE, SAH TAH CANYON

Arrows indicate open cut mine workings in the lower sandstone unit of the Morrison formation. Jms, Morrison sandstone; Jsr, San Rafael beds.

RmD 28 p1.6