Manganese Resources of the Artillery Mountains Region Mohave County, Arizona

GEOLOGICAL SURVEY BULLETIN 961

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By S. G. LASKY *and* B. N. WEBBER

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A description of low-grade deposits of economic and scientific interest

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MANGANESE RESOURCES OF THE ARTILLERY MOUNTAINS REGION, MOHAVE COUNTY, ARIZ.

By S. G. Lasky and B. N. Webber

ABSTRACT

Since 1929, investigations of manganiferous sediments on the west side of Bill Williams River, near Alamo in western Arizona, have proved the existence of hundreds of millions of tons of low-grade material. The principal manganese-bearing formation underlies an area of possibly 25 square miles in the dissected valley between the Artillery and Rawhide Mountains, but the richest and most extensive croppings, and the only ones that have been explored, lie along the northeast side of this area, among the foothills of the Artillery Mountains.

In order of age the rocks include: A pre-Cambrian complex, largely granite; contact-metamorphosed Palezoic (?) sediments; the Artillery formation, apparently thousands of feet thick and consisting of closed-basin deposits of early Eocene (?) age; Miocene (?) volcanics; the Chapin Wash formation, which is the principal manganese-bearing formation and which consists of alluvial-fan and playa deposits of early Pliocene (?) age; the Cobwebb basalt of early Pliocene (?) age, lying conformably on the Chapin Wash formation; the Sandtrap conglomerate, of late Pliocene (?) age; early Pleistocene (?) basalt; and alluvium. The Sandtrap conglomerate contains a basalt member, and this member seems megascopically and microscopically identical with the Cobwebb basalt and the Pleistocene (?) basalt, even to odd intergrowths of the plagioclase and glass. The several formation names are used for the first time in this report.

The most pronounced structural feature in the area is a thrust fault that brings the pre-Cambrian and Paleozoic (?) rocks on top of the Artillery formation and that is overlapped by the Miocene (?) volcanics. This fault may be in part contemporaneous with the Artillery formation, which was deposited in a basin that may well have been formed by faulting. The Chapin Wash formation and the Cobwebb basalt also were deposited in a fault basin, probably of basin-and-range type, that lay within the limits of the earlier basin and had the same trend. The Sandtrap conglomerate was deposited after this basin had been captured by through drainage. The Chapin Wash formation, the Cobwebb basalt, and the Sandtrap conglomerate are folded into a shallow composite syncline having the same trend as the basin; and these folded rocks, together with the overlying Pleistocene (?) basalt, are broken by faults that presumably represent renewed movement along the old fault zones.

The manganese deposits include: (1) Stratified oxide deposits in the Artillery, Chapin Wash, and Sandtrap formations; (2) faults, fissure zones, and breccia zones in the Artillery formation, cemented with manganese oxides and antedating the Chapin Wash formation; and (3) supergene vein deposits of oxides, with some related replacement bodies, along the latest faults and fissure zones. The only deposits that show promise of commercial exploitation are the bedded

deposits in the Chapin Wash formation. The other deposits may contain considerable manganese in the aggregate, but the amount of available manganese in them is small and has no value as compared with the immense tonnage of prospective ore in the Chapin Wash formation.

The manganiferous beds in the Chapin Wash formation include all the kinds of rock that occur in the formation, from fanglomerate to clay and tuff; they differ from the barren beds primarily in that, besides the amorphous iron oxides such as accompany the clay cement of the barren beds, they contain also amorphous manganese oxides intimately associated with the iron oxides. In part the manganiferous beds are interlensed with barren beds, and in part they grade laterally into barren rock. Some of the manganiferous conglomerate and sandstone has been impregnated with opal and calcite, the original wad having at the same time been altered to psilomelane and manganite. Locally the rocks have been enriched in the process.

The manganese content ranges from less than 1 percent to as much as 30 percent locally in the altered (supergene) ore, but a content exceeding 20 percent is rare. By far the greatest part contains less than 5 percent. The average manganese content of the unaltered material, consisting largely of manganiferous sandstone and conglomerate, is 3 to 4 percent, and the average manganese content of the supergene material, called hard ore, is 6 to 7 percent. The average material contains 3 percent of iron, 0.08 percent of phosphorus, 1.1 percent of barium, and minute amounts of copper, lead, and zinc. Although the manganese content locally changes abruptly from bed to bed, the content within individual beds, except where they contain hard ore, changes but gradually, and in terms of large volumes of material, both the iron and manganese content are remarkably uniform.

The manganiferous beds of the Chapin Wash formation lie within two zones, 750 to 1,000 feet apart stratigraphically, that underlie most of the valley between the Rawhide and Artillery Mountains. The lower zone crops out mainly along the Rawhide Mountains, on the southeast side of the valley, where it is traceable along the strike for nearly 4 miles. Although it is as much as 350 feet thick, it consists only of widely separated manganiferous lenses lying among thicker and more numerous barren members. The lower zone has not been prospected, and its possibilities below the outcrop cannot even be guessed.

The upper zone crops out mainly along the Artillery Mountains, on the northeast side of the valley. It lies at or near the top of the Chapin Wash formation. Continuously manganiferous parts of this zone are traceable for as much as 3 miles along the strike, and the zone as a whole can be traced discontinuously for 6 miles. As shown by diamond-drill holes, the zone is continuously manganiferous for at least a mile down the dip. Its thickness ranges from a few feet to as much as 350 or 400 feet, and in places it is almost continuously manganiferous for a stratigraphic thickness of as much as 165 feet. Diamond drilling indicates an average aggregate thickness of about 65 feet over an area of about 1,000 acres in the two main blocks.

Except for the hard ore, the deposits in the Chapin Wash formation are syngenetic—that is, they were laid down as part of the formation that contains them—and the manganese oxides in them were transported and deposited largely by mechanical processes in a playa basin. The source of the manganese is uncertain, but, as other conceivable sources are quantitatively inadequate, it is assumed, though not with entire satisfaction, that the manganese was contributed primarily by hot springs associated with the volcanism of the time.

Up to June 1941 the upper manganiferous zone had been prospected by 43 diamond-drill holes and by scattered surface cuts and shallow underground workings. Fifteen of the holes were drilled by the Bureau of Mines, U. S. Department of the Interior, in the course of a joint investigation of the strategic mineral resources of the Nation made by the Geological Survey and the Bureau of Mines under an act of Congress. As computed from drill-hole data, supplemented by samples collected for the purpose by the Geological Survey and by measurements of areal extent and thickness beyond the limits of the diamond drilling, all interpreted in the light of the geologic study, the upper zone contains at least 175,000,000 tons averaging 3.5 to 4 percent of manganese. It is estimated that of this total 70,000 tons contains 20 percent or more of manganese, 450,000 tons contains 15 percent or more, somewhat over 2,000,000 tons contains 10 percent or more, and 15,000,000 to 20,000,000 tons contains 5 percent or more. About 15,000,000 tons is hard (supergene) ore averaging 6.5 percent of manganese, about 100,000,000 tons is manganiferous sandstone averaging about 3.5 percent, and about 60,000,000 tons is manganiferous clay averaging about 3.5 or 4 percent.

Further exploration of known ore bodies may increase these estimates, and additional ore bodies may be present in the many square miles as yet unexplored. It is probably safe to say that the area contains an assured minimum of 200,000,000 tons averaging 3 to 4 percent of manganese, of which about 20,000,000 tons contains 5 percent or more of manganese and 2,000,000 to 3,000,000 tons contains 10 percent or more. To what extent these deposits may become a source of manganese is a metallurgical and economic problem.

INTRODUCTION

SCOPE AND BASIS OF THE REPORT

As a result of investigations begun in 1929 it had become known by about 1932 that the foothills of the Artillery Mountains, in western Arizona, contain large reserves of low-grade manganiferous material. Engineers of the Federal Bureau of Mines [1] in 1934 estimated the reserves at 50,000,000 tons, and some private engineers placed the figure much higher.

The Bureau of Mines reported [2] that beneficiation of the deposits by known methods of ore dressing appeared hopeless, but it nevertheless rated them as the second largest of the low-grade deposits in the United States that might prove amenable to some form of hydrometallurgical treatment.[3] Attention was again focused on these deposits in 1936 when the Bureau of Mines reported the development of a laboratory method of recovering metallic manganese from low-grade ores by leaching and electrolysis,[4] for the Artillery Mountains lie well within the zone of efficient transmission of electric power from Boulder Dam.

Apart from their potential economic value, the deposits had been regarded with unusual scientific interest as well, for the available

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[1] Dean, R. S., and others, Manganese; its occurrence, milling, and metallurgy, pt. 3: U. S. Bur. Mines Inf. Circ. 6770, p. 168, 1934.

[2] Dean, R. S., and others, Manganese, its occurrence, milling, and metallurgy, pt. 1: U. S. Bur. Mines Inf. Circ. 6768, pp. 39–41, 1934.

[3] Dean, R. S., and others, op. cit. (Circ. 6770), pp. 168–169.

[4] Shelton, S. M., Electrolysis of manganese solutions: U. S. Bur. Mines Rept. Inv. 3322, pp. 29–37, 1936.

information indicated them to be of sedimentary origin. Short descriptions of them had appeared from time to time,[5] but no comprehensive examination had been made. Therefore, when funds and personnel became available in the spring of 1938, S. G. Lasky and R. J. Roberts of the Geological Survey were instructed to make a geologic study of the deposits and to sample them for an independent appraisal of reserves. The time seemed particularly opportune, because the M. A. Hanna Co. was preparing to establish a diamond-drilling camp in the Artillery Mountains, in charge of B. N. Webber, who had been associated with the development of the area since 1929.

Field work was begun by Lasky and Roberts on March 19, 1938, and continued until June 16, with headquarters at Webber's camp until the camp was dismantled late in May. The district was revisited by Lasky for a few days in April 1939. About 85 square miles was mapped. The area of most prominent exposures was mapped geologically on a scale of 600 feet to the inch on a topographic base map previously prepared by Webber for the M. A. Hanna Co. This map covers about 6 square miles. In addition, 45 square miles of the surrounding territory, enough to include all manganiferous exposures and to show the relations of the manganese-bearing formations to the older and younger rocks, was mapped topographically and geologically on a scale of one-half mile to the inch. Vertical control for this mapping was carried from two bench marks established by the United States Coast and Geodetic Survey; horizontal control was carried from township and section corners established by the General Land Office and from claim corners of the M. A. Hanna holdings. Stadia traverses were made along or near geologic boundaries, and the topographic sketching was further tied to points located by intersection. An additional area of about 35 square miles was surveyed geologically in a general way to show the regional setting.

Webber had already prepared various maps, charts, drill logs, and reports for the M. A. Hanna Co., and most of these records were placed at Lasky's disposal. Webber also contributed what knowledge he had gathered of the country outside the company holdings and participated in some field conferences.

The sampling on which the estimates of ore reserves in this report are partly based was done by Lasky and Roberts. The text was written by Lasky, who, except where otherwise noted, is responsible for any descriptions, comments, and conclusions concerning the area beyond the limits of the Hanna holdings, as well as for all statements concerning reserves and recommendations for future prospecting.

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[5] See Bibliography, p. 6.

Completion of the report was considerably delayed by assignment of Lasky to other duties connected with the Strategic and War Minerals Investigations of 1939–44.

HISTORICAL NOTE

According to local information the manganese deposits of the Artillery Mountains area were first identified about 1880 by a man named Andy Shannon. They probably attracted some attention many years earlier, for according to local tradition the road from Alamo to Signal, which passes the most prominent cropping, is the "old Government road built by Captain Bill Williams" about 1860 or earlier. The builders of this road must have noted the manganese croppings (though perhaps without understanding their significance), but this reference to Bill Williams is romance, for he died in 1849,[6] whereas the first surveys for the "Government road" were not made until 1851, when Captain Lorenzo Sitgreaves was commissioned to survey a wagon road from Zuni to the Colorado River.[7]

The first claim locations for manganese are said to have been made by one of the Rogers brothers of Alamo in 1914 on a prominent exposure that is included in what later became known as the Graham property and is now roughly covered by the Chapin No. 23 claim. (See pl. 2.) These early claims were called the Black Warrior Nos. 1 and 2. By the spring of 1918 several other exposures had been located and partly explored under the stimulus of the demand for manganese during the World War, and W. H. Graham and associates were preparing to ship ore from the Black Warrior deposit.[8] No shipments were made, however, until early in 1928, when about 4 cars of sorted ore containing 41 to 45 percent of manganese are said to have been shipped to Alabama.[9] Al Rogers of Alamo says that a total of about 11 cars was shipped. Though ore obviously has been mined from the Graham deposit, no official records of shipments from it can be found, unless references in the volumes of Mineral Resources[10] to shipments of manganese ore from "the Black Warrior mine near Congress" relate to the Graham property.

In 1929 the Chapin Exploration Co. of Duluth, Minn., acquired about 1,700 acres[11] and prospected some of the outcrops with shallow

[6] Favour, A. H., Old Bill Williams, mountain man: North Carolina Univ. Press, p. 179, 1936.

[7] Idem, pp. 180–181.

[8] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710–D, pp. 143–151, 1920.

[9] Wilson, E. D., and Butler, G. M., Manganese ore deposits in Arizona: Arizona Bur. Mines Bull. 127, p. 71, 1930.

[10] Mineral Resources U. S., 1928, 1929, and 1930.

[11] Wilson, E. D., and Butler, G. M., op. cit., p. 71.

holes, on the basis of which it was reported [12] that the area contained a considerable tonnage of ore averaging less than 10 percent of manganese. A private report indicates that the Chapin engineers estimated their holdings to contain about 66,000,000 tons of ore averaging about 8.5 percent of manganese. The Chapin Exploration Co. seems to have acquired all the promising ground known at that time. The following year D. W. Woodbridge and associates discovered the outcrop in Maggie Canyon and acquired about 2,000 acres, which became the holdings of the Arizona Manganese Corp. The Woodbridge holdings adjoined the Chapin holdings and were on the same ore body over which the Chapin Co. had located some of its claims.

In 1936 the M. A. Hanna Co., of Cleveland, Ohio, acquired control under long-term leases of about 2,500 acres of the largest holdings and started an extensive diamond-drilling program, which continued until 1940. In 1941 the U. S. Bureau of Mines explored the blocks north and south of Maggie Canyon in search of more complete information on the grade and distribution of ore in these blocks. This work was part of the joint investigation of the strategic mineral resources of the Nation by the Geological Survey and the Bureau of Mines, authorized by Act of Congress. At the same time the Bureau of Mines took out several thousand tons of ore from the Maggie tunnel for the double purpose of testing mining methods and of obtaining ore for metallurgical tests at its plant at Boulder City, Nev.

BIBLIOGRAPHY

The earliest geologic work in the Artillery Mountains was done by Jules Marcou, the geologist on the Whipple railroad survey of 1853 and 1854. Later work included a hurried reconnaissance of a part of western Arizona by Willis T. Lee in 1903 and 1904, reconnaissance observations on the manganese deposits by E. L. Jones, Jr., in 1917 and 1918, a short visit by D. F. Hewett in 1931, and the work of B. N. Webber and other private geologists. The following bibliography includes the publications based on these earlier examinations, together with a few others that contain references to the manganese deposits.

1856. Marcou, Jules, in Reports of explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean, vol. 3, pt. 4, U. S. War Dept., 1856. Part of the route followed by the survey near the 35th parallel was down the Big Sandy and Bill Williams Rivers to the Colorado.

1908. Lee, W. T., Geologic reconnaissance of part of western Arizona: U. S. Geol. Survey Bull. 352. Primarily a study of water resources. Lee's route skirted the northeast edge of the area covered by the present survey, and his report includes, in addition to general observations applicable to the whole region, a few paragraphs on the Artillery Mountains.

[12] Mineral Resources U. S., 1929, p. 281, 1932.

1920. Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull, 710–D. Includes a description of the area under the heading "Artillery Mountains and Williams River region," and a description of relations at the various manganese properties, with some estimates of tonnage. Contributes much original information.

1930. Wilson, E. D., and Butler, G. M., Manganese ore deposits in Arizona: Arizona Bur. Mines Bull. 127. Includes a description of the deposits of the Artillery Mountains compiled from earlier descriptions by Jones in 1920 and information contributed by B. N. Webber.

1933. Hewett, D. F., in Ore deposits of the Western States (Lindgren volume), p. 489, Am. Inst. Min. Met. Eng. A description based on one week's work by D. F. Hewett and B. N. Webber in 1931.

1934. Dean, R. S., and others, Manganese, its occurrence, milling, and metallurgy, pt. 1: U. S. Bur. Mines Inf. Circ. 6768, pp. 39–51. Under the heading of "Kingman district, Arizona," describes concentration tests on ore from the Artillery Mountains. Idem, pt. 3, Inf. Circ. 6770, pp. 168–169. Includes the "Kingman" district in a table showing grade, tonnage, and mineralogy of 12 large low-grade manganese deposits in the United States that may be amenable to some form of hydrometallurgical treatment.

Woodbridge, D .W., An addition to domestic manganese reserves: Eng. and Min. Jour., vol. 135, pp. 459–460. An enthusiastic account by a man connected with developments in the area since 1930.

1936. Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, pp. 81–83. A somewhat more detailed description than that given by Hewett in 1933 but based on the same examination.

1938. Lasky, S. G., and Webber, B. N., Artillery Mountains manganese district, Mohave County, Arizona, in Some Arizona ore deposits: Arizona Bur. Mines Bull. 145, pp. 133–136. A preliminary statement based on the same investigation as the present report.

Shelton, S. M., Royer, M. B., and Town, A. P., Electrolytic manganese: U. S. Bureau Mines Rept. Inv. 3406, p. 13. Reports the recovery of metallic manganese from a sample of ore from the Artillery Mountains, by a method of leaching and electrolytic deposition, in an experimental plant at Boulder City, Nev.

1918–37. Mineral Resources of the United States, published annually until 1923 by the U. S. Geological Survey and from 1924 to 1931 by the U. S. Bureau of Mines; published as the Minerals Yearbook since 1932. References to the Artillery Mountains appear in the volumes for 1918 (pl. 5), 1929, and 1937. Volumes for 1928, 1929, and 1930 contain statements about shipments from the "Black Warrior mine near Congress," that may refer to the Artillery Mountains deposits.

ACKNOWLEDGMENTS

The M. A. Hanna Co. generously cooperated in this investigation by placing the facilities of its camp in the Artillery Mountains at the disposal of Lasky and Roberts and by permitting study and publication of company records. D. W. Woodbridge, of the Arizona Manganese Corp., furnished confidential information, and G. T. Harley, of Socorro, N. Mex., kindly permitted study and use of a private report he had written in 1929 on the Chapin holdings.

The authors wish to thank the residents of Alamo, particularly Mr. and Mrs. George Lewis, the Rogers brothers, and Mr. Kimmel, for many favors. The senior author is grateful for the able and energetic assistance of R. J. Roberts throughout the field season and for fruitful discussions with him then and later.

The field and laboratory investigations were made under the guidance of D. F. Hewett, who contributed not only from his first-hand acquaintance with the Artillery Mountains area but also from his wide knowledge of manganese deposits in general. Prof. R. E. Peck, of the University of Missouri, examined plant remains from the Artillery formation and furnished an opinion as to their geologic age. K. E. Lohman, of the Geological Survey, visited the area with Lasky in 1939 in search of diatoms that might date the formations. Although the search was unsuccessful, discussion with Lohman in the field was helpful in crystallizing some ideas about the geology. The photomicrographs appearing herein were made under Lohman's direction.

The excellent work by the Section of Illustrations of the Geological Survey, in preparing the illustrations from difficult copy, adds materially to the utility and value of the various maps and diagrams.

GEOGRAPHY

LOCATION AND ACCESSIBILITY

The Artillery Mountains are in west-central Arizona, about 30 miles east of the Colorado River. (See fig. 1.) Except for two or three small isolated exposures, the manganese deposits lie within an area roughly 3½ miles wide by 7½ miles long, on the west side of the Bill Williams River, between Alamo crossing and the point where the Big Sandy and Santa Maria Rivers join to become the Bill Williams River. Except for the isolated croppings just mentioned, which are in Yuma County, the deposits are at the south edge of Mohave County. The manganiferous croppings are partly in the valley between the Artillery and Rawhide Mountains and partly among the foothills on either side. The richest croppings and the only ones that have been prospected, are on the northeast side of the valley, among the hills that form the southeast flank of the Artillery Mountains. They are 6 to 10 miles by road from Alamo.

The district is isolated and undeveloped. Its only inhabitants are a few prospectors and miners and two or three ranchers. The entire population in 1938 was probably less than 25 persons. Alamo is the only settlement, and at times even it is abandoned. The nearest other settlement is Signal, about 16 miles north on the Big Sandy River. The nearest supply points are Congress (or Congress Junction), 46 miles by desert road east of Alamo, and Aguila, about the

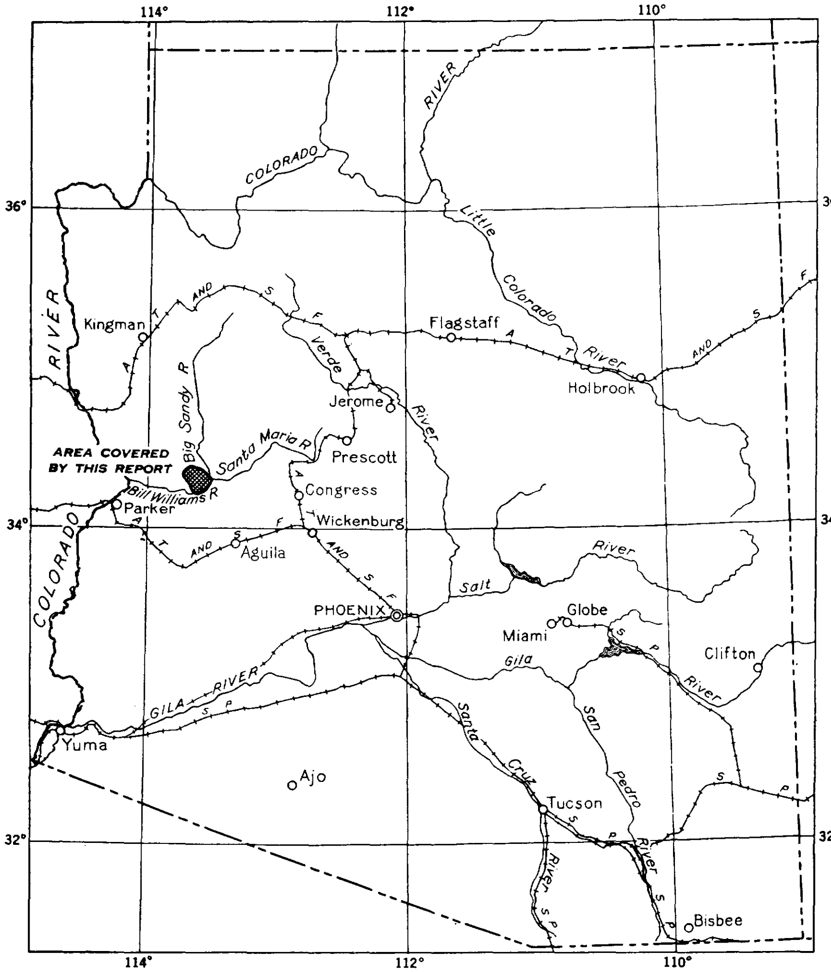

FIGURE 1.—Map of Arizona, showing location of area covered by this report.

same distance by road southeast. Congress is on U. S. Highway No. 89, 15 miles north of Wickenburg, and Aguila is on U. S. Highway No. 70, 27 miles west of Wickenburg. Both towns are stations on the Santa Fe Railway and both are used as shipping points, but Wickenburg is generally used as the trading center.

In flood season the Bill Williams River may be impassable at Alamo for several weeks, but at such times the manganese area can be reached by way of Kingman and Yucca to the north. Yucca is 63 miles from Alamo.

TOPOGRAPHY

The area covered by this report is in a group of mountains and hills that rim the western end of an unnamed desert valley extending about 8 or 9 inches.[16] Recorded temperatures at Signal often rise well above 100° from May to September, and in May and June the daily range in temperature is often as much as 40° to 50°. As in all the desert country, the combination of low rainfall and high temperature keeps the air dry, yet fogs occasionally rise from the river and extend several miles from it. Evaporation from standing water may be as much as 10 or 15 times the average annual rainfall.

The most conspicuous plants are the giant or sahuaro cactus, the palo verde, ocotilla, creosote, and mesquite. Mesquite is particularly abundant along the river, where it forms heavy thickets and grows to large size. Other trees in the river thickets and along other water courses are cottonwood, palo verde, desert willow, and smoke trees. The joshua tree grows abundantly on parts of the desert east of the river.

GEOLOGY

GENERAL SUMMARY

The distribution of the various formations in and around the Artillery Mountains manganese area is shown on plates 1 and 2. The rocks range in age from probable pre-Cambrian to Recent, but as the few fossils that have been found are not diagnostic, the geologic ages have been determined indirectly and remain uncertain. In order of age the rocks include: A basement complex, which consists mainly of granite, gneiss, and subordinate schist that are probably pre-Cambrian but which includes some igneous rock that may be of later age; metamorphosed limestone, shale, and quartzite possibly of Paleozoic age; the Artillery formation, tentatively assigned to the lower Eocene, consisting of closed-basin deposits of reddish clay, conglomerate, arkose, sandstone, shale, and some limestone and tuff, with a widespread basalt member; volcanic rocks that are probably Miocene; the Chapin Wash formation, which consists of alluvial-fan and playa deposits tentatively assigned to the early Pliocene and which is the principal manganese-bearing formation; the Cobwebb basalt, also perhaps of early Pliocene age; the Sandtrap conglomerate, locally including a basalt member, perhaps of late Pliocene age; basalt flows that cap some of the extensive mesas and that may be early Pleistocene; late Pleistocene alluvium; and Recent alluvium and slide rock. The thicknesses, for most of which only minimum or uncertain figures can be determined, are given in the table on page 14. The various formation names are used for the first time in this report.

Angular unconformities underlie the Paleozoic (?) sediments, the Artillery formation, the Miocene (?) volcanics, the Chapin Wash formation, the Pleistocene (?) basalt, and the Pleistocene alluvium;

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[16] Smith, H. V., The climate of Arizona: Arizona Agr. Coll. Bull. 130, fig. 6, p. 386, 1930.

erosional unconformities underlie the Sandtrap conglomerate and the Recent alluvium. At least eight stages of deformation can be recognized, but the significance of some, particularly the earlier, cannot be determined without a great deal more detailed regional study.

The earliest structural feature that is well displayed within the area and of obvious geologic import is a thrust fault that brings pre-Cambrian complex and Paleozoic (?) rocks onto the Artillery formation. The present distribution of parts of these formations and of the mountains is due indirectly to this thrust. The thrusting occurred before extrusion of the Miocene (?) volcanic rocks; there is some chance that the Artillery formation was in part derived from the advancing front of the thrust plate, in which event the thrusting would be lower Eocene to Oligocene.

The next obviously significant deformation was the normal faulting, post-Miocene (?), that first established the general position of the valley between the Artillery and Rawhide Mountains. A closed graben basin was formed, in which the Chapin Wash formation and the Cobwebb basalt were deposited. The Sandtrap conglomerate also was deposited in this basin, but at a later time, when the basin had been enlarged by faulting or when through drainage had been established. This graben block is referred to hereafter as the "manganese basin," and the Chapin Wash formation, the Cobwebb basalt, and the Sandtrap conglomerate are referred to as the "formations of the manganese basin."

These three formations—the Chapin Wash formation, Cobwebb basalt, and Sandtrap conglomerate—are folded into a shallow syncline whose axis parallels the northwesterly trend of the valley. Numerous minor folds, of varying degrees of sharpness and mostly trending northwestward, modify the smooth contours of the syncline. Some movement seems to have occurred at the base of the Sandtrap conglomerate in response to this folding, and there may have been some sympathetic faulting in the older rocks, particularly the pre-Cambrian. The thrust fault itself is folded.

The folded rocks along both sides of the manganese basin are broken by northwestward-trending faults, which presumably represent renewed movement along the old fault zones. As some of those in the Rawhide Mountains appear to follow veins of pre-Artillery age, the zones of weakness may have been outlined at a very early period. The faults along the Artillery Mountains on the northeast side of the valley are particularly extensive and clear-cut and involve the Pleistocene (?) basalt as well as the older rocks. They control the present topography to a considerable degree; some of the fault scarps are still sharply defined.

TABLE 2.—*Formations in the Artillery Mountains manganese area*

Age	Formation	Character	Thickness (feet)
Recent	Later alluvium	Talus deposits and gravel and sand along the present drainage.	
———Erosional unconformity———			
Late Pleistocene	Earlier alluvium	Pediment gravel and valley fill	
———Angular unconformity———			
Early Pleistocene(?).	Basalt	Massive fine-grained to vesicular glassy basalt	0–350+.
———Angular unconformity———			
Late Pliocene(?)	Sandtrap conglomerate.	Largely light-red to dark-red poorly sorted conglomerate with discontinuous bedding. Includes a prominent basalt member in the northwest part of the area.	0 to possibly 2,000.
———Erosional unconformity———			
	Cobwebb basalt	Massive aphanitic vesicular basalt	0–250+.
Early Pliocene(?)	Chapin Wash formation.	Alluvial-fan and playa deposits—fanglomerate, conglomerate, sandstone, siltstone, mudstone, clay, and limestone; in part gypsiferous. The principal manganese-bearing formation.	0 to possibly 1,500 or more.
———Angular unconformity———			
Miocene(?)	Volcanic rocks	Tuffs, breccias, and flows, rhyolitic to andesitic	1,800+.
———Angular unconformity———			
Early Eocene(?)	Artillery formation.	Conglomerate, arkose, sandstone, shale, limestone, and a little clay, with some tuff and a widespread basalt member; in large part highly indurated.	2,500+.
———Angular unconformity———			
Paleozoic(?)		Limestone, shale, and quartzite, in part metamorphosed.	
———Angular unconformity———			
Pre-Cambrian		Granite, gneiss, microbreccia, and subordinate schist; includes some monzonitic rock in the Rawhide and Buckskin Mountains that may be younger than pre-Cambrian.	

BASEMENT ROCKS OF THE MANGANESE BASIN

PRE-CAMBRIAN COMPLEX

The oldest rocks of the Artillery Mountains region form a complex of granite, gneiss, and subordinate schist. Lee [17] assumed these rocks to be pre-Cambrian, and later geologists who have worked in the area (see bibliography, p. 6) have likewise so considered them. The present writer sees no reason to believe otherwise concerning most of the rocks of the complex, but some monzonitic rock in the Rawhide and Buckskin Mountains may be younger. Because of the economic purpose of the survey and the limited time available, the pre-Cambrian complex was examined in a general way only, and no attempt was made to map the different rock types separately.

The granite around Artillery Peak is a coarse-grained pink to red biotite granite that weathers into rounded boulders. Similar granite is exposed in the thrust sheet that constitutes the central spur of the range (where in part the pre-Cambrian rocks immediately underlie the manganese-bearing sediments), but most of the granite in this spur is gneissic. This spur contains also some finer-grained granite

[17] Lee, W. T., Geologic reconnaissance of part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 14–15, 22, pls. 1, 5, 1908.

and schist, the schist being most widely exposed in the eastern part of sec. 29, T. 12 N., R. 13 W.

In the Rawhide Mountains, rocks similar to those just described constitute the pre-Cambrian complex between the Deer Trail and Rawhide mines, near the west side of T. 11 N., R. 13 W., but farther southeast in the same range the complex consists mostly of gray to greenish chloritized granite and gneiss and much rock that looks like a medium-grained chloritized monzonite. Some of the monzonitic rock, however, is distinctly transitional into the gneiss, and a typical specimen was found on microscopic examination to be a chloritized, microbrecciated biotite-granite, so pulverized in places that its constituent minerals are unrecognizable. The gneiss is in places a typical "augen" gneiss. Basic dikes are common in the high hills of secs. 27 and 28. All these rock types are irregularly discolored by weathering to red, green, and white; along old vein deposits and other zones of mineralization they are largely oxidized to various shades of yellow and red.

In the Buckskin Mountains, a monzonitic rock resembling that in the Rawhide Mountains may not be pre-Cambrian, as it is associated with contact-metamorphosed sediments and seems to contain inclusions of them.

PALEOZOIC(?) SEDIMENTS

The thrust plate in the Artillery Mountains consists partly of sedimentary rocks that in some places overlie the pre-Cambrian complex and in other places are thrust over rocks of the Artillery formation. Three small masses are exposed. The largest, about a tenth of a square mile in area, forms a rugged hill in secs. 20 and 29, T. 12 N., R. 13 W., where the rocks of the thrust plate are overlain by the Miocene(?) volcanics and the Chapin Wash formation. (See pl. 1.) A short distance southeast is a sliver of limestone that forms the basal slice of the thrust plate, and in the valley to the east a small mass forms a klippe resting on the basalt member of the Artillery formation. (See pl. 1, sec. *B–B′*.) The sediments consist mainly of highly brecciated, distorted gray limestone, in part marmarized and exhibiting prominent flow lines, and include subordinate layers of quartzite, cherty hornfels-like shale, and some layers of garnet-epidote rock.

The monzonitic rock in the Buckskin Mountains, mapped with the pre-Cambrian but perhaps of later age, is capped in places by, and perhaps contains inclusions of, metamorphosed sediments that include epidotized and marmarized limestone, cherty shale, and green and white hornstone.

No fossils could be found in these rocks. They are assumed to be Paleozoic, but on no better evidence than the relations here described.

ARTILLERY FORMATION (EARLY EOCENE?)

GENERAL RELATIONS

The Artillery formation is named for the Artillery Mountains, where it is thickest and most conspicuous. The name is used here for the first time.

The formation occupies broad tracts within the area mapped and extends far beyond its borders, particularly northward along the Big Sandy River and westward into the Rawhide Mountains. It rests upon the rocks of the pre-Cambrian complex and the Paleozoic (?) sediments. At some places it seems to have been deposited upon highly brecciated rocks of the basal complex, as suggested most strongly in Chapin Wash west of the Plancha Mountain fault. Around the Rawhide and Deer Trail mines, in the Rawhide Mountains, it rests upon the oxidized outcrops of veins and of mineralized igneous rock of the pre-Cambrian complex. It is overlain by Miocene (?) volcanics west of the Signal road in the northern part of the mapped area and also at Artillery Peak and in the bluffs on the west bank of the Big Sandy River, just above the mouth of the Santa Maria River (see pl. 3*B*); elsewhere it is overlain by the Chapin Wash formation, the Cobwebb basalt, or the Sandtrap conglomerate. On the east side of the Bill Williams River it is overlain by the extensive gravel blanket of the desert, and in the Santa Maria district, on the Santa Maria River, by Quaternary (?) basalt. In the central spur of the Artillery Mountains the Artillery formation has been overthrust by the pre-Cambrian complex and the Paleozoic (?) rocks. (See pls. 3*A* and 6*A*.)

The thickness, lithologic character, induration, and topographic expression of the Artillery formation vary widely, but some features, such as a widespread basalt member and a conglomerate composed of granite boulders, are typical of the formation as a whole, throughout the area mapped. Some parts of the formation, mostly the light-colored parts, erode easily, whereas other parts, mostly dark-colored, are highly indurated and tend to form cliff-bordered ridges and mesas. The dark indurated parts are commonly shattered. In general the softer rocks underlie the thrust plate of the Artillery Mountains, and the indurated shattered rocks overlie the granite in the thrust plate. In the Rawhide Mountains the indurated rocks constitute most of the exposures. The induration is presumed to have antedated the thrusting, for the shattering of the indurated rocks seems best explained as representing the cracking of the brittle parts of the thrust plate; it is older, at any rate, than the deposition of the next younger sediments, the Chapin Wash formation. (See p. 30.)

STRATIGRAPHY

Near Artillery Peak.—The valley between Artillery Peak and the present edge of the thrust sheet contains the thickest, most varied, and generally least-resistant part of the Artillery formation. (See pls. 1 and 3*A*.) At that place the pre-Cambrian granite is overlain by an estimated 1,500 feet or more of multicolored, coarse-grained arkose, containing in the upper part much sandstone and shale interbedded with a few layers of limestone. Sorting in the arkose is poor, and bedding tends to be indistinct. At the south end of Artillery Peak the arkose contains lenses of conglomerate, composed of granite boulders, that resemble the chaotic assemblages of boulders at the mouths of some present-day arroyos. Above the arkose there is some yellow to white limestone, which forms prominent parallel ridges extending in an arc from the Big Sandy River northwestward to the Miocene (?) volcanics. Between Artillery Peak and the river this limestone contains a prominent layer of white stuff.

The rocks immediately above the limestone are poorly exposed, but a good deal of purple volcanic material seems to be present. Above this interval of poor exposures is a great thickness of massive to thin-bedded sandstone, which contains the extensive basalt member of the Artillery formation mentioned above. The sandstone is mostly red and fine-grained, but is partly gray or somewhat greenish and partly gritty and arkosic. It contains thin partings of mudstone, siltstone, and clay shale, and locally some thin layers of limestone. Many of the partings are highly micaceous, and some consist of soft sericitic clay. Included within this section of the formation is a peculiar breccia-like material consisting largely of angular fragments of schist, gneiss, and other rocks of the pre-Cambrian complex. Some parts of this material seem to consist entirely of one kind of rock. In some respects it resembles the breccia near the base of the thrust sheet (see p. 41), but it is interbedded with the other members of the formation. It is conformably overlain by the higher members and seems to lie conformably upon the underlying members; in some exposures it appears to grade downward into what looks like ordinary fanglomerate. The breccia occurs in a belt extending northwestward from the 2,550-foot peak to the middle of sec. 28, T. 12 N., R. 13 W. The exposures are not continuous, but they all appear to be at about the same stratigraphic interval below the basalt. Some of them are at least 1,000 feet long. Farther north similar breccia-like rock crops out along the road to Signal and near the Big Sandy River in the southwest corner of T. 12 N., R. 12 W.

The uppermost beds above the basalt include indurated torrential deposits of red sand and gravel overlain by massive indurated beds of coarse bouldery conglomerate. (See pl. 7*A*.) In general the larger boulders are 3 to 4 feet in diameter; but some slablike ones have even greater dimensions. The outlines of the boulders vary from well rounded to angular. Most of them are granite, many are gneiss, and a few are schist; some pebbles of rhyolite were recognized. Such bouldery beds compose much of the ridge extending westward from the 2,550-foot peak opposite the Big Sandy River. In the talus on the north side of this ridge the granite boulders are so numerous and so large as to give the impression at first sight that the bedrock is granite.

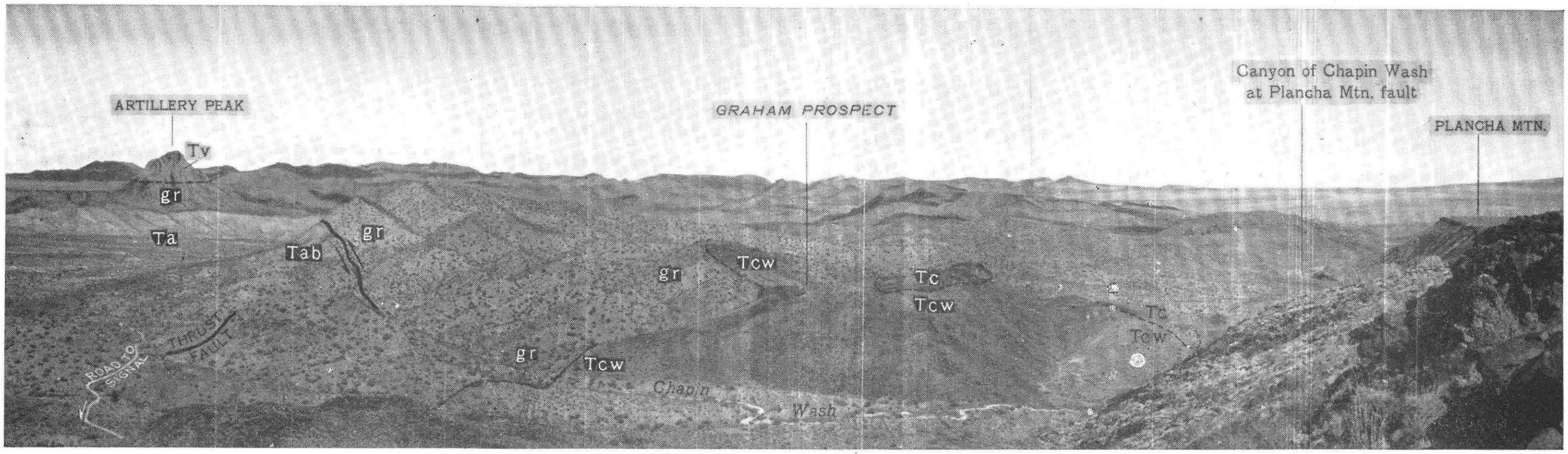
The basalt member is generally amygdaloidal and highly altered, but locally it is a tough, fine-grained, essentially unaltered black rock containing phenocrysts of olivine megascopically recognizable. A thin section shows it to be a normal olivine-augite basalt containing much glass in the groundmass. Spots in the glassy groundmass are replaced by small radiating intergrowths of pink and white zeolites, whose optical properties are those of natrolite and thomsonite. These zeolites, together with calcite, fill amygdules in other parts of the rock.

Because part of the formation just below the thrust plate is highly distorted (see p. 41) and there is some duplication by faulting in the basal part of the section (see p. 42), a reliable measure of thickness cannot be made until the structure is mapped in detail. A continuous basal section of at least 1,300 feet was measured, and the total thickness must amount to thousands of feet. The measured thickness of the basalt member ranges from 40 to 310 feet, with the uppermost part of the thickest exposure cut off by the thrust fault. (See pl. 6*A*.)

Near Burro Wash and south of the Santa Maria River.—The deeply trenched ridges of the Artillery formation lying in the northeast part of T. 11 N., R. 13 W., and extending eastward to the river are composed of the dark indurated beds resting on the granite and gneiss of the thrust sheet. These exposures are typical of the indurated beds, which are composed dominantly of dark reddish-brown hard quartzitic sandstone, generally arkosic and in part a true arkose. In the thin section examined each grain is coated with red iron oxide; the cement is mostly quartz but partly barite. The few plagioclase grains and biotite flakes that are present are remarkably fresh.

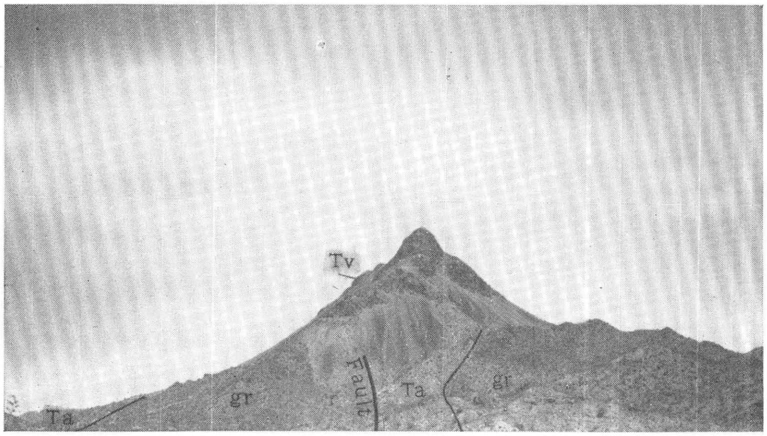
The many zones of shattering and brecciation in these beds are commonly cemented with manganese oxides which also stain practically all the joints and fracture surfaces, so that when viewed from a distance the formation appears almost black. Here and there is a layer of hard shale similarly colored. A few beds are brick red and not indurated, and a few are gray, but all are stained with manganese.

Many large boulders of granite high on the slope south of Burro Wash indicate the presence of some of the bouldery beds, and other bouldery beds, like the torrential deposits illustrated by plate 7*A*, form the basal part of the exposure just north of Plancha Mountain to the



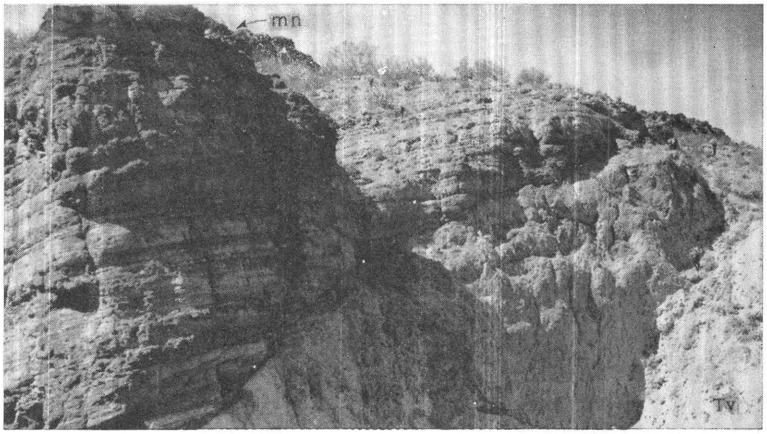
A. PANORAMIC VIEW EASTWARD FROM THE EDGE OF MANGANESE MESA OPPOSITE DIAMOND-DRILL HOLE NO. 5.

At the right are the talus-covered slopes of Manganese Mesa. In the middle is the Chapin Wash formation (*Tcw*). It is capped, on the Chapin Nos. 16 and 23 claims (see pl. 2), by the Cobwebb basalt (*Tc*) and rests on the thrust plate of pre-Cambrian granite (*gr*) that constitutes most of the central spur of the Artillery Mountains. *Tv*, Miocene volcanics; *Tab*, basalt member of Artillery formation. The valley at the left is carved in soft rocks of the Artillery formation (*Ta*) below the thrust plate. The white ridge on the far side of the valley is limestone of the Artillery formation. Beyond Artillery Peak and in the middle background are the Aquarius Mountains, on the east side of the Big Sandy River.



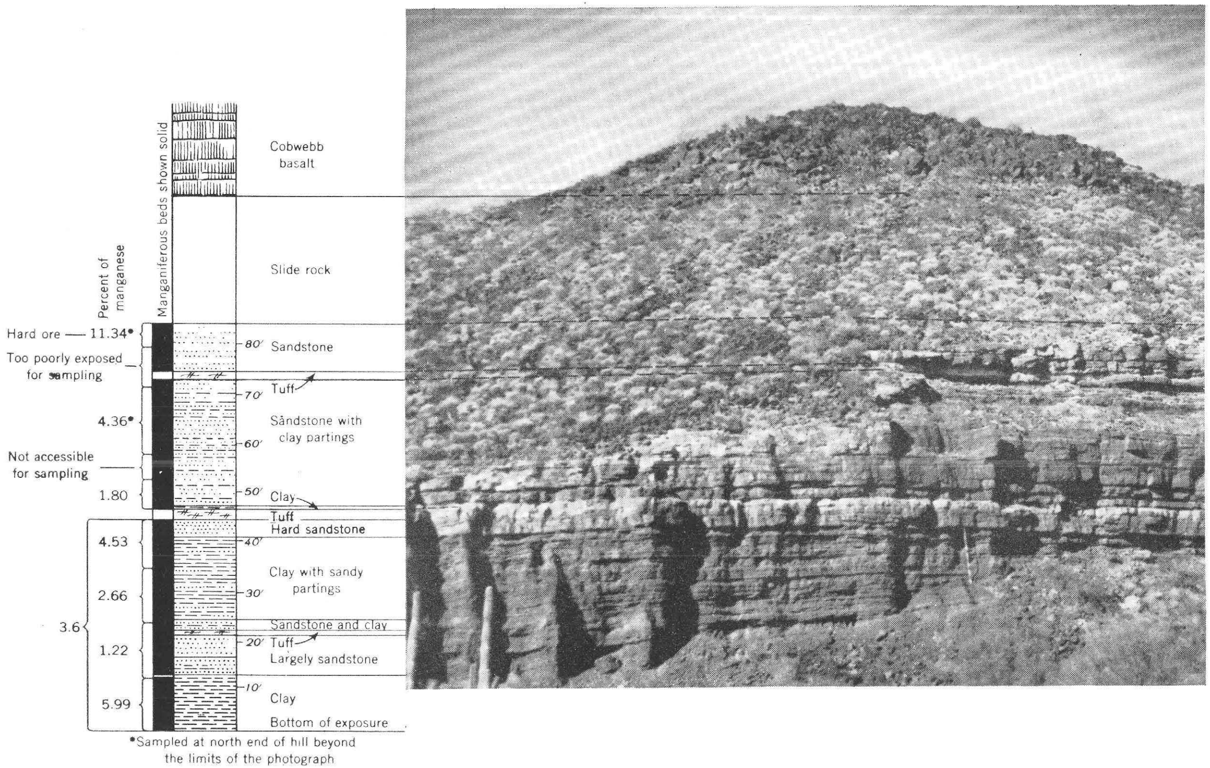
B. ARTILLERY PEAK FROM THE SOUTHEAST.

Shows latite of the Miocene(?) volcanics (*Tv*) resting on pre-Cambrian granite (*gr*) and on basal arkose and conglomerate of the Artillery formation (*Ta*), which was faulted before emplacement of the latite.



C. UPPER PUMICE-FELSITE BRECCIA MEMBER OF THE MIOCENE(?) VOLCANICS (*Tv*) OVERLAPPED BY BEDS OF THE CHAPIN WASH FORMATION.

mn, Manganese layer. SE¼ sec. 19, T. 12 N., R. 13 W.



MANGANIFEROUS BEDS OF THE CHAPIN WASH FORMATION, IN CHAPIN WASH, AT COBWEBB HILL.

west. Mud-filled drying cracks were observed in some sandstone in the Plancha Mountain area.

The basalt member of the Artillery formation crops out in the indurated beds at and near the Bill Williams River and shows up again on the east bank, but east of the river the beds consist largely of gray and red sandstone containing a notable proportion of clay, clay shale, limestone, and some conglomerate transitional from sandstone. The partings are commonly stained with manganese oxide, and some thin beds a few feet above the basalt member are in places uniformly manganiferous. At one place a lens of breccia-like material similar to that near Artillery Peak, and about 300 feet long and 15 feet thick, crops out a few feet stratigraphically below the basalt member. It is clearly overlain by limestone, which cements the rough bouldery top of the breccia, and almost as clearly is underlain conformably by micaceous clay and shale.

Brown limestone is prominently exposed in the ridge along part of the contact between the Artillery formation and the Sandtrap conglomerate, and a prominent zone of white fine-grained, sandy to ashy tuff, 25 feet in maximum thickness, lies below the limestone. This limestone and tuff lie stratigraphically well above the basalt member and are thus distinct from the limestone and tuff exposed near Artillery Peak.

In the Rawhide and Buckskin Mountains.—The great thickness of Artillery formation in the Artillery Mountains is not present in the Rawhide and Buckskin Mountains, where at some places the basalt member rests directly upon the pre-Cambrian rocks. At no place in the area examined is there much more than 150 feet of sediments below the basalt. At some places in the Rawhide Mountains the base of the formation consists of angular conglomerate that looks much like cemented granite debris; at other places there is about 10 feet of red to green blocky shale that seems to be composed of oxidized material derived from old vein deposits and other mineralized zones in the igneous rocks that underlie the formation. Between this basal conglomerate or shale and the basalt there is 50 feet or less of limestone, some of which is red or black and cherty, some dark brown, and some dense and light-colored; the light-colored limestone weathers yellow and resembles the limestone near Artillery Peak. Above the basalt is 200 feet or more of the typical dark indurated sandstone and bouldery conglomerate, which in places rests directly upon the basement rocks.

In the Buckskin Mountains the basalt member is interbedded with ordinary red sandstone and shale, and some clay. Many of the sandstone beds are splintery, and some of the harder ones begin to resemble typical indurated beds. The bedding planes are commonly stained with manganese oxides of syngenetic origin (see p. 50), and there are some manganiferous partings a quarter of an inch or so in thickness.

ORIGIN

Although the precise thickness of the beds below the basalt member is not everywhere known, the distribution of the basalt member and its relation to the pre-Cambrian rocks indicate that the surface on which the formation was deposited had a regional relief of several thousand feet. The configuration of this surface is not known, for the horizontal displacement of the thrust fault has not been determined (see p. 42), but it seems safe to infer that there was a flat upland on the southwest (composed of the resistant rocks of the Rawhide Mountains area) bordered by a broad valley in the soft granite of the Artillery Mountains area. Local relief on this upland seems not to have exceeded 150 feet, and there were essentially flat areas as much as a mile wide. At Artillery Peak the great thickness of coarse basal arkose, composed of material derived from the granite upon which it lies, presumably represents a thick fan bordering another upland on the northeast side of the valley area.

Viewed broadly, then, the Artillery formation is interpreted as having been deposited in a northwestward-trending valley, of uncertain dimensions, that received debris from the bordering hills. The abundance of boulder beds in the upper part of the formation and the size and character of the boulders suggest derivation of that part from the weathered boulder-clad slopes of roughly graded [18] granite mountains. This interpretation is supported by the wide extent of the boulder beds above the basalt, which flowed out after the basin had been largely filled and the sediments were lapping onto the smooth highland, where large boulders would be abundant. Moreover, the boulders in some members appear to have been cemented with sand and fine-grained gravel at their points of origin, for in some places it is difficult to define the precise contact between the conglomerate and the granite on which it rests. Rocks like those composing the boulders crop out today in the area mapped and are yielding boulders on weathering. The limestone beds at various stratigraphic positions imply that lakes or playas existed from time to time.

The origin of the valley or basin itself is obscure. It may be a fault valley, perhaps of basin-and-range type, perhaps related to the thrusting. Favoring this interpretation are the pre-Artillery mineralized faults in the Rawhide Mountains and the pre-Artillery brecciated rocks in the Artillery Mountains. The breccia beds also favor it. The position of at least some of the breccia masses not far below the basalt member indicates that these particular masses were probably deposited, like the basalt, after the bordering hills had been well worn down. Yet such material would seem to indicate steep slopes

[18] Davis, W. M., Sheetfloods and streamfloods: Geol. Soc. America Bull., vol. 49, pp. 1360–1361, 1938.

nearby, and if so they would therefore imply contemporaneous faulting.

The fact that both the breccia beds and the pre-Artillery faults are relatively close to the margins of the basin suggests that the basin may be of basin-and-range origin. Some speculations suggest, however, that the basin of deposition may be related to the thrusting. The Rawhide Mountains area may be part of the thrust plate (see p. 42), and if it is the relatively smaller thickness of the Artillery formation there as compared with that in the lower plate would suggest a sinking basin bordering the overthrust. The breccia beds could imply thrust faulting as well as normal faulting. Under this interpretation the Artillery formation presumably would have been derived in part from the advancing plate, which finally overrode it. This concept, if true, has strong regional significance, for rocks resembling the Artillery formation and believed by some Arizona geologists [19] to be its equivalent are widespread in southern and western Arizona.[20]

AGE

The Artillery formation is tentatively assigned to the lower Eocene. Silicified palm roots were collected from two of the limestone beds above the basalt south of the Santa Maria River, algae and silicified palm roots were collected from one of the limestone beds on the southeast slope of Artillery Peak, and calcitized palm roots were collected in the Santa Maria district.

Several years before the study of the Artillery Mountains area was started, Webber discovered snail shells in a thin slabby limestone in the NE¼ sec. 17 on the east side of the Bill Williams River, in the same general locality at which some of the palm roots were collected but stratigraphically below the basalt member. They were submitted to the Geological Survey for identification and were described by J. B. Reeside, Jr., as an amnicolid gastropod, possibly a new form and not helpful for age assignment. Collections made at the same locality in the course of the present investigation were found to contain, in addition to the many snail shells, some *Chara* fruits, concerning which Prof. R. E. Peck expressed the following opinion:

> I have not had an opportunity to examine this material as carefully as I would like. I would judge, however, that it is younger than Morrison and older than Bridger. * * * I have hastily compared it with material from Upper and Lower Cretaceous, and Eocene, and think that it is approximately Wasatch in age.
>
> The specimens from the Artillery formation are internal molds and rather difficult to compare with better preserved material. I believe that several species from the Artillery are the same as those I collected in the Flagstaff member

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[19] Wilson, Eldred, personal communication.

[20] Ross, C. P., Geology of the lower Gila region, Arizona: U. S. Geol. Survey Prof. Paper 129–H, pp. 188–190, 1922. Bryan, Kirk, The Papago country, Arizona: U. S. Geol. Survey Water-supply Paper 499, pp. 59–60, 1925. Wilson, E. D., Geology and mineral deposits of southern Yuma County, Arizona: Arizona Bur. Mines Bull. 134, pp. 30–31, 1933.

of the Wasatch in Central Utah. * * * At least, they compare more closely to that member than to any other that I have had opportunity to examine. * * *

To this report Mr. Reeside has added the following statement:

As palm roots (also collected from the Artillery formation), by all known standards, could not be older than the later part of the Upper Cretaceous, the age bracket is reduced to later Upper Cretaceous and Bridger (middle Eocene). Professor Peck's tentative assignment of the specimens to the Wasatch (lower Eocene) seems reasonable.

MIOCENE(?) VOLCANICS

Volcanic rocks, probably of mid-Tertiary age, occupy four small areas in the part of the Artillery Mountains covered by this report. Doubtless the several exposures were once continuous. The volcanic rocks rest with angular unconformity upon the older formations and are unconformably overlain by the Chapin Wash and Sandtrap formations and by Quaternary (?) basalt. (See pl. 3*C*.)

The largest exposure is in T. 12 N., R. 13 W., west of the road to Signal. At that place the Miocene (?) volcanics overlap the Artillery Mountains thrust fault. The following section was measured near the south tip of the exposure.

Miocene (?) volcanic rocks in SW¼ sec. 20, T. 12 N., R. 13 W.

	Feet
Chapin Wash formation (early Pliocene?)	
Angular unconformity.	
Miocene (?) volcanics:	
Pumice-felsite breccia like that below	600
Perlite, black, containing a few spherulites and nodules as in the felsite member below it	100
Felsite, brown, partly with flow structure, partly massive and without flow structure; generally crowded with spherulites and odd nodular growths as much as 10 inches across. Top part is composed almost entirely of such nodules	560
Pumice-felsite breccia, white, generally coarse-grained, containing fragments of pumice and devitrified sheeted felsite as much as a foot or more across	470
Tuff, white to yellow, well laminated; fine-grained and sandy to coarse-grained, ashy, and breccia-like, with a minor proportion of rock fragments	70
Angular unconformity.	
Basalt member of the Artillery formation (early Eocene?)	

The spherulitic felsite pinches out a short distance south of the above section, and the two beds of pumice-felsite breccia merge. The perlite and breccia have contributed a high proportion of the material that now constitutes the upper part of the Chapin Wash formation in the Maggie Canyon area.

At Artillery Peak the Miocene (?) volcanics include only some latite that truncates the granite and basal arkose of the Artillery formation and forms conspicuous talus slopes. (See pl. 3*B*.) It is dense and brittle and contains a few phenocrysts of biotite and white feldspar, mostly 1 to 2 millimeters long, and many minute flakes of oxidized biotite, in a lavender to pink fine-grained to almost aphanitic groundmass. The feldspar phenocrysts are orthoclase and a plagioclase having a low index of refraction. The groundmass is an indistinctly crystalline aggregate of orthoclase, plagioclase, and quartz.

The rock at the 2,550-foot peak to the southeast is identical in appearance with that at Artillery Peak. In sec. 1, T. 11 N., R. 13 W., west of the 2,550-foot peak, there are outcrops of a fine-grained to coarse-grained volcanic breccia composed of fragments of only one kind of rock. These fragments are light brown and contain a few sparkling phenocrysts of white feldspar and biotite in an aphanitic groundmass. The rock looks like a coarser phase of the latite at Artillery Peak, but on microscopic examination it proves to be a biotite andesite containing much andesine (about An_{40}) and subordinate orthoclase and biotite in a dirty, indistinctly crystalline, feldspathic groundmass. There may originally have been some hornblende, for there are a few pseudomorphs (composed of alteration products) that have outlines suggesting that mineral. The andesine is variably replaced by a feldspar of low refractive index that may be oligoclase. Pebbles of this rock and of the latite at Artillery Peak are so numerous in the conglomerate beds of the Chapin Wash formation and in the Sandtrap conglomerate east of the Bill Williams River as to suggest that both rocks formerly extended over a much greater area.

Volcanic rocks resembling those in the Artillery Peak region and presumably related to them are widespread in southwest United States and are usually assigned to the Miocene. Although nowhere in Arizona have these rocks been precisely dated, they have been assumed to be of Miocene age because they are bracketed between an old erosion surface of late Cretaceous or early Tertiary age and the Gila conglomerate of Pliocene to possibly Pleistocene age. For western Arizona an upper age limit is indicated by the fact that the Tertiary volcanics of the Cibola region, along the Colorado River, are overlain by sediments containing fossils of Miocene or Pliocene age.[21] The lower age limit for western Arizona would seem to be restricted somewhat more closely than heretofore by the fact that the volcanic rocks in the Artillery Mountains are younger than a thrust fault that involves the lower Eocene(?) Artillery formation.

FORMATIONS OF THE MANGANESE BASIN

CHAPIN WASH FORMATION (EARLY PLIOCENE?)

DEFINITION

The Chapin Wash formation, of which the most valuable bedded manganese deposits of the area are a part, rests with angular un-

[21] Wilson, E. D., Geology and mineral deposits of southern Yuma County, Arizona: Arizona Bur. Mines Bull. 134, pp. 31–32, 1933.

conformity upon the smoothly eroded surface of the older rocks. It is overlain in part conformably by the Cobwebb basalt and in part unconformably by the Sandtrap conglomerate and younger rocks. It pinches out between the basement rocks and the overlying formations at the edges of the basin but thickens to a maximum of possibly 1,500 feet or more toward the central part of the basin.

The formation consists of alluvial-fan and playa deposits derived from the older rocks, and is extremely variable. As its variations are best exposed along Chapin Wash, it is named the Chapin Wash formation. This name is here used for the first time.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Chapin Wash formation crops out roughly in the form of an elongated U, 6 to 7 miles long and 3 to 5 miles wide, outlining the shallow syncline that occupies the valley between the Rawhide and Artillery Mountains. Presumably the formation is continuous below the surface across the trough of the syncline. The continuity of the outcrop is broken by a number of faults in the Artillery Mountains and by a subordinate anticline in the Rawhide Mountains.

Where exposed near the Rawhide mine, in the Rawhide Mountains, the Chapin Wash formation pinches out between the basement rocks and the Sandtrap conglomerate, and these exposures evidently represent the western limit of the formation in that area. In the Artillery Mountains, however, the westernmost exposures, in Maggie Canyon and near the head of Chapin Wash, show sufficient thickness to suggest that the formation extends much farther westward or northwestward under the basalt of Manganese Mesa.

Most of the exposures are in the dissected pediment of the valley and are cut by Sandtrap and Chapin Washes and their tributaries and by similar parallel washes. In the foothill areas erosion of the formation has been influenced more by structure and by the distribution of the more resistant neighboring rocks than it has in the valley area, and the formation is somewhat more intricately dissected. (See pl. 3*A*.)

LITHOLOGIC CHARACTER

The Chapin Wash formation consists mainly of pink to red and brown clay, mudstone, siltstone, and sandstone, with gradations into one another, and each kind of rock containing partings of the others. A few layers of tuff and limestone constitute useful horizon markers. (See pls. 4 and 9*A*.) The reddish beds owe their color to the presence of iron oxides, whereas the manganiferous beds are black with manganiferous oxides. Most beds contain thin lenses of conglomerate, and there are several fairly extensive conglomerate zones. Cross bedding, ripple marks, drying cracks, mud flakes, intra-formational conglomerates, and scour-and-fill surfaces have been noted here and there. At the base of the formation there is usually a conglomerate composed of angular fragments of the material upon which it rests. The dominant sands, silts, and clays merge and intertongue laterally into alluvial-fan material or conglomerate.

All the beds, from clay to fanglomerate, are composed of the same kinds of material and differ from one another chiefly in texture and in the proportion of clay to rock fragments. The gradations in character are particularly noticeable in the northwestern part of the Artillery Mountains, along the upper part of Chapin Wash. In secs. 19 and 20 of that area most of the formation consists of red and brown soft, bricklike rock containing abundant angular fragments of felsite and pumice, obviously derived from the underlying volcanics, accompanied by grains of quartz, feldspar, and biotite, in a red clayey matrix. In most of the beds the fragments are less than half an inch across, but some beds contain fragments as much as 2 inches across, derived not only from the volcanics but also from the other rocks of the area. Some beds are massive boulder conglomerates, and a few contain rounded boulders of granite as much as 3 feet in diameter. Although the formation as a whole is relatively well-bedded in this area, the individual layers are not sorted, each bed consisting of angular fragments of various sizes in a matrix of iron-stained rock flour or clay. The measured section below (see pl. 5, measured sec. 1) illustrates some variations in the formation. This is the kind of material deposited by sheet floods—those momentary torrents laden with mud, sand, and rock, which they drop without sorting—and thus this part of the formation is best interpreted as a fanglomerate, its comparatively fine grain probably being due to the fact that all the rocks in the neighborhood are of kinds that disintegrate readily. Perhaps some of the big granite boulders were derived directly from the granite, but most of them were probably reworked from the boulder beds of the Artillery formation that crop out only 1,000 to 2,000 feet away.

Measured section of the Chapin Wash formation in the Artillery Mountains

	Thickness of bed Ft.	Thickness of bed In.	Total thickness Feet.
Quaternary (?) basalt.			
Angular unconformity.			
Chapin Wash formation:			
Tuffaceous conglomerate, poorly consolidated, with subordinate beds of tuffaceous sandstone. Generally gray, but some beds pink, red, and brown. Occasional knife edge streaks are manganiferous			85

	Thickness of bed Ft.	Thickness of bed In.	Total thickness Feet
Chapin Wash formation—Continued			
Manganiferous zone. Grades into gray conglomerate above and into brown bricky fanglomerate below:			
Alternating beds of unconsolidated conglomerate and sandstone, 1 to 2 feet thick and stained by manganese oxides like beds below but less so. About 10 feet away these beds are bouldery conglomerate	8	0	
Pumiceous conglomerate stained with manganese oxides	1	6	
Pumiceous sandstone with bedwise streaks of manganese oxides	1	4	
Tuffaceous gravel lensing sideways into sandstone; upper part blackened by manganese oxides		10	
Gray fine-grained pumiceous fanglomerate with bedwise streaks and lenses of manganese oxides	1	2	
Manganiferous pumiceous conglomerate, grading upward to sandstone. Pumice fragments altered to pink beidellite-montmorillonite clay	1	4	
Pumiceous fanglomerate like that of section below but gray and blackened by streaks of manganese oxides. Pumice fragments altered to pink beidellite-montmorillonite clay	1	8	
Gray tuffaceous clay marked with streaks of manganese oxides		11	
Chocolate-colored sandy clay		3	
			17
Fanglomerate like that of the 130-foot section below, in layers as thin as 2 inches. Includes a few gravelly or bouldery and gritty better-sorted beds. Upper 5 feet seems to be tuff altered to clay			158
Bouldery and fine-grained fanglomerate like the 130-foot section below			118
Boulder conglomerate without continuous layers of the fine-grained fanglomerate; average thickness of individual beds about 2 feet			35
Fanglomerate-conglomerate beds. Transitional with beds immediately below. A few beds in the basal part contain pebbles or scattered cobblestones; upward the pebble-bearing beds are increasingly more common, and the pebbles, cobblestones, and boulders become sufficiently abundant to form conglomerate beds. The beds between conglomerate layers are fine-grained, bricklike pumiceous fanglomerate (see text) with which the conglomerate layers interfinger. Pebbles and boulders include the various pre-Cambrian and Miocene (?) rocks and rhyolite like that in the boulder beds of the Artillery formation. Maximum thickness of individual fanglomerate beds is about 4 feet; thickness of conglomerate beds ranges from 1 to 4 feet and is commonly about 2 feet			130

	Thickness of bed Ft.	In.	Total thickness Feet
Chapin Wash formation—Continued			
Soft pink tuff, like basal layer; thin-bedded below, more massive above in beds 3 feet or less thick, showing depositional banding			28
Hard brown tuffaceous sandstone, well-sorted			1
Soft pink sandy tuff, with recognizable quartz, feldspar, and biotite; well-layered in beds 1 to 6 inches thick			10
			582

Angular unconformity.
Marmarized Paleozoic (?) limestone of the thrust sheet.

To the south, near the quarter corner between secs. 29 and 30, the conglomeratic parts are less common, and the formation consists mostly of fine-grained, well-bedded, red fanglomerate, showing all possible gradations between fanglomerate, clayey gritty sandstone, and well-laminated siltstone. Part of the formation contains beds of chocolate-brown clay and clay shale ranging from 1 inch to 3 feet in thickness. Measured sections 1 and 2, plate 5, show the variations in this area in somewhat more detail than is described here. The plant-bearing zone near the bottom of section 2 grades laterally into sandy, cherty, pumiceous limestone.

The fanglomerate beds extend southward to the place on the Maggie 24 claim where the outcrop of the overlying manganiferous beds is cut off by the Manganese Mesa fault. (See pl. 2.) At that place the manganiferous beds, which consist of sandstone and conglomerate, are underlain by the typical red and brown fanglomerate, but within the fanglomerate is a zone of finely laminated sandstone and siltstone containing paper-thin streaks of manganiferous limestone and limy clay. Southward the fanglomerate becomes pumiceous gritty sandstone, the zone of sandstone and siltstone becomes a zone of siltstone and clay, and the manganiferous limy partings are represented by richer streaks of manganese oxides, as much as 2 feet thick, in creamy limestone. Much of the lower part of the section in this general area consists of buff and cream-colored sandy limestone. Still farther southward the clays are gypsiferous and form thick beds predominating over the sandy layers, as shown in the following section. (See also pl. 5, sec. 3.)

Measured section of the Chapin Wash formation on the Minnesota Nos. 1 and 4 claims, Artillery Mountains

	Feet
Talus.	
Chapin Wash formation.	
Tuffaceous and pumiceous sandstone, grit, fine-grained conglomerate, and cobblestone-boulder beds, cemented with manganese oxides. Grades into beds below	18
Gray, thin-bedded pumiceous sandstone and grit with some conglomeratic layers. Identical with underlying unit except for absence of manganese	13
Gray to black pumiceous gritty arkose or arkosic sandstone; manganiferous	4
White to yellow and gray finely laminated, shaly vitric and crystal-vitric tuff; some laminae black with manganese oxides. Top part heavily manganiferous. Top part of manganiferous layer locally contains crystals of sand-calcite and nodular aggregates of barite crystals	3
Coarse-grained sandstone or arkose, with gravelly partings; thin-bedded at top	5
Interbedded tuffaceous sandstone and brown clay; some streaks of both sandstone and clay are manganiferous, manganiferous parts fading out laterally. Top is tuffaceous clay, separated from overlying layer by scour-and-fill surface	4
Gray tuffaceous conglomerate darkened by streaks of manganese oxides roughly parallel to the bedding	2
Brown fine-grained sandstone with wavy laminations, some of which are manganiferous	1
Brown, thin-bedded, interlayered nodular clay, siltstone, and tuffaceous sandstone; clay and siltstone very dark with manganese oxides and in part interlaminated with richer streaks of sooty black oxide. At top is a 1-foot layer of thin-bedded manganiferous gritty sandstone or arkose	6
Brown tuffaceous sandstone, cut by several faults having throws of 1 foot or less. Massive-bedded in lower part, thinner-bedded in upper part. Six inches of fine-grained conglomerate at base. A few thin manganiferous layers in upper thin-bedded part	7
Alternations of brown clay, tuff, and sooty manganese oxide. Basal layer consists of interlaminated sooty oxide and sandy tuff, with scour-and-fill surfaces at top and bottom. (See pl. 19 *B*)	5–6
Clay like that below but without gypsum. One or two streaks, 1 inch or less thick, are manganiferous; manganese oxide looks like original part of clay, making it black, just as iron oxides make the other clays brown or red	14
Light chocolate-colored clay with some silty parts, containing numerous bedwise and crosscutting streaks of gypsum 2 inches and less thick. The bedwise streaks are coarsely crystalline, with clay inclusions, and are generally crystallized in rosettes; the cross-cutting streaks are satin spar, usually pure. Gypsum most abundant in central part, with gypsum layers a few inches to 1 foot apart; lower 10 feet is gypsum-free. Includes several black manganiferous streaks 1 foot or less thick	46

Measured section of the Chapin Wash formation on the Minnesota Nos. 1 and 4 claims, Artillery Mountains—Continued

	Feet
Chapin Wash formation—Continued	
Chocolate-brown shaly clay, with occasional thin layers of brown siltstone, in part blackened with manganese oxides that seem to lie along the partings of the siltstone. Upper 3 feet contains several layers consisting of essentially pure sooty pyrolusite. Topmost layer is limy and gypsiferous	29
Clay, clay shale, and siltstone, thin-bedded. Partings in siltstone are manganiferous	9
Brown to white tuffaceous and gritty arkosic sandstone, with thin clay and silty partings	2
Fault, cutting out part of section.	
Thin-bedded sandstone and mudstone, in part conglomeratic, with some incoherent tuffaceous sand; much mica locally on bedding planes; splintery fracture; some beds hematitic. At top are two beds, 2 inches and 10 inches thick, of white to buff sandy limestone typical of much of the lower part of the formation for some distance north	22
Fault, cutting out part of section.	
Gray tuffaceous gravel and, in central part, interbedded brown tuffaceous sandstone and sandy clay or clayey tuff	12
	203±

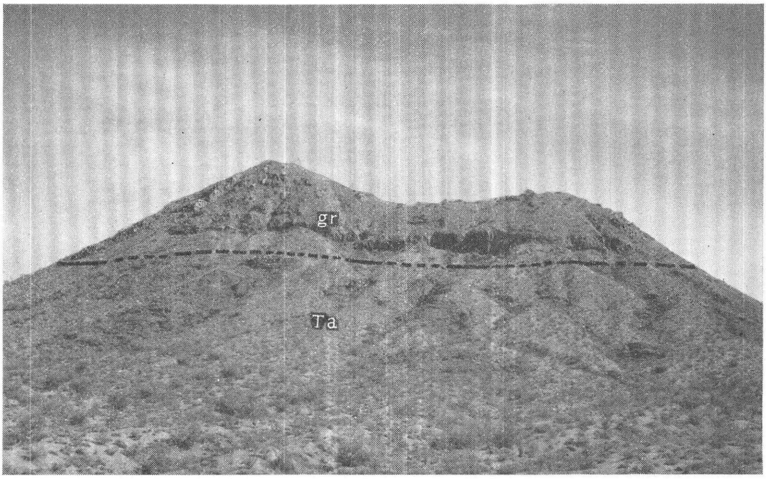
Angular unconformity.
Basalt member of the Artillery formation (early Eocene?).

In addition to the limestone beds already mentioned, others crop out at other horizons in widely separated places. The individual beds of limestone are generally less than 5 feet thick. The most prominent and persistent lie in a zone, perhaps as much as 40 feet thick, at and near the base of the formation along the upper part of Chapin Wash. Generally two limestone beds, but at some places one or three, are present in this zone. These limestone beds are shown on plate 2 as the "minor manganiferous members" below the main manganese zone between the Plancha Mountain fault and the north side of sec. 32. What may be the same zone was cut in diamond-drill hole No. 5, near the center of sec. 32. (See pl. 5.) In the southwest corner of sec. 12, T. 11 N., R. 13 W., the Chapin Wash formation includes a 50-foot zone containing four limestone beds whose stratigraphic position with relation to the Cobwebb basalt suggests that they lie at about the same horizon as the zone just described. A 10-foot zone of limestone intercalated with fine sandstone crops out in the manganiferous beds in section 21, on the southwest side of the valley; although there is some uncertainty about its exact stratigraphic position (see p. 31), this limestone may lie at about the same horizon as the plant-bearing limestone bed near the head of Chapin Wash (see p. 27).

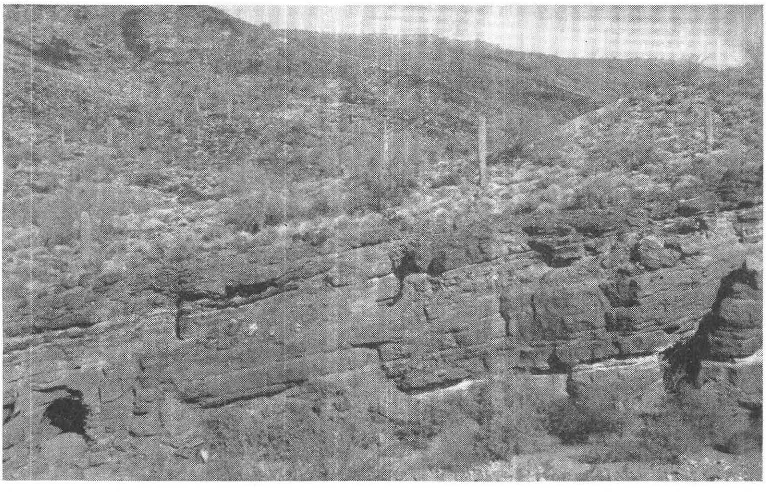
The Chapin Wash formation includes also several layers of vitric and crystal-vitric tuff, a fraction of an inch to 8 feet thick. They are most numerous in the sandstone-conglomerate zone that constitutes the principal part of the manganiferous beds in upper Chapin Wash and Maggie Canyon. (See pls. 4, 5, and 6*B*.) This zone of tuff beds extends almost to the Bill Williams River. Thin layers of tuff also crop out in the Chapin Wash formation on the southwest side of the manganese basin, in general association with the manganiferous zone there, probably at a horizon several hundred feet lower than the zone just described. Although some of the tuff may have been reworked from the Miocene (?) volcanics, at least a part of it settled from the air, for some layers contain loose, unoriented aggregates of glass fragments enclosing many unbroken delicate bubbles. In view of the general color of the formation, any layer of clean white tuff high in the section is probably of subaerial origin and composed of particles that had been thrown into the air by active volcanoes of the time.

The formation is generally cemented only with clay and with the iron and manganese oxides of the red and black layers respectively; but in Maggie Canyon and locally in Chapin Wash west of the Planche Mountain fault the upper part of the manganiferous zone, including the tuff members, is cemented with supergene manganese oxides, opal, chalcedony, and analcite. Crystals of sand-calcite also form a cement in many of the manganiferous beds and associated tuff beds. The cementation is more fully discussed under the heading "Manganese deposits," page 59.

The differences in the lithologic character of the Chapin Wash formation in different parts of its basin correspond in general with the lithologic differences in the older rocks from which the formation is derived. The fanglomerate along the upper part of Chapin Wash, already described, is one example of this relation; in fact, the arkosic nature of the sandstone and the abundance of pebbles and cobblestones of pumice, perlite, and granite in the conglomerate in upper Chapin Wash and throughout Maggie Canyon are connected with the presence of Miocene (?) pumice and felsite and pre-Cambrian granite in nearby outcrops. (See pl. 15*B*.) In parts of Burro Wash and elsewhere the Chapin Wash formation rests upon indurated beds of the Artillery formation, and there the lower part of the Chapin Wash formation, above a basal part of variable thickness, is dark-brown coarse-grained sandstone closely resembling underlying sandstone of the Artillery formation, though less indurated and lacking the usual manganese stain of the Artillery formation. Where the Chapin Wash formation rests on the less-indurated beds of the Artillery formation the contact is locally obscure because of the similarity between the beds above and below it, and in such places it is clear that the younger formation is derived from the older. At some places the basal conglomerate is 100 feet or more thick and is similar to, and evidently



A. PRE-CAMBRIAN GRANITE (*gr*) THRUST OVER THE BASALT MEMBER OF THE ARTILLERY FORMATION (*Ta*).



B. MANGANIFEROUS SANDSTONE OF THE CHAPIN WASH FORMATION ON THE CHAPIN NO. 17 CLAIM.

White layer is tuff. Bed of Chapin Wash in the foreground. The average manganese content of 17 feet of sediments here is 3.6 percent.

A. RED CONGLOMERATE AND SANDSTONE OF THE ARTILLERY FORMATION

Bed of arroyo, SW¼ sec. 20, T. 12 N., R. 13 W.

B. BASAL CONGLOMERATE OF THE CHAPIN WASH FORMATION BETWEEN THE PLANCHA MOUNTAIN FAULT AND THE NORTHWEST CORNER OF SEC. 3, T. 11 N., R 13 W.

derived from, bouldery beds of the Artillery formation upon which it rests or that crop out nearby. (See pl. 7*B*.) The red color of the Chapin Wash formation as a whole is probably inherited from the Artillery formation.

THICKNESS

The thickness of the Chapin Wash formation differs from place to place because of the unconformities at top and bottom. The greatest thickness measured is 582 feet (see pp. 25–27), and one of the drill holes cut through as much as 576 feet, but the actual maximum may be two or three times that. The uncertainties are partly due to the absence, in the exposures along the Rawhide Mountains, of horizon markers that would permit reliable correlation between the Rawhide and the Artillery Mountains, and partly to the danger of interpolating structure between isolated exposures of the incompetent beds.

The best approach to correlating between the Rawhide and Artillery Mountains, and thus to estimating the maximum thickness of the Chapin Wash formation, depends upon the stratigraphic interval between the manganiferous zone exposed in sec. 23, T. 11 N., R. 13 W., and the one extending northeastward from sec. 22 in the same township. On the basis of what is thought to be a reasonable interpretation of strike and dip observations, it is estimated that the top of the zone in sec. 22 is about 700 or 800 feet stratigraphically below the zone in sec. 23. Exposures of tuff between the manganiferous beds in sec. 23 and the Cobwebb basalt in sec. 13 suggest that the manganiferous beds in sec. 23 are roughly equivalent to those underlying the Cobwebb basalt at other places, and if that is so the top of the lower manganiferous zone would be about 1,000 feet below the top of the formation. The lower manganiferous zone is about 350 feet thick, and an unknown thickness in addition to this is covered by the wide band af alluvium between the Chapin Wash formation and the basement rocks in the Rawhide Mountains. The total thickness of the formation, therefore, is probably at least 1,350 feet and maybe greater.

UNCONFORMITY AT THE BASE

In sec. 29, along the upper part of Chapin Wash, a distinctive plant-bearing bed near the base of the Chapin Wash formation (see p. 27, and pl. 5, columnar sec. 2) crops out nearly parallel to the contact between that formation and the underlying pre-Cambrian rocks for a distance of about 2,000 feet. A short distance to the south (beyond a stretch in which relations are obscured by structure and by surface debris) a limestone zone about 125 feet higher stratigraphically than the plant-bearing bed, roughly parallels the old granite surface for as much as 1½ miles, being nowhere more than about 50 feet above it.

The fact that limestone is cut about 80 feet above the base of the formation in diamond-drill hole No. 5, half a mile southwest of the limestone outcrop (see p. 29 and pl. 5), suggests that this zone may be roughly parallel to the old surface for considerable distances down dip as well as along the strike. The limestone zone is missing to the east beyond the Plancha Mountain fault, but there the manganiferous beds, which are stratigraphically higher than the limestone, lie near and at the base of the formation and are parallel to the basal contact for about 2 miles in the lower part of Chapin Wash, and for a similar distance along Burro Wash. In each of these three general areas, where successively higher beds lie near the base of the formation, there seems to have been a broad flat area on the old surface—possibly a local valley or a bench on an extensive graded surface—a mile or more wide and 500 to 700 feet deep, with sides sloping upward from the flat part at an average of only 10° to 15°.

Thus along the 8 miles or more of contact exposed in the Artillery Mountains the Chapin Wash formation was deposited over extensive areas upon a rock-cut surface that cuts indiscriminately across all varieties of older rocks and strong structural features and that is nearly parallel to the bedding of the formation. The divergence from parallelism is in general only enough to permit successively higher beds to lap onto the old surface; only near the two ends of the mountain front is there any pronounced divergence.

In the Rawhide Mountains a distinctive bed that crops out essentially parallel to the basal contact for nearly 2 miles, and is nowhere more than 40 feet above it, indicates a similar condition there.

So far as known, however, this apparent parallelism between the bedding and the surface on which the formation lies exists only near the edges of the basin of deposition. The nature of the unexposed part of this surface is uncertain, except that fanglomerate grading out into finer material toward the center of the basin (see p. 27) might mean that high scarps were present at least originally.

ORIGIN

As proved by its lithologic character, the Chapin Wash formation was deposited in a closed basin or bolson. Several things collectively suggest that this basin was formed by faulting: (1) Normal faults older than the Chapin Wash formation parallel the trend of the basin; (2) later normal faults following the same trends border the original basin (see p. 44); (3) the smooth rock-cut surface at the base of the formation is analogous to present-day pediments, and the feathery overlap of the Chapin Wash formation onto this rock-cut floor is what is to be expected from the concurrent wearing back and burial of fault-block mountains draining to an aggrading playa;[22] and (4) the area is in a province where fault basins are common.

Because of the advanced stage to which degradation of the mountain blocks appears to have advanced, with resulting burial of possible related structures, it would naturally be hard to find any possible basin-and-range faults older than the Chapin Wash formation, but at least one such fault has been proved to exist, and there is evidence for others.

The one fault found that is demonstrably older than the Chapin Wash formation is in sec. 7, T. 11 N., R 13 W., in the Rawhide Mountains. This fault drops the Artillery formation against pre-Cambrian granite and is overlapped by the Chapin Wash formation. Some of the faults in secs. 18 and 19, due south of sec. 7, may likewise be of pre-Chapin Wash age, but their significance is obscured because of some post-Chapin Wash movement. In sec. 21, T. 11 N., R. 12 W., on the east side of the Bill Williams River, the Sandtrap conglomerate overlaps a fault scarp in the Artillery formation; although this relation proves only that the fault is older than the Sandtrap conglomerate, in view of the structural concordance between the Sandtrap conglomerate and the Chapin Wash formation, the fault is probably older than the Chapin Wash formation as well. Other pre-Chapin Wash faults are suggested by the presence of fanglomerate in the Chapin Wash formation, grading out into finer sediments; additional evidence is provided by barite-fluorite stringers stained with malachite and wulfenite(?) in the Artillery formation between Burro and Chapin Washes, for this kind of mineralization is not known in fissures younger than the Chapin Wash formation.

Although the bolson deposits are 3 to 5 miles wide, the graben block in which they are inferred to have been deposited was probably less than 2 miles wide, the greater width of the fill being due to overlap beyond the edge of the graben. The exact position of the faults or fault zones bordering the graben is not known, but at least those bordering the Artillery Mountains would lie along a northwestward-trending line somewhat southwest of diamond-drill hole No. 5, which is on the back-worn slope.

AGE

The palm roots found in one zone in the Chapin Wash formation were not helpful for age assignment, but a fragment of a jawbone found by Webber in the lower beds on the Minnesota No. 2 claim (see pl. 2) was reported upon by C. L. Gazin as follows:

> A fragmentary lower jaw, with teeth broken away, of a large canid about the size of a modern wolf. Age apparently upper Tertiary or Pleistocene.

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[22] Davis, W. M., Sheetfloods and streamfloods: Geol. Soc. America Bull., vol. 49, pp. 1337–1416, 1938. This paper includes a bibliography on the general subject of the weathering of fault block mountains.

The formations of the manganese basin are assigned to the Pliocene because they rest with angular unconformity upon Miocene(?) volcanic rocks and are overlain with angular unconformity by early Pleistocene(?) basalt. As the Chapin Wash formation is the oldest of the formations of the manganese basin, it is tentatively assigned to the lower Pliocene.

COBWEBB BASALT (EARLY PLIOCENE?)

The Cobwebb basalt is named from its exposure on Cobwebb Hill, in upper Chapin Wash. (See pls. 2 and 4.) The name is used here for the first time.

The Cobwebb basalt lies conformably upon the Chapin Wash formation, but it overlaps onto the Artillery formation along Burro Wash, where the Chapin Wash formation thins out. An erosional unconformity separates it from the overlying Sandtrap conglomerate, which locally cuts out the basalt. The Cobwebb basalt crops out along most of the Artillery Mountains side of the manganese basin, especially along Chapin and Burro Washes, but it is nowhere exposed along the Rawhide Mountains side.

Although in its largest exposures along upper Chapin Wash the Cobwebb basalt tends to form buttes, in general it is beveled by the old pediment surface carved across the several formations of the manganese basin (see p. 10) and rises only here and there in low swells above the Chapin Wash and Sandtrap formations. Its distribution with relation to Chapin and Burro Washes suggests that it helped determine the position of these washes.

The maximum thickness of the Cobwebb basalt is about 250 feet and is shown at the two larger exposures in the upper Chapin area. (See pl. 2.) The outcrop of the thick part is somewhat less than a mile long; the basalt thins rapidly along the strike and is only 10 to 20 feet thick where it is cut off on the northwest by the Manganese Mesa fault and on the southeast by the Plancha Mountain fault. Southeast of the Plancha Mountain fault its thickness, except where it is locally cut out by the Sandtrap conglomerate, seems fairly uniform at 90 to 125 feet. The thickness appears fairly uniform also along Burro Wash, where, however, it hardly exceeds 30 feet.

The Cobwebb basalt is a hypersthene(?)-augite-olivine basalt. Most of the rock is gray to brown, fine-grained to aphanitic, and contains only a few vesicles, but in the exposure where it is relatively thick the upper part is black, mostly aphanitic, and highly vesicular. Some vesicles are quite clean or lined with only a thin crust of caliche; others contain black calcite, white calcite, quartz, chalcedony, opal, and manganese oxides. Parts of the dense phase seem highly altered, weathering to brown and brownish-green gravelly sand and to the familiar "niggerheads" so common in basalts. Except that the vesicular rock is the more glassy, the dense and vesicular phases are mineralogically alike. A few medium-sized phenocrysts of brown or black plagioclase can be recognized in the hand specimen, and most hand specimens of the dense rock show a grain or two of quartz, evidently foreign inclusions.

The plagioclase phenocrysts and the microlites in the groundmass are labradorite, at least as calcic as An_{55}, and zoned labradorite-andesine having a maximum zonal range from An_{65} to about An_{40}. The color of the plagioclase phenocrysts is due to much glass intergrown with, or included in, the plagioclase. (See pl. 8.) Associated with the glass in some of the plagioclase phenocrysts are a few grains of augite and olivine, and some augite phenocrysts are similarly "intergrown" with glass. The rock also contains many grains of a colorless mineral that resembles the augite in ordinary light but has parallel extinction for all orientations. Some grains of this mineral have cores, and many have rims, of augite. Low birefringence and absence of pleochroism imply enstatite, but the mineral is optically negative, like hypersthene. Most of the olivine, which is present only in the groundmass, and in some thin sections virtually all the olivine, is replaced by a soft red and brown mineral of high birefringence, perhaps iddingsite. A little calcite and fibrous zeolite partly replace the glass.

Except for some differences in degree of freshness, the Cobwebb basalt is essentially identical, megascopically and microscopically, with parts of the Quaternary (?) basalt and with the basalt member of the Sandtrap conglomerate. Consequently, unless the stratigraphic relations of any particular basalt exposure are clear, there may be some uncertainty about its proper assignment. This is particularly true of the lower part of the basaltic lavas capping the mesas. For example, in some of the drill holes on Manganese Mesa the base of the lava lies at the same stratigraphic interval above the tuff members of the Chapin Wash formation as the Cobwebb basalt (see pl. 5, drill holes 3 and 5), but there is no way of distinguishing between possible Cobwebb basalt and a younger basalt lying upon it.

Because of its conformity with the underlying Chapin Wash formation and its unconformity with the overlying Sandstrap conglomerate, the Cobwebb basalt is thought to belong to the same geologic epoch as the Chapin Wash formation, and therefore to be tentatively of lower Pliocene age.

SANDTRAP CONGLOMERATE (LATE PLIOCENE?)

DEFINITION

The Sandtrap conglomerate is named from Sandtrap Wash, along which it is typically and extensively exposed. The name is used here for the first time.

The formation rests with erosional unconformity upon the Cobwebb basalt, or, where the basalt is absent, upon the Chapin Wash formation, and it extends well beyond the limits of both to rest with angular unconformity upon the Artillery formation and the pre-Cambrian rocks. It is overlain unconformably by the Quaternary (?) basalt and Quaternary alluvium.

The Sandtrap conglomerate cuts out practically all the Chapin Wash formation along the Rawhide Mountains on the southwest side of the basin, so that the unconformity must there have a relief of at least 1,300 feet. (See p. 31.) Along the Artillery Mountains on the northeast side of the basin, however, the fairly uniform thickness of the Cobwebb basalt indicates that there the relief on the unconformity must be small; the local relief was hardly more than 125 feet, and the maximum relief, assuming that the original thickness of the Cobwebb basalt was moderately uniform, can hardly have exceeded 250 feet.

The lower beds of the Sandtrap conglomerate, where the formation rests on the Cobwebb basalt, locally resemble the playa deposits in the Chapin Wash formation (see p. 37), and there may be an unconformity of considerable relief between those beds and the typical conglomerate, but no such break could be recognized.

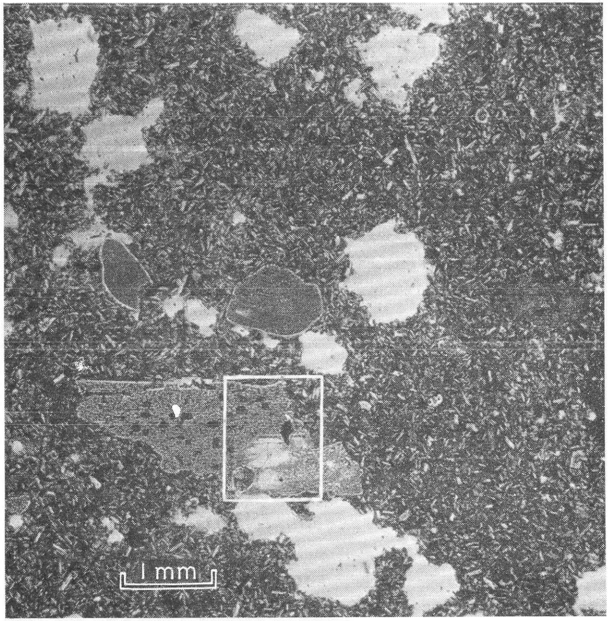
DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Sandtrap conglomerate in the area covered by this report occupies mainly the central part of the valley between the Artillery and Rawhide Mountains. It crops out also in a strip on the east side of the Bill Williams River. The formation extends westward far beyond the area mapped, and some isolated exposures occur to the east, as at Date Creek, where it underlies Quaternary (?) basalt and Quaternary valley fill.

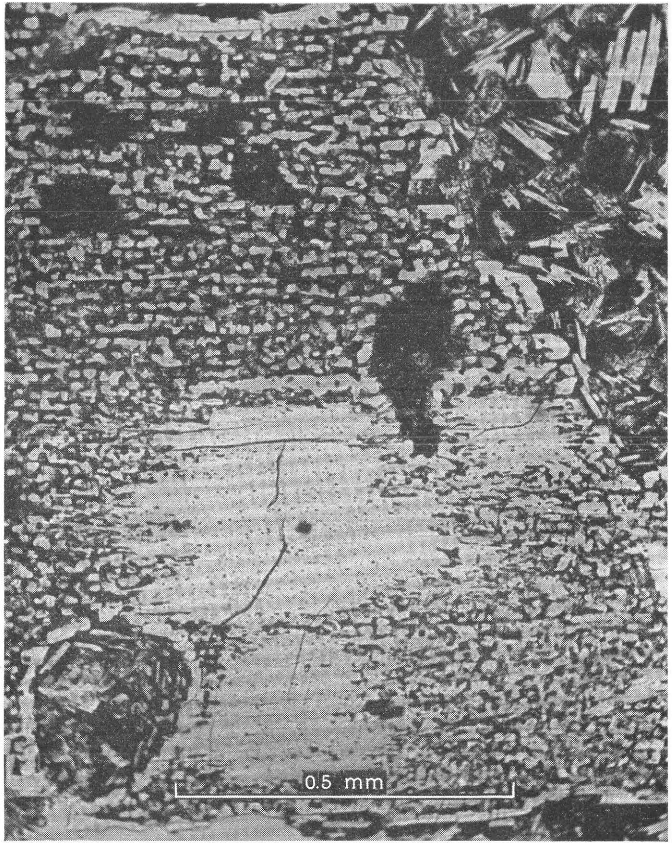
Topographically the Sandtrap conglomerate constitutes most of the dissected pediment between the Artillery and Rawhide Mountains (see p. 10).

LITHOLOGIC CHARACTER

The Sandtrap conglomerate is mostly a light-red to dark-red rock in which most of the pebbles are between a quarter of an inch and 6 inches in diameter. It contains a few boulders as much as 6 feet in diameter. The pebbles are angular to well rounded and in general are poorly sorted. As seen from a distance the conglomerate appears fairly well bedded, but the bedding is discontinuous and the formation as a whole tends to be massive. The bedding is marked by streaks of clay, sand, and fine gravel. Locally there are beds up to 4 feet thick that consist of well-bedded and well-sorted sandstone and clay. A typical exposure is illustrated by plate 12*A*.

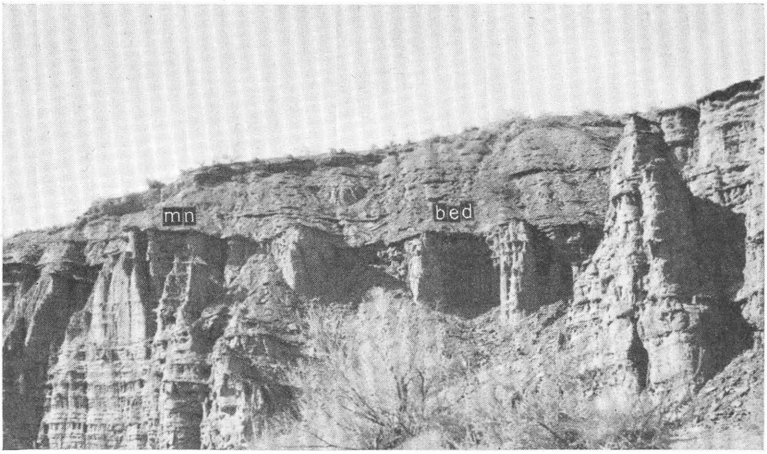


A



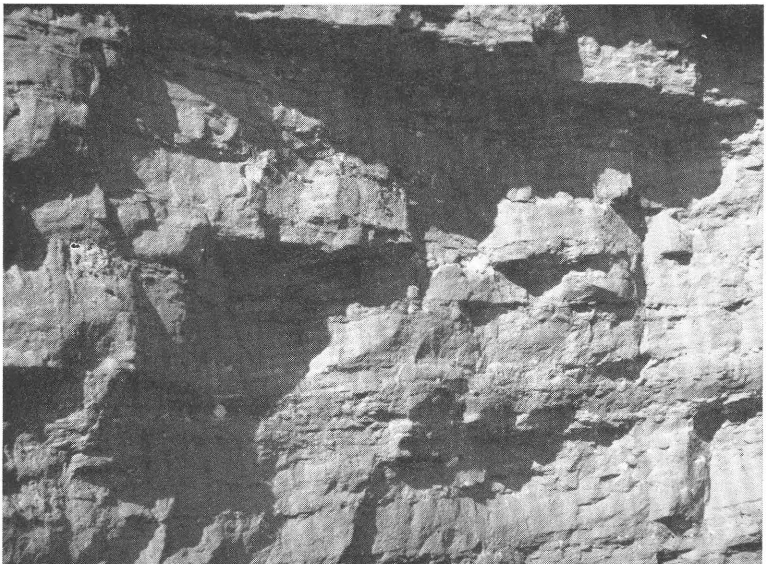
PHOTOMICROGRAPHS OF THE COBWEBB BASALT. B

Irregular white spots in *A* are vesicles. *B* is an enlarged view of part of the large feldspar phenocryst in *A*, showing the odd "intergrowth" of glass and feldspar.



A. TYPICAL EXPOSURE OF THE MANGANESE-BEARING CHAPIN WASH FORMATION, SOUTH WALL OF CHAPIN WASH, SEC. 10, T. 11 N., R. 13 W.

All light-brown clay, siltstone, and sandstone. *mn*, Manganiferous bed. Contact with the Artillery formation is at the bed of the wash.



B. SANDTRAP CONGLOMERATE, WALL OF CHAPIN WASH, NEAR SOUTHWEST CORNER OF CHAPIN NO. 15 CLAIM.

Typical of the fine-grained beds that constitute the basal part of the formation at most places on the northeast side of the manganese basin.

The formation is evidently derived from the slopes adjoining the basin in which it lies, for all the rocks exposed on those slopes are represented by pebbles in the conglomerate, and the abundance of any given kind of rock in the conglomerate is roughly proportional to the area of its outcrops on the bordering slopes. Particularly striking is the wide distribution of manganiferous pebbles, which were derived from the manganiferous beds of the Chapin Wash formation.

Along most of the northeast side of the basin the bottom part of the Sandtrap conglomerate consists of red to pink sandstone, siltstone, and clay, all in part gravelly and very much resembling the Chapin Wash formation below. (See pl. 9*B*.) The thickness of this fine-grained phase is variable, but the maximum may be at least 400 feet. The resemblance of the fine-grained phase to the Chapin Wash formation is so great that the contact between the two is obscure in those places where the Cobwebb basalt is absent. At such places the contact was mapped on the basis of the tuff layers of the Chapin Wash formation. Similar but less difficulty was experienced in locating the contact where, as in some places along the southwest side of the valley, the Sandtrap conglomerate is in contact, or nearly so, with conglomerate beds in the Chapin Wash formation.

A basalt flow in the Sandtrap conglomerate crops out along Sandtrap Wash west of Maggie Canyon. The flow is relatively thin in the eastern part of the exposure but thickens tremendously northwestward, where it constitutes the westward extension of Manganese Mesa and forms a continuous body with the apparently younger basalt capping the eastern part of the mesa. It is partly dense and partly vesicular. It resembles the Cobwebb basalt so closely that the petrographic description of that rock given on pages 34–35 can be applied to it without essential modification.

THICKNESS

The exposure showing the greatest thickness of Sandtrap conglomerate is at the reentrant along the upper part of Burro Wash, where 1,500 feet or more of typical beds is exposed. (See pl. 1, sec. A–A′.) Measurable thicknesses of 300 to 400 feet crop out near the south end of Plancha Mountain and near the south end of Manganese Mesa. (See pl. 2.) In the main part of the valley the thickness is uncertain because the structure is incompletely exposed, but it is estimated to range from 300 to possibly 2,000 feet. (See pl. 1, structure sections.) The original thickness of the Sandtrap conglomerate must have been at least 2,800 feet, for it would have been equal to the thickness of 1,500 feet or more exposed at Burro Wash above the Cobwebb basalt plus the 1,300 feet that fills in the basal unconformity below the horizon of the Cobwebb basalt (see p. 36).

ORIGIN

The change from an aggrading playa, in which the Chapin Wash formation and Cobwebb basalt were deposited, to a degradational valley, from parts of which 1,300 feet or more of the playa beds were eroded, may have been due either to rejuvenation of the drainage by renewed structural movements in the neighborhood, or to capture of the playa by a through-flowing stream.

Movements sufficient to lead to 1,300 feet or more of erosion should have caused recognizable deformation of the playa deposits and have led to an angular unconformity between the Chapin Wash formation and the Sandtrap conglomerate. In the absence of such an unconformity, clearly recognizable, it is inferred that the erosion was due to capture of the basin by a through-flowing stream. If so, the Sandtrap conglomerate was probably deposited in the flood plain of the stream and as fan wash on the tributary slopes.

CORRELATION AND AGE

The formation here called the Sandtrap conglomerate was originally included by Lee [23] in what he called the Temple Bar conglomerate. Lee,[24] however, apparently applied this name to most of the deformed valley deposits of northwestern Arizona, including not only the Sandtrap conglomerate but also the playa deposits represented by the Chapin Wash formation and the much older deposits described in this report as the Artillery formation.

The Sandtrap conglomerate is tentatively referred to the upper Pliocene, because it is the youngest of the three supposedly Pliocene formations in the manganese basin and is separated from the other two by an erosional unconformity.

QUATERNARY(?) BASALT

Basalt of probably early Pleistocene age caps the eastern part of Manganese Mesa and the small outlying mesa called Plancha Mountain and is also exposed in the benchland and desert flat south of the Santa Maria River.

The basalt rests with angular unconformity upon a fairly smooth erosion surface that truncates most of the older formations. The local irregularities at its base are no more than 100 feet high, although some of the old hills and valleys have steep slopes. The basalt itself has been beveled by later erosion, particularly south of the Santa Maria River, and at most of these places it is overlapped by Pleistocene gravel.

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[23] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, p. 17, 1908.

[24] Idem, pl. 5, pp. 51–56.

Within the area mapped the basalt is thickest on the mesa northwest of Maggie Canyon, where the thickness is 350 feet or more. In the part of Manganese Mesa where the basalt constitutes an overburden to the manganese deposits that will influence the choice of a mining method, the thickness ranges roughly from 70 to 145 feet. The variations in thickness as determined by drilling on this part of the mesa are indicated on plate 10.

The Quaternary (?) basalt includes several flows, which individually seem not more than 50 feet thick. The rock is massive to vesicular. Some of the vesicles are quite clean, whereas others contain quartz, chalcedony, or calcite. All the flows are glassy olivine-bearing basalt, apparently identical mineralogically and texturally with the Cobwebb basalt and with the basalt member of the Sandtrap conglomerate, even to the unusual "intergrowths" of glass and feldspar. (See pl. 11.) All are porphyritic, containing a few phenocrysts of plagioclase, and, in some specimens, augite and hypersthene (?) as well, in a groundmass composed of plagioclase laths, augite, hypersthene (?), olivine, and brown to black glass; in some vesicular specimens the glass constitutes as much as 40 percent of the rock. The plagioclase includes labradorite and grains zoned about An_{65-40}. Part of the olivine is pseudomorphically altered to a red-brown mineral that may be iddingsite. One thin section contains some indistinct grains of what may be hornblende; another contains a cluster of quartz grains surrounded by a halo of augite crystals embedded in brown glass.

QUATERNARY ALLUVIUM

Alluvium of two ages is present—an early alluvium related to an aggrading stage of the Bill Williams River and its tributary streams and arroyos, and Recent sand and gravel in the stream channels, with which are included extensive talus deposits. (See pl. 12*B*.) There may be some small landslides also. The alluvium is shown on the geologic maps (pls. 1 and 2) only where the character of the bedrock could not be safely inferred on the scale used.

The early alluvium consists of the gravel, sand, and clay constituting the top part of the valley fill in the desert area east of the Bill Williams River and covering the pediments west of the river. On the west side of the river this alluvium is thickest and most conspicuous where it caps the Sandtrap conglomerate and Chapin Wash formation in the river bluffs. The early alluvium is everywhere being dissected and stripped away by present-day erosion.

A typical exposure of early alluvium is shown on plate 13*A*.

STRUCTURE

STAGES OF DEFORMATION

Six periods of structural deformation since about the beginning of the Laramide revolution have been recognized in the Artillery Mountains area, and a seventh period may be inferred. There was also some deformation before the Laramide revolution, of course, involving particularly the pre-Cambrian rocks, but inasmuch as it has no bearing on the manganese deposits it is not discussed in this report.

The sequence of the several periods of deformation is not entirely clear, but for purposes of description the following order is assumed, beginning with the oldest:

(1) Normal faulting and the development, possibly related to it, of the basin in which the Artillery formation was deposited.
(2) Thrust faulting.
(3) Normal faulting.
(4) Normal faulting and the probable related development of the manganese basin.
(5) Inferred movements of uncertain nature.
(6) Folding and faulting of the rocks of the manganese basin.
(7) Pleistocene faulting.

Except the one fault that proves the existence of the third period, all the major faults and folds and most of the minor ones, of whatever period, trend westward to northwestward.

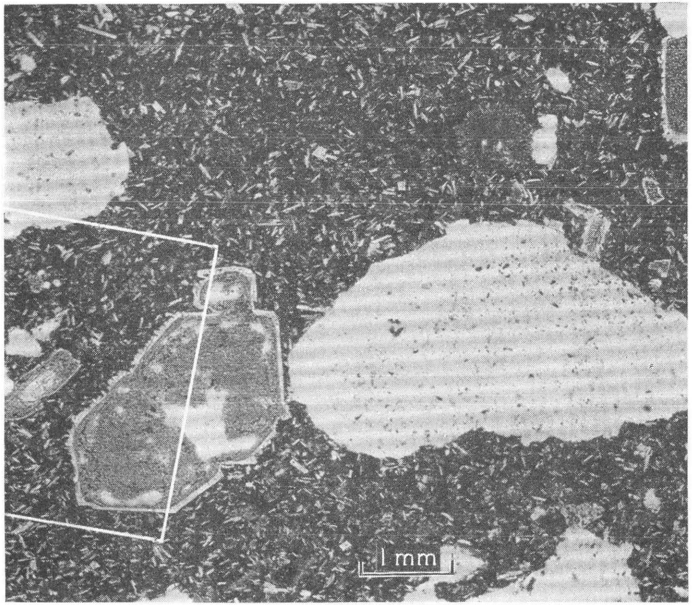
FIRST PERIOD

The Artillery formation was deposited in a northwestward-trending valley that may have been related to normal faulting of pre-Artillery age. The origin of the valley, the deposition in it of the Artillery formation, and some faulting contemporaneous with deposition of the Artillery formation are discussed on pages 20, 21.

SECOND PERIOD

In the central spur of the Artillery Mountains a thrust fault brings pre-Cambrian and Paleozoic (?) rocks on top of rocks high in the Artillery formation. (See pls. 3*A* and 6*A*.) In secs. 20 and 29, T. 12 N., R. 13 W., the eroded trace of the fault is overlapped by the Miocene (?) volcanics and by the Chapin Wash formation. The fault may be partly contemporaneous with the Artillery formation. (See p. 21.)

The fault has been traced from sec. 20 southeastward nearly to the Bill Williams River, and throughout this distance the thrust plate lies at or very close to the horizon of the basalt in the Artillery forma-



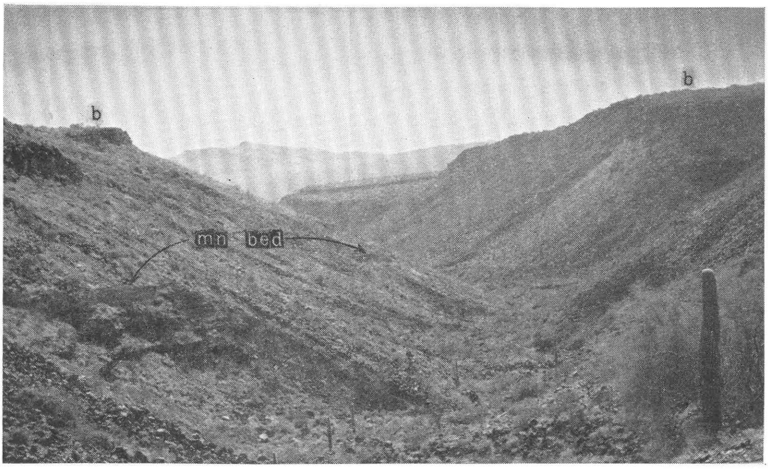
A

PHOTOMICROGRAPHS OF QUATERNARY(?) BASALT.

B

B is an enlarged view of part of *A*, showing details of the "intergrowth" of glass and feldspar. Large irregular white spots are holes and vesicles.

A. TYPICAL EXPOSURE OF THE SANDTRAP CONGLOMERATE, NEAR SANDTRAP WASH, SEC. 36, T. 12 N., R. 14 W.



B. VIEW DOWN MAGGIE CANYON FROM THE ADIT ON THE MAGGIE NO. 13 CLAIM.

Shows how effectively the talus slopes conceal large areas of bedrock and also the resemblance between the basalt cliffs (*b*) and some of those formed by the hard manganiferous beds (*mn*).

tion. Intricate deformation of the Artillery formation in the angle between the Bill Williams and Santa Maria Rivers suggests that the thrust may extend much farther eastward than it was possible to map it, and the fault may thus be at least 10 miles long.

The thrust plane seems to dip in general southwestward at a low, but variable, angle that does not average more than 10° over any considerable distance. As suggested by the position of the klippe of Paleozoic (?) limestone a little north of the main thrust mass, the thrust surface may be gently rolling and have an average dip virtually horizontal over distances of a mile and a half or more. (See pl. 1, sec. *B–B′*.) The thrust was folded and faulted during later periods of deformation; figure 2 shows the degree to which it is folded at one locality. Locally, as in secs. 28 and 29, T. 12 N., R. 13 W., the

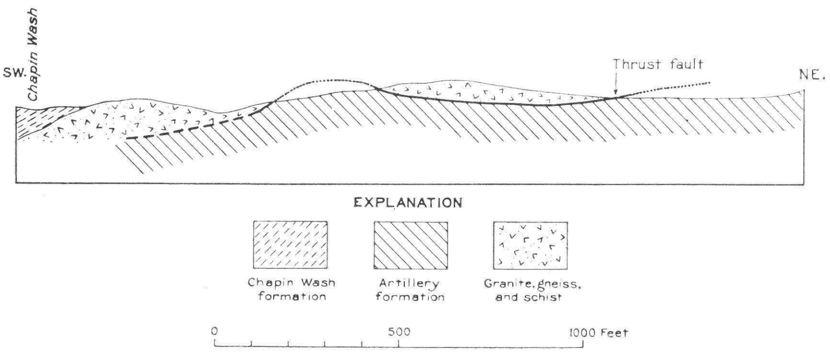


FIGURE 2.—Cross section through the southeast corner of sec. 29, T. 12 N., R. 13 W., showing folding of the thrust fault.

fault is composed of several members that include subordinate slices of rock between them, but at most places there seems to be a single plane of movement. At some places the fault is a fairly sharp surface; at others it contains brecciated and pulverized granite, gneiss, and sedimentary rocks mixed together on a large scale.

The Artillery formation immediately below the thrust is cut by many small faults and is pushed into many small folds, so disposed that the average dip of the formation is almost parallel to the thrust plane. (See pl. 13*B*.) In the thrust plate itself the Paleozoic (?) limestone at places is intensely brecciated, marmarized, and intricately folded and shows evidence of flowage. The structure is so complicated that no average attitude was recognized on the scale on which the formation was mapped. The granite and gneiss in the thrust sheet are intensely crushed at the fault, and in places this crushed or brecciated zone is more than 350 feet thick. This breccia and similar breccia of Paleozoic (?) rocks are the source of the boulders of breccia so common along the upper part of Chapin Wash.

The direction of the thrust and the extent of movement are not known. The fact that the Paleozoic (?) rocks of the thrust plate are metamorphosed and that similar metamorphosed rocks crop out in the Buckskin Mountains hints that the thrust may have come from the Rawhide-Buckskin area, and the fact that the thrust fault now passes below the surface southward might support this idea.

THIRD PERIOD

At Artillery Peak a normal fault brings basal arkose of the Artillery formation against pre-Cambrian granite and duplicates part of the Artillery formation. The stratigraphic throw of this fault on the south side of the peak is at least 500 feet. The fault is older than the Miocene (?) lava that caps the peak (see pl. 1, sec. *B–B′*, and pl. 3*B*), and therefore is similar in age to the thrust fault, but nothing is known of its relation, either structural or in point of time, to the thrust.

Many smaller faults also duplicate beds of the Artillery formation near Artillery Peak and may or may not be of the same age as the one at the peak.

FOURTH PERIOD

The manganese basin, in which the Chapin Wash formation was deposited, was a closed basin formed by faulting of basin-and-range type. The reasons for this conclusion are discussed on pages 32–33.

The manganese basin had the same trend as, and lay within the limits of, the earlier basin in which the Artillery formation was deposited.

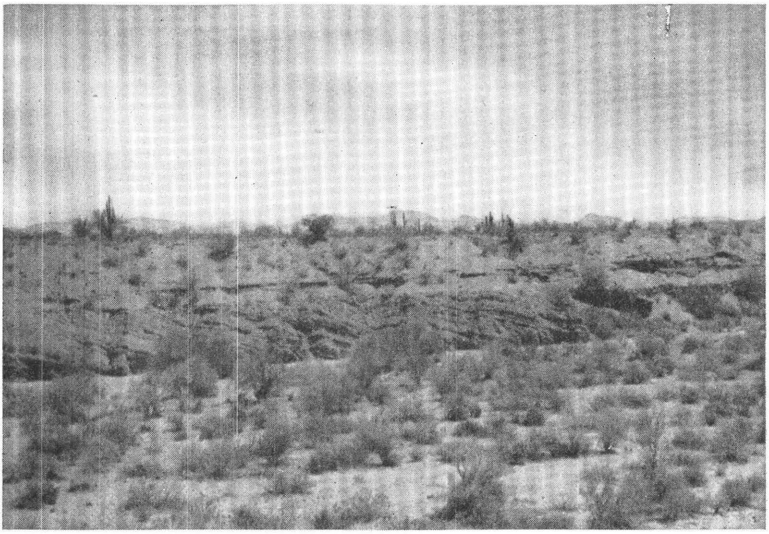
FIFTH PERIOD

As stated on page 38, the stream activity within the manganese basin changed from aggradation to degradation after extrusion of the Cobwebb basalt. Reasons were given for inferring that this change, and the resulting deep erosion that preceded deposition of the Sandtrap conglomerate, were caused by stream piracy. The cause of the piracy is unknown; conceivably climatic changes may have been a factor, but as this general period was one of structural unbalance it is probable that the chief cause was structural, presumably regional tilting or faulting in another part of the drainage area.

SIXTH PERIOD

FOLDS

The Chapin Wash formation, the Cobwebb basalt, and the Sandtrap conglomerate have been forced into a group of folds that trend northwestward, parallel with the trend of the basin in which these formations were deposited. The present structure is a shallow composite syncline made up of roughly parallel synclinal and anticlinal



A. EARLY ALLUVIUM CAPPING TILTED BEDS OF THE CHAPIN WASH FORMATION.

North bank of Sandtrap Wash, near the mouth.

B. OVERTURNED FOLD IN A LIMESTONE MEMBER OF THE ARTILLERY FORMATION, MINNESOTA NO. 1 CLAIM.

Typical of the details of some of the folding below the thrust fault.

zones, each of which is itself largely a composite fold. (See pl. 14.) Many of the folds have curved axes. Few are continuous over any great distance, and apparently none extends throughout the length of the basin. The most persistent fold appears to be the syncline whose western limb is now partly followed by the Manganese Mesa fault.

Most dips are less than 20°, but some are as high as 70°. They are persistently steeper along the southwest side of the basin than elsewhere. Not all the dips, however, are entirely the result of deformation, for the deposits, particularly the Chapin Wash formation, probably had an original synclinal structure because of original basinward dips, possibly as high as 7°, on the margins of the aggrading basin.[25]

The folding of the thrust fault (see p. 41) presumably occurred in part during this sixth period.

FAULTS

Some of the folds, such as the large anticline east of the Rawhide mine, involve not only the basin deposits but also the Artillery formation and pre-Cambrian granite and gneiss. Folding in sedimentary rocks takes place by slipping of the beds past one another, and such rocks as granite and gneiss do not yield in this manner unless they are in comparatively thin bodies interlayered with sediments. Therefore, where the stronger folds in this area involve a core of pre-Cambrian rocks, the pre-Cambrian rocks presumably yielded by faulting. Some of the indurated parts of the Artillery formation probably yielded in like fashion, for these indurated parts are relatively competent. For example, the two minor faults near the southeast end of the large anticline just mentioned, near its crest, enclose a small graben of indurated rocks of the Artillery formation, but neither fault extends very far into the incompetent beds of the Chapin Wash formation on the flanks.

A different type of faulting, also related to the folding of the beds of the manganese basin, consists of local movement on the unconformity at the base of the Sandtrap conglomerate. (See pl. 14.) In some places the plane of movement is almost knife-sharp; in others it is marked by massive or laminated clay ranging in thickness from less than an inch to as much as 5 feet. Movement along this surface obviously has been irregular, for the depositional contact is undisturbed close to places where there has been movement. It would seem that during folding the fairly massive Sandtrap conglomerate adjusted itself to the underlying rocks by slipping here and there along

[25] Davis, W. M., Sheetfloods and streamfloods: Geol. Soc. America Bull., vol. 49, p. 1363, 1938.

the contact. Additional movement may have occurred along this contact during the next period of deformation.

SEVENTH PERIOD

The folded beds on each side of the manganese basin are cut by northwestward-trending normal faults. The two sets converge toward the west, tending to form a single V-shaped group that encloses the valley area.

The faults along the Artillery Mountains on the northeast side of the basin are fairly well exposed. From west to east the more significant ones are the Rudy fault, the Manganese Mesa fault, the Common Corner-Plancha Mountain fault zone, and the Price fault zone. (See pls. 1 and 2.) The Rudy fault marks the western limit of the exposures of the Chapin Wash formation and of the bedded manganese deposits on the northeast side of the basin. Its maximum throw, as measured by the offset of the Quaternary (?) basalt, is about 300 feet. The Manganese Mesa fault is a strike fault that partly follows the axis of one of the major synclines. The abundant slide rock skirting Manganese Mesa conceals the fault for a large part of its length, but there are enough exposures to locate the fault zone within fairly close limits. In the area where the fault displaces the manganiferous beds, its throw, as measured on the Cobwebb basalt and on the tuff and limestone members of the Chapin Wash formation, is about 250 feet. The throw diminishes northward at an average rate of about 100 feet for each 1,000 feet of strike length, and the fault ends about half a mile beyond the line of the geologic section through drill hole 11 and point C. (See pl. 2.)

The Plancha Mountain fault, whose scarp forms the eastern face of Plancha Mountain, has a stratigraphic throw of 500 to 600 feet, as measured against the Cobwebb basalt in the plane of section *C–C′*, plate 1.

The Price fault must have a stratigraphic throw of more than 1,500 feet, for it brings at least that thickness of Sandtrap conglomerate against the Artillery formation. (See pl. 1, sec. *A–A′*.) Along the line of section *D–D′*, plate 1, the Price fault brings the lower manganese horizon of the Chapin Wash formation against the upper manganese horizon and against the Cobwebb basalt, and thus at that place has a stratigraphic throw of about 1,000 feet. (See p. 31.) Along the line of section *E–E′*, plate 1, the throw is about 400 feet, as measured on the Cobwebb basalt.

Four reverse faults of relatively small throw have been recognized on this side of the basin. The most prominent, on Chapin Nos. 2 and 3 claims (see pl. 2), has a maximum stratigraphic throw of about 125 feet, for it brings the Cobwebb basalt against the manganiferous beds of the Chapin Wash formation. In sec. 19, T. 12 N., R. 13 W., each of two closely spaced reverse faults offsets the manganiferous beds and the overlying basalt about 10 feet. A fourth reverse fault, having a stratigraphic throw of about 50 feet, is exposed on the east bank of Burro Wash in sec. 12. (See pl. 15 *A*.)

The faults on the northeast side of the basin are arranged somewhat en échelon and produce a group of horsts, grabens, and step-fault blocks. They convert what was once a fairly continuous body of manganiferous sediments into several blocks that, if they were to be mined, would have to be treated as separate bodies. These are known locally as the Maggie (or Manganese Mesa) block, between the Rudy and Manganese Mesa faults; the Upper Chapin block, between the Manganese Mesa fault and the Common Corner-Plancha Mountain fault zone; the lower Chapin block, between the Plancha Mountain and Price faults; and the Price block, northeast of the Price fault.

The fault pattern suggests that all the faults are of the same age, and so, as some of them involve the early Pleistocene (?) basalt and yet are older than the pediment gravels of late Pleistocene age, the whole set is considered to be early to middle Pleistocene.

On the southwest side of the basin the latest faults are not well exposed. Though some of the faulting there represents renewed movement along old faults (see pp. 20, 23), the latest movement was later than the Sandtrap conglomerate but earlier than the pediment gravel. This dating is about the same as for the set on the northeast side of the basin, though not quite so closely bracketed. There was, then, comparatively recent and perhaps contemporaneous faulting along both sides of the basin, inferentially in response to renewed settling of the graben block. This settling may have caused the curvature of some of the fold axes, and possibly a few of the folds themselves.

INTERPRETATION OF GEOLOGIC HISTORY

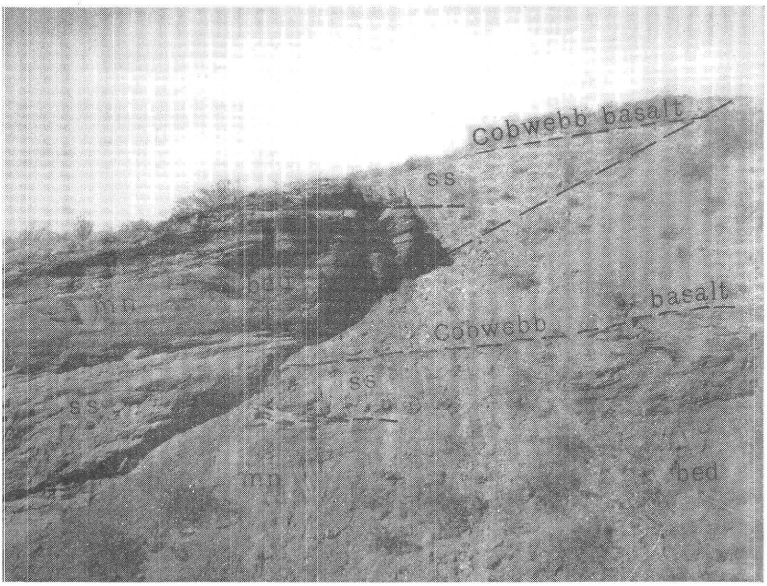
Although the pre-Cambrian rocks in the Artillery Mountains region record processes of sedimentation, igneous activity, and orogeny, these rocks were given little attention in the present study. Similarly, very little is known about the Paleozoic (?) rocks. They contain contact-metamorphic silicates, but the igneous rocks that presumably caused the metamorphism have not been recognized, unless they are some of the monzonitic-appearing rocks in the Rawhide and Buckskin Mountains. There is no record of the Mesozoic in the area studied.

The geologic record becomes more complete at about the beginning of the Tertiary. From that time on the history of the area is primarily one of recurrent faulting and the filling of closed structural basins that were produced by faulting. Volcanic activity accompanied these events, beginning with minor eruptions in what was probably the Eocene, culminating in widespread eruptions that apparently dominated what was probably the Miocene, and then recurring off and on until probably early Pleistocene.

The recognizable Tertiary record begins with a northwestward-trending valley, or closed basin, of considerable though unknown dimensions. This valley was enclosed by mountains of pre-Cambrian rocks and was filled, probably in early Eocene time, with material derived from them. Manganiferous oxides from an unknown source were brought in with some of the sediments. Lakes existed from time to time, with associated plant and animal life, and extensive, thick bodies of fresh-water limestone were formed in them. Volcanic activity contributed material to the basin at four periods, particularly a layer of basalt that covered much if not all of the basin and extended onto the neighboring hills. This valley fill, which attained a thickness of several thousand feet in its deepest parts, constitutes what in this report is called the Artillery formation.

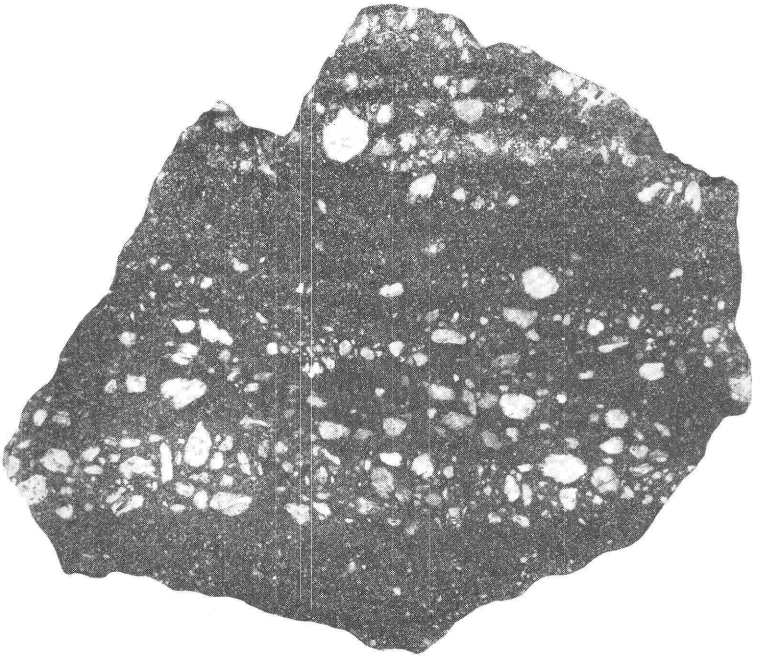
Although its origin is not clear, the basin is probably a fault valley, perhaps of basin-and-range type, perhaps related to thrust faulting. (See p. 20.) Some faulting occurred while the basin was being filled, and the filling was followed by thrust faulting that pushed pre-Cambrian and Paleozoic (?) rocks onto the upper beds of the Artillery formation. The rocks directly below the thrust plate were intricately distorted, and the base of the thrust plate itself was brecciated, in some places for as much as 350 feet above the fault. Some normal faulting occurred at about that time, but no evidence has been recognized that would indicate its relation to the thrusting, either in time or origin. Volcanic rocks were deposited, probably in Miocene time, across the eroded trace of the thrust fault and of these normal faults. Later, block faulting produced a closed graben basin, probably not more than 2 miles wide, lying within the limits of the earlier Artillery basin and occupying the general position of the present valley between the Rawhide and Artillery Mountains. Pre-Cambrian rocks, the Artillery formation, and the Miocene (?) volcanics bordered the graben and constituted the Rawhide and Artillery Mountains of that time.

In this basin was deposited the Chapin Wash formation, a typical bolson deposit largely derived from the bordering mountains, which were worn back on smooth rock-cut surfaces that were buried as quickly as formed. Somewhat more than 1,300 feet of material was deposited, including a little tuff derived from contemporaneous volcanoes somewhere in the region. The basin contained intermittent playa lakes in which were formed beds of limestone and gypsum. An extraordinary amount of manganese, many millions of tons in all, was brought in with some of the sediments, probably as manganese

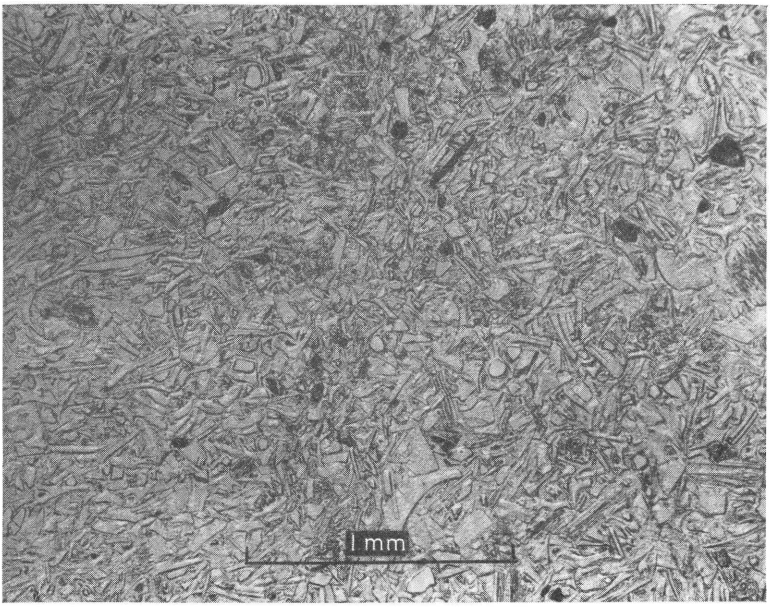


A. REVERSE FAULT EXPOSED IN EAST BANK OF BURRO WASH, SEC. 12, T. 11 N., R. 13 W.

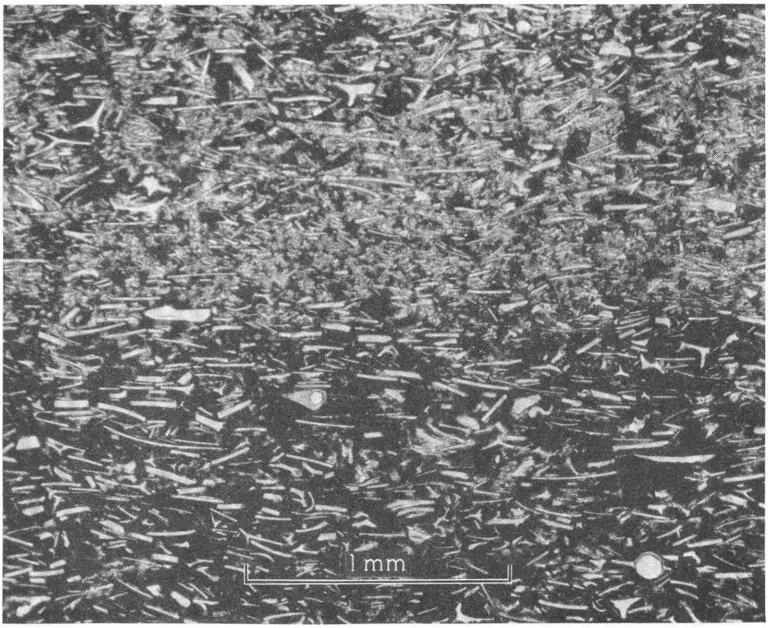
mn, Manganiferous bed; *ss*, sandstone.



B. POLISHED SPECIMEN OF MANGANIFEROUS PUMICE-PERLITE CONGLOMERATE.



A. VITRIC TUFF CEMENTED WITH OPAL.



B. VITRIC TUFF CEMENTED WITH MANGANESE OXIDES AND OPAL.

PHOTOMICROGRAPHS OF VITRIC TUFF FROM THE CHAPIN WASH FORMATION oxide, and deposited with them to form the bedded manganese deposits of the area. In general the manganiferous beds seem related to the playa or low-lying part of the basin, which shifted from place to place as the basin was filled. Though some of the manganese was carried in detrital particles derived from the manganiferous beds in the Artillery formation and from faults and breccia zones that had been cemented with manganese oxides, the principal source of the manganese is uncertain. The most logical source appears to be hot springs, though this conclusion is not entirely satisfactory. (See pp. 68–69.)

Filling of the basin with the playa deposits ended with eruption of the Cobwebb basalt, and following this eruption erosion began to take away material previously deposited. The Cobwebb basalt was removed at places, and on the southwest side of the basin as much as 1,300 feet of the underlying bolson deposits, including parts of the manganiferous beds, were also removed. This change in the drainage regimen is attributed to capture of the playa by a through-flowing stream (see p. 38), which, however, eventually reached an aggrading stage and, with its tributaries, deposited the Sandtrap conglomerate. The Sandtrap conglomerate entirely covered the eroded surface of the Chapin Wash formation and Cobwebb basalt and lapped onto the older rocks bordering the basin. A temporary renewal of volcanism contributed some basalt flows locally to the Sandtrap conglomerate.

The deposition of the Chapin Wash formation, the Cobwebb basalt, and the Sandtrap conglomerate seems to have occurred in Pliocene time. At the close of the Pliocene or early in the Pleistocene these formations were squeezed into many folds whose axes parallel the general trend of the basin. Some of the folds involve the basement rocks, so the folding presumably was caused by regional compression rather than by simple gravitative settling of the basin deposits. During this folding the basin deposits slid along their contact with the basement rocks, and the basement rocks themselves were faulted. Erosion then reduced the general area to a relatively smooth surface and further destroyed much of the manganiferous sediments, although during this period the loss of manganese by erosion appears to have been more than compensated by local supergene enrichment of the deposits. Several basalt flows, 350 feet or more in aggregate thickness, were deposited upon this eroded surface, probably in early Pleistocene time. Renewed faulting along the borders of the manganese basin disrupted the basalt cover and seriously broke the continuity of the underlying manganiferous beds. Manganese oxides, presumably derived from the older deposits and accompanied by such gangue minerals as barite, calcite, and quartz, were deposited in some of the faults and fissures formed during this period.

The Bill Williams River probably assumed its present position at that time, and the manganese basin became the site of tributary streams that not only stripped off the basalt capping but removed also parts of the Cobwebb basalt and Sandtrap conglomerate, and some of the manganese-bearing beds as well. Eventually the area was graded to the Bill Williams River and its tributary drainage, the widespread rock-cut or pediment surfaces formed in the process being covered with sand and gravel when an aggrading stage of the river was reached. At present the streams are actively eroding, and the pediments are being dissected.

MANGANESE DEPOSITS

The manganese deposits that have been commercially investigated in the Artillery Mountains area are bedded deposits in the Chapin Wash formation. In addition there are similar stratified deposits in the Artillery formation; stratified deposits in the Sandtrap conglomerate; faults, fissure zones, and breccia zones in the Artillery formation cemented with manganese oxides; and vein deposits, with some related replacement bodies, along the Pleistocene faults and along fissure zones of similar age, particularly where these cut the Sandtrap conglomerate and the Quaternary basalt. These deposits may be classified according to form and age as follows:

- Bedded deposits:
  - In the Artillery formation.
  - In the Chapin Wash formation.
  - In the Sandtrap conglomerate.
- Vein and breccia-zone deposits:
  - Older than the Chapin Wash formation:
    - Breccia zones in the Artillery formation.
    - Veins in the Artillery formation.
  - Younger than the Chapin Wash formation:
    - Deposits along the Pleistocene faults and fissure zones.

The only deposits that show promise of commercial exploitation are the bedded deposits of the Chapin Wash formation. The others may contain considerable manganese in the aggregate, but the available manganese in them is small and for practical purposes is negligible as compared with the immense tonnage of prospective ore in the deposits of the Chapin Wash formation. Except as they may be referred to in connection with other matters, these other deposits may be dismissed with the brief descriptions that follow.

In the following pages the term "ore" is used, as a matter of convenience, for any manganiferous material in which the manganese oxides can be readily recognized with the unaided eye. Under present metallurgical practice almost none of the material in the deposits in the Artillery region constitutes ore in the usual sense that the manganese in it can be made available for use at a profit. The table of reserves on page 81 and figures 3 and 4 indicate the quantity of material of various grades that is present and afford a basis for estimating how much may become ore in the strict sense as practice improves.

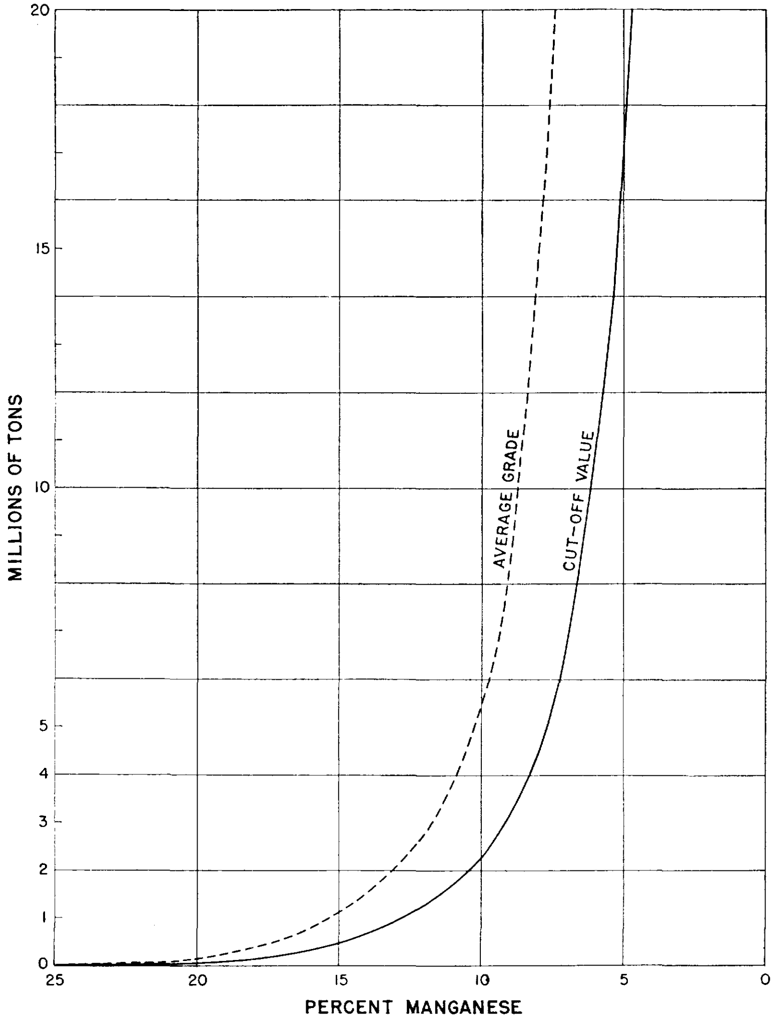


FIGURE 3.—Graph showing reserves of manganese ore of all kinds in the Artillery Mountains for various cut-off values and corresponding average grades. Based on explorations to June 1941.

MINOR DEPOSITS

DEPOSITS IN THE ARTILLERY FORMATION

BEDDED DEPOSITS

Several beds of strongly manganiferous sandstone and clay in the Artillery formation crop out across an acre or two in sec. 16, T. 11 N.,

R. 12 W. (See pl. 1.) They are interlayered with nonmanganiferous beds in a zone 15 feet or less thick directly overlying the basalt member. Most of the manganiferous layers are an inch or less thick, and the thickest is about 1 foot. A few shallow prospect holes have been dug in them.

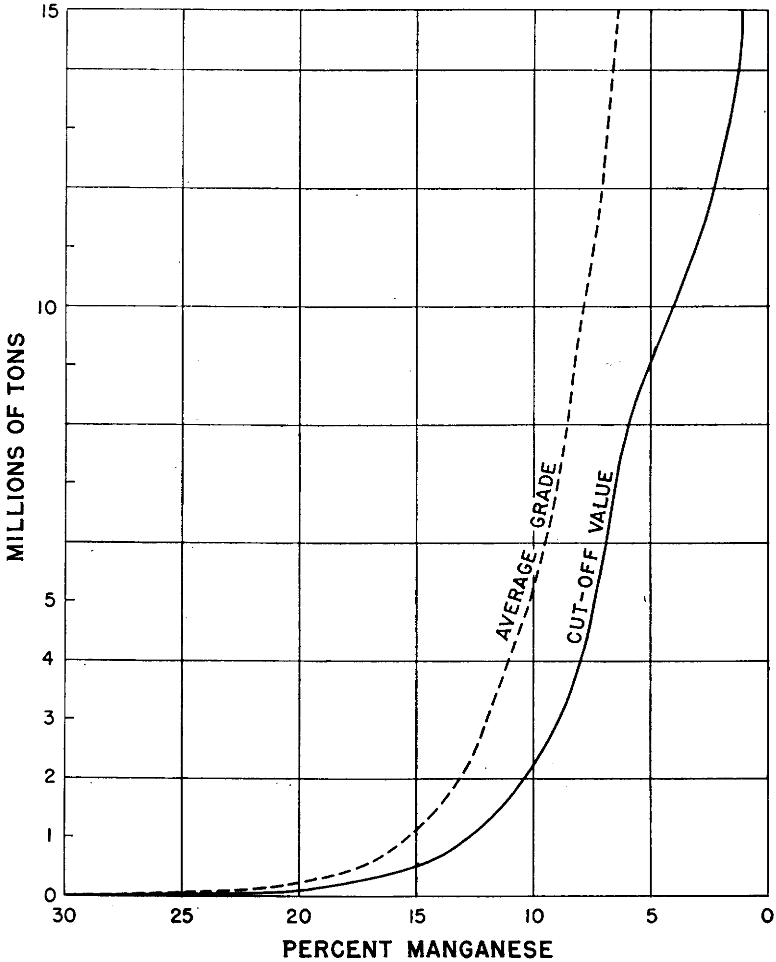


FIGURE 4.—Graph showing reserves of hard ore in the Artillery Mountains for various cut-off values and corresponding average grades. Based on explorations to June 1941.

The zone extends westward into sec. 17, but there the beds are only faintly manganiferous. Some insignificant manganiferous showings are present along the partings at about this same stratigraphic position in the foothills of the Buckskin Mountains. (See p. 19.) Two beds of black manganiferous sandstone in the Artillery formation, 8 to 12 inches thick, crop out for a distance of about 200 feet in the Lower Chapin area, a little east of the Lake No. 33 claim. (See pl. 2.)

In all respects these deposits are indistinguishable from manganiferous beds in the Chapin Wash formation. Because of this fact and because of their stratigraphic relations, it is believed that they, like the deposits in the Chapin Wash formation, are of sedimentary origin, or syngenetic.

The manganese deposits in the Santa Maria district, on the south bank of the Santa Maria River 8 miles east of its junction with the Big Sandy, also seem to be in the Artillery formation. (See pl. 1.) Though Jones[26] considers them replacement deposits, they closely resemble the bedded deposits of the Artillery region and are believed to be primarily syngenetic, though somewhat modified by replacement.

BRECCIA ZONES AND VEINS

The indurated beds of the Artillery formation are typically shattered and brecciated (see p. 16), and the broken rock is commonly cemented with manganese oxides. Although some of the shatter and breccia zones are related to the Pleistocene faulting, others cannot be correlated with recognizable faults in the younger formations. At some places, indeed, the manganiferous breccia is demonstrably older than the overlying formations, for locally the Chapin Wash formation rests upon the eroded surface of brecciated rock cemented with psilomelane and has a basal conglomerate containing chips of psilomelane and fragments of the cemented breccia.

The ridge of Artillery formation northeast of Burro Wash contains many of these cemented breccia zones; the old John Carr claims described by Jones[27] are on a part of the ridge where the early age of these zones can be proved. Apart from details of size, trend, and the like, the following excerpt from Jones' description of the John Carr claims is applicable to many of these deposits:

> The sandstones are brecciated through a length of 600 feet in a northerly direction, along the strike, and a width of about 50 feet, forming a network of seams in which manganese and iron oxides have been deposited. Psilomelane is the dominant manganese oxide, and limonite is the dominant iron oxide. These seams rarely are more than 2 inches wide, and they are so sparsely distributed that it does not appear possible to mine and concentrate the material profitably * * *
>
> Little development work has been done, and the depth to which the manganese oxides extend is not known.

Although the geologic controls are not clear in the vicinity of the Carr claims, elsewhere in the region the brecciation in the Artillery formation seems to be parallel to the bedding, as though only a particularly brittle bed or part of a bed had cracked. If that is true, and as manganese oxides are confined to the brecciated parts, the manga-

[26] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710–D, pp. 183–184, 1920.

[27] Jones, E. L., Jr., and Ransome, F. L., op. cit., p. 149.

niferous breccia bodies are likely to be flat-lying, and at least some of them may be shallow.

Early breccia in the Artillery formation is exposed also along Chapin Wash downstream from the fault of the Minnesota No. 10 claim. The brecciated rock is cut by many stringers of barite, and the brecciation is so intense that the formation there resembles the brecciated base of the thrust plate. Early breccia is also extensively exposed on the ridge east of the Rawhide silver mine, in the Rawhide Mountains. Over a considerable area on the northeast side of the ridge shattered rock in the Artillery formation is cemented by psilomelane in a network of veinlets, and several stringers on the southeast side of the ridge have barite walls and psilomelane centers, some of which are as much as 6 inches wide.

In sec. 21, east of the Bill Williams River, manganese oxides and barite cement a fault of pre-Sandtrap and probably pre-Chapin Wash age in indurated beds of the Artillery formation. (See p. 33.) The fault at the 2,550-foot hill in sec. 28, on the west side of the river, contains manganese oxides, black calcite, and barite.

BEDDED DEPOSITS IN THE SANDTRAP CONGLOMERATE

A thin layer of friable, slightly manganiferous gray sandstone overlies the Cobwebb basalt at the northwest point of the basalt outcrop on Burro Wash. (See pl. 1.) The manganese is probably derived from erosion of the Chapin Wash deposits, which crop out a few hundred feet to the south.

In sec. 20, T. 11 N., R. 12 W., there is a little manganiferous sandstone and conglomerate near the base of the formation, presumably derived from bedded deposits in the Artillery formation or from the manganese-cemented fault to the southeast. (See above.) Manganiferous sandstones tentatively assigned to the Sandtrap conglomerate crop out in sec. 22 of the same township, where they have been exposed by erosion of an overlying cap of Quaternary (?) basalt.

The Sandtrap conglomerate contains many pebbles of manganese ore, derived chiefly from the deposits in the Chapin Wash formation and perhaps in part from the Artillery formation.

None of these deposits have any commercial value, but they are of interest because on the whole they represent a period during which parts of the deposits in the Chapin Wash formation were eroded and scattered beyond recovery.

DEPOSITS IN PLEISTOCENE FISSURES AND FAULTS

Some of the Pleistocene fissures and faults on the northeast side of the manganese basin contain manganese oxides associated variably with barite, black and white calcite, and chalcedony, and with quartz in slender prismatic water-clear crystals. The barite is veined with manganese oxides, and in some fissures it constitutes the walls upon which the manganese oxides were deposited. The manganese oxides in turn are veined and coated with calcite, quartz, and chalcedony. Some of the calcite on being oxidized and leached has left a residue of manganese oxides.

Deposits of this period are most common in the western part of the district, west of the Rudy fault. The best known is the Shannon deposit, which lies along a fissure zone that trends eastward through the Sandtrap conglomerate in the north half of sec. 1 (unsurveyed), T. 11 N., R. 14 W. The conglomerate at that place is complexly folded, so that the fissure zone is in part parallel to the beds and in part cuts across them. (See pl. 14.) Where clearly observable, the fissures are steep and are cemented with pyrolusite and psilomene, which also impregnate the wall rock. The manganese oxides appear to have replaced the matrix of the conglomerate, and they vein and partly replace the pebbles. Some of the fissures contain a little barite and vugs of scalenohedral calcite and quartz. The calcite is manganiferous and shades from black at the base of the crystals into gray and white towards the tips. Quartz and chalcedony vein the parts of the conglomerate that have been replaced. The mineralized zone is traceable for about 2,000 feet along the strike and is as much as 150 feet wide. Other cemented fissures crop out here and there on either side of the main zone.

The only workings in the Shannon area in 1938 were scattered assessment holes. Considering the abundance of rock pebbles in the conglomerate as a whole, the average grade of the deposit is probably very low and the amount of available manganese in it small.

In the south half of section 36, T. 12 N., R. 14 W., north of the Shannon deposit, black and white calcite are abundant along much of the traceable length of a fault in the Sandtrap conglomerate; barite, with manganese oxides, mostly manganite, is abundant locally along the fault crossing the north line of this section. Veinlets of barite associated with manganese oxides (mostly psilomelane) and a small amount of quartz cut the Sandtrap conglomerate west of the Chapin No. 14 claim, roughly along the southeast continuation of the line of the Rudy fault. (See pl. 2.) They seem to be mainly fissure fillings, though there has been some replacement of the walls by barite. Most of them are less than 3 inches wide. In this general area many veinlets of manganese oxides cut both the conglomerate and the basalt along the mesa front. The fault that passes near the southwest corner of the Rudy claim contains a 2-foot vein of pyrolusite in arborescent growths cemented with a little calcite, and fissures in the shattered basalt on the hanging wall contain similar material. This occurrence is one of the old Barbee Nigger Boy claims and is described by Jones[28] as follows:

> The vein strikes N. 20° W. and is nearly vertical. It was traced for 250 feet and is about 2 feet wide. A hole 6 feet deep was dug on the vein and into the underlying conglomerate and sandstone. Mr. Barbee has reported that he was unable to find the vein in the conglomerate and sandstone. As shown in a polished specimen, the ore is an intergrowth of manganite, pyrolusite, and subordinate psilomelane, arranged in a most intricate pattern. Some of the oxides, probably pyrolusite and psilomelane, show concentric deposition in laminae of minute thickness in parts of the specimen, and merging into this structure in another part pyrolusite is intergrown with calcite in long spindles. In places narrow seams in the ore are lined with stubby manganite crystals. A partial analysis of the ore in this vein as reported by Mr. Barbee yielded Mn 47.3 percent, SiO_2 1.80 percent, Fe 1.7 percent, and P. 0.01 percent.

The zone of the Manganese Mesa fault contains a little calcite, quartz, and manganese oxide here and there, particularly near the north end, where the Chapin Wash formation contains streaks of fine-grained black calcite in a stockwork zone 8 to 10 feet wide.

The big north spur of the Price fault is mineralized for a total distance of about 1,500 feet east and west of where it crosses the line between secs. 1 and 2. The fault itself contains barite, and at many places the brecciated and fissured rock for as much as 50 feet each side of the fault is cemented with psilomelane. Barite, black calcite, and manganese oxides, perhaps of Pleistocene age, or related to the fissure deposits in the Artillery formation, are present at the 2,550-foot hill to the east along the zone of the fault.

The ores in the bedded deposits of the Chapin Wash formation have been enriched locally where crossed by faults and fissures, notably at the old Graham prospect along the Common Corner fault. Some details regarding such enrichment are given in the section (pp. 71–75) that describes the various ways in which the ores were modified after their original deposition.

BEDDED DEPOSITS IN THE CHAPIN WASH FORMATION

GENERAL SUMMARY

The manganiferous beds of the Chapin Wash formation differ from the barren beds primarily in that they contain manganese oxide in the cement as well as iron oxide or hydroxide such as accompanies the clay cement of the barren beds. In addition to beds that are uniformly manganiferous throughout, some beds that are generally barren contain minute knots of manganese oxides distributed on the partings.

[28] Jones, E. L., Jr., and Ransome, F. L., op. cit., p. 150.

The manganiferous beds are present at various horizons and include every kind of rock in the formation, not omitting the tuff. (See pls. 4, 5, 15*B*, 16*B*, 17, 20, 21, 22*A*.)

Like the barren beds, the various manganiferous rocks, from conglomerate to clay, differ from one another only in texture and in the proportion of coarse clastic grains to clay and other cement. The manganiferous beds are in part interlensed with barren beds and in part merge into barren rock through diminution of manganese oxide in the matrix. The manganiferous rocks range from gray through brown to deep black, but assays prove that the color is only a rough indication of the manganese content, for the color depends not only upon the proportion of manganese oxide present but also upon its nature. The color of the manganese oxides ranges from shades of brown in those having a low state of oxidation, such as wad, to deep black in those having a high state of oxidation, such as pyrolusite, yet wad may contain as much manganese as pyrolusite. In some exposures weathering has lightened the color and apparent richness of the manganiferous clays; in others it has made the clay blacker and apparently richer, but this darkening may indicate either residual enrichment in manganese or only a higher state of oxidation.

Although there are gradations from one kind of manganiferous material to another (as from clay to sandstone or from sandstone to conglomerate), and though in part the different kinds are intimately interbedded, from the point of view of the miner and metallurgist there are three distinct kinds of ore, each of which offers particular problems of mining and concentration. These are (1) sandstone ore, which includes friable to compact siltstone, sandstone, and conglomerate; (2) clay ore, which includes clay and mudstone; and (3) a hard cemented material that is a supergene modification of the sandstone ore. Each of the three kinds is present in enormous tonnages, but the hard ore, because parts of it have been enriched, offers the best prospect for any attempt at commercial exploitation. (See p. 60.)

The manganese content of the three main kinds of ore, in the broad sense indicated on page 48, ranges from less than 1 percent to as much as 30 percent; but it rarely exceeds 20 percent, and in by far the greatest part of the ore it is less than 5 percent. The average grade of the sandstone and clay ores is between 3 and 4 percent and that of the hard ore about 6 or 7 percent. (See pp. 50, 80.) Twelve of the samples that were collected for manganese analysis (see p. 75), including 3 of sandstone ore, 3 of clay ore, and 6 of hard ore, were analyzed also for iron, copper, lead, zinc, tungsten, phosphorus, barium, and sulfuric anhydride, with the following results:

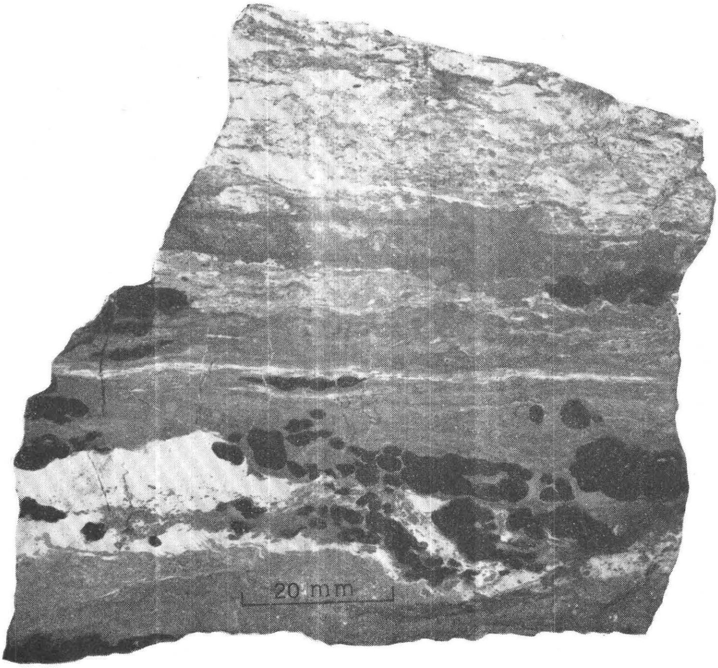
	Range (percent)	Average (percent)
Mn	4.1 –23.7	-----
Fe	1.1 – 5.1	3.5
CuO	.01– .16	.045
PbO	0 – .59	.22
ZnO	.02– .23	.09
W	0 – .03	Trace
P_2O_5	.08– .32	.18
BaO	.05– 4.40	1.3
SO_3	0 – 3.54	.54

Plotting of these figures on both a rectilinear and a logarithmic basis fails to disclose any systematic relation between any two of these constituents or between any one of them and manganese.

The iron content of the 125 drill-core samples of manganiferous material for which it has been determined averages 3.0 percent. The highest iron content in these samples is 7.1 percent, and in all but three of them it lies within the ranges indicated in the table above. This relatively narrow range of iron content is paralleled for all but the hard ore by a relatively narrow range in the manganese content as well. The uniformity in grade thus indicated is such that a few samples collected at widely spaced intervals show an average manganese content that is close to the average indicated by a greater number of samples more closely spaced. Chip samples yield practically the same results as channel samples from the same place. (See also comparison of reserves in Maggie and Upper Chapin blocks, pages 80–81.) The manganese content may change sharply from bed to bed (see pl. 5), but both sampling and geologic observations show that within individual beds it changes only gradually. The grade of the different kinds of ore is discussed more fully below and on pages 76–81.

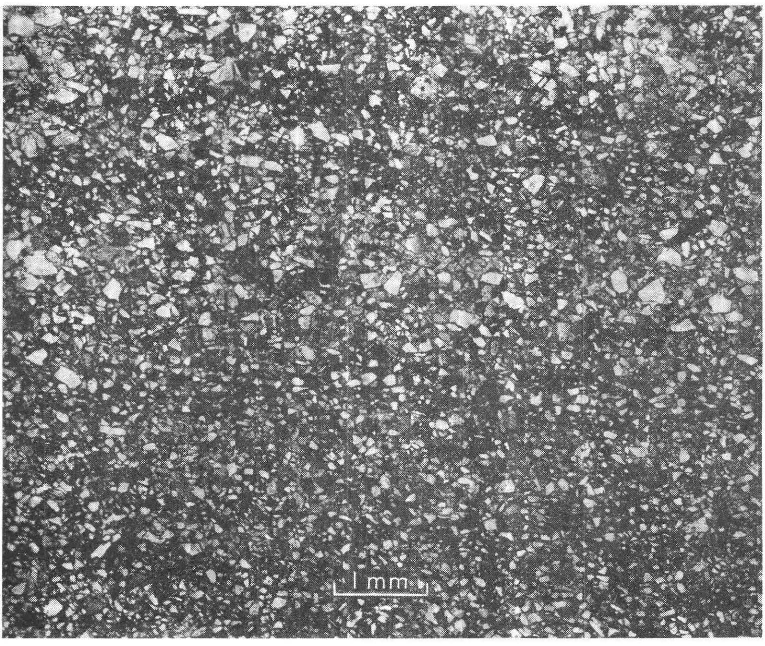
SANDSTONE ORE

The sandstone ore includes friable siltstone, sandstone, grit, and conglomerate that are well compacted but not hard and that have no cement other than clay and oxides of manganese and iron. Such ore consists of sand grains or pebbles in a matrix that ranges from reddish clay to brown and black opaque material. The opaque material is the manganese-bearing part of the rock. As seen in thin section the opaque matter consists in some places of red or brown iron hydroxide, in other places of black manganese oxide, and in still other places of oxides and manganese and iron intimately mixed. There are no recognizable signs of replacement of sand grains by the oxides; the rocks show the same textures and the same relations between sand grains and cement as the same kinds of rock in the barren beds. (See pls. 17*B* and 18.)



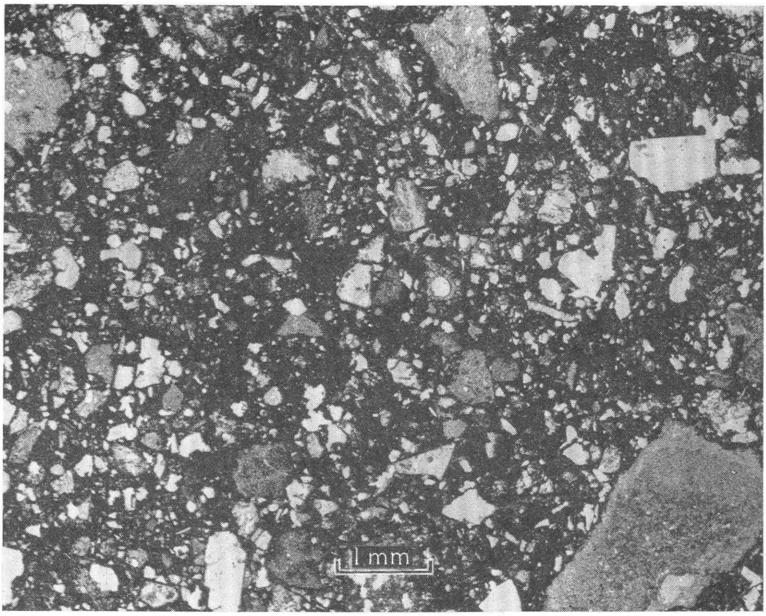
A. POLISHED SPECIMEN OF MANGANESE ORE.

Interlaminated pink and black (manganiferous) clays with laminae and blebs of pure manganese oxides.

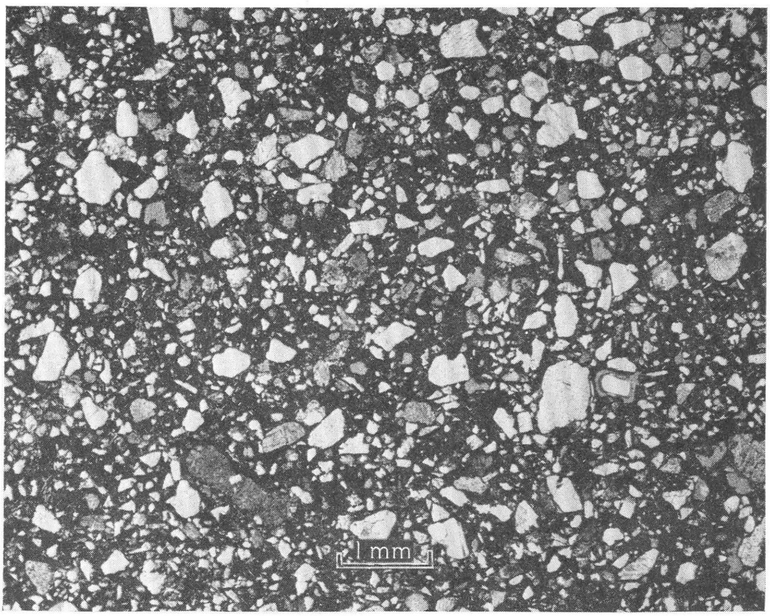


B. PHOTOMICROGRAPH OF MANGANIFEROUS SEDIMENTS.

Laminated limy siltstone in which the sand grains lie in a matrix of calcite, clay, and iron and manganese oxides.



A. BARREN SANDSTONE CONTAINING FRAGMENTS OF ROCKS AND MINERALS IN A MATRIX OF CLAY AND IRON OXIDES.



B. MANGANIFEROUS SANDSTONE CONTAINING FRAGMENTS OF ROCKS AND MINERALS IN A MATRIX OF CLAY AND IRON AND MANGANESE OXIDES.

PHOTOMICROGRAPHS COMPARING BARREN AND MANGANIFEROUS SANDSTONES OF THE CHAPIN WASH FORMATION.

The manganiferous part of the cement is almost wholly amorphous, and precise identification of the manganese minerals present may be impossible. X-ray analysis and chemical investigation of the state of oxidation of the manganese may be the only satisfactory ways of studying them. Most of the ore is brownish with a brown streak and soils the fingers, and the cementing material of such ore may properly be called wad. Some ore is sooty black to blue-black, and the manganese oxide in it must be largely pyrolusite. All the ore, brown or black, decomposes hydrogen peroxide vigorously. But whatever the manganese minerals may be, more than one oxide must be present, for some of the manganiferous matter, even in the blackest ore, quickly dissolves in dilute nitric acid, which will not attack MnO_2 but will dissolve the MnO component of the other manganese-oxide minerals.[29]

The manganese minerals cannot be adequately studied microscopically because the manganiferous part of the sediments is so soft and yielding that it cannot be made into satisfactory polished sections, even after impregnation with some such material as bakelite. An hour's hand buffing of a specimen of brown sandstone ore, previously polished mechanically, produced enough polish to reveal some minute grains of an isotropic mineral. Similar buffing of a specimen of black sandstone ore revealed spots composed of matted anisotropic needles (manganite or one of the phases of psilomelane) and other spots composed of interlocking grains of pyrolusite.

Some of the manganiferous tuff beds belong in this class of ore, the manganiferous layers being, as in the sandstone ore, delicately to coarsely interlaminated with nonmanganiferous layers and differing from the barren tuff only in the presence of manganese oxides.

The sandstone ore constitutes about half the reserves in the area. Its manganese content ranges from a trace to as much as 24 percent, but this high figure was approached in only one sample. A little contains about 10 percent of manganese. The average grade of those parts of the manganiferous beds that are of sufficient thickness and lateral extent to be minable ranges from 1.5 to 4 percent of manganese in individual blocks of ore, and is estimated at 3 to 3.5 percent for the district as a whole. (See p. 80.) Plate 5 indicates the usual degree of variability in richness from bed to bed.

Three samples specially analyzed for minor constituents showed the following content:

	Percent		*Percent*
Fe	1.5–2.5	W	Trace
CuO	.01–.03	P_2O_5	0.16–0.19
PbO	0–.17	BaO	.65–1.25
ZnO	.03–.10	SO_3	0–.28

[29] Treadwell, F. P., and Hall, W. T., Anal. Chemistry, p. 170, 1921.

The supergene equivalent of the sandstone ore, called hard ore, is described on page 59.

CLAY ORE

The clay ore has the same sort of conchoidal fracture as the common red and brown clay and mudstone of the Chapin Wash formation, is similarly plastic when wet, and slakes similarly on weathering. (See pls. 19 *B* and 20.) Microscopically it is like the sandstone ore except that it has a smaller proportion of coarse clastic grains. (See pls. 21 and 22*A*.)

The clay ore ranges from massive black clay to brown manganiferous clay and silt interlaminated with barren clay and silt. The laminated material as a whole contains blebs and bedding streaks of virtually pure oxides, some brown and some black and sootlike. (See pl. 17*A*.) Some ore that is mostly black or brown contains thin laminae of ordinary red or pink clay and silt, and the red clayey layers in the laminated ores include thin maganiferous laminae. (See pl. 21.) In some laminated ore sooty blue-black material forms persistent layers as much as 4 inches thick, and some groups of laminae that consist mostly of such material make up layers as much as 2 feet thick. (See pl. 19*B*.) The sooty material is almost completely soluble in sulfurous acid and so must consist almost entirely of oxides. Its physical properties suggest pyrolusite, but it must contain some of the lower oxides as well, for it is partly soluble in nitric acid.[30] A sample from one of the laminae shown on plate 19*B*, was found to contain 59 percent of manganese.

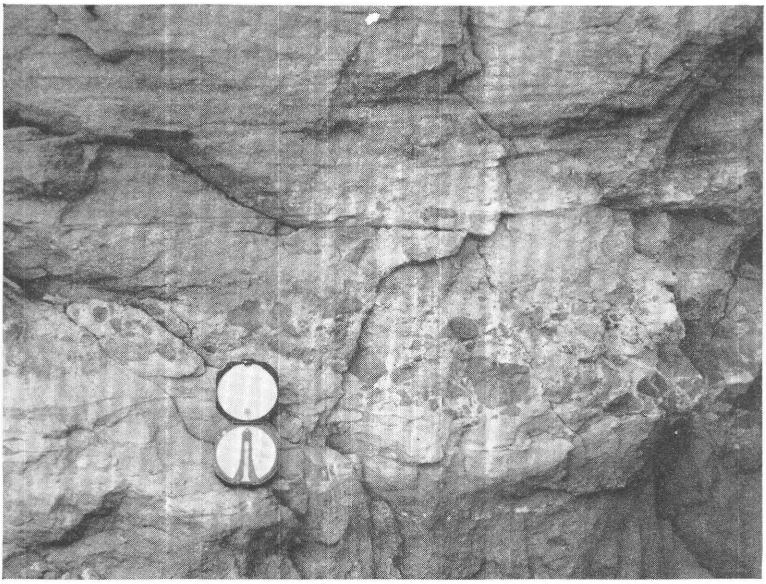
Most of the clay ore is near the bottom of the manganiferous zone, and in the area shown on plate 2 this material constitutes almost as large a reserve as the sandstone ore. (See p. 80.) Samples collected for assay from croppings and drill holes over an area of about 125 acres, and, as nearly as could be judged, from the same bed, contained 4.5 to 9 percent of manganese, with an average of about 5 percent. Three of the samples were analyzed for minor constituents and showed the following content:

	Percent		*Percent*
Fe[1]	3–4	PbO	0.29–0.51
P_2O_5	0.19–0.32	W	Trace
CuO	.05–.16	BaO	.31–2.13
ZnO	.09–.23	SO_3	.07–3.54

[1] Four samples.

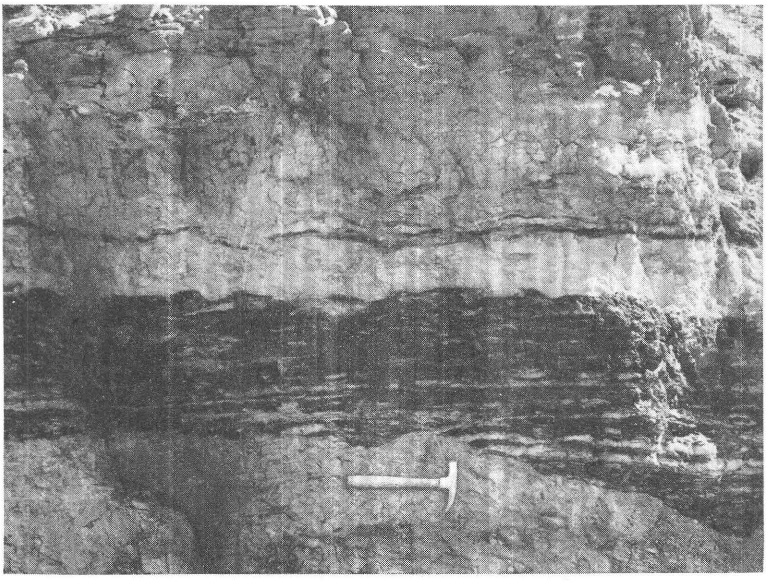
The extent to which the manganese content varies from bed to bed is indicated on plate 5. The manganese content in any one bed, and for the clay zone as a whole, seems remarkably uniform.

[30] Treadwell, F. P., and Hall, W. T., op. cit., p. 170.



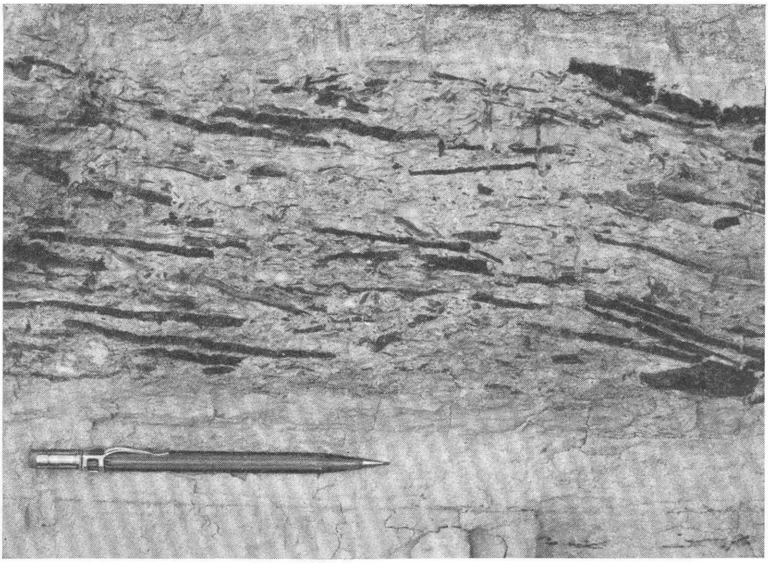
A. FRAGMENTS OF FRIABLE MANGANIFEROUS SANDSTONE AND A FEW FRAGMENTS OF MUDSTONE IN COARSE-GRAINED BARREN SANDSTONE.

Manganiferous sandstone above and below the conglomerate. The manganiferous pebbles are so friable that they could not have been transported more than a few feet without disintegrating; at right edge of photograph it appears as if the pebbles were derived from the manganiferous sandstone below. Portal of 50-foot adit in south bank of Burro Wash in the Price block. See plate 5, measured section 7, for stratigraphic position.

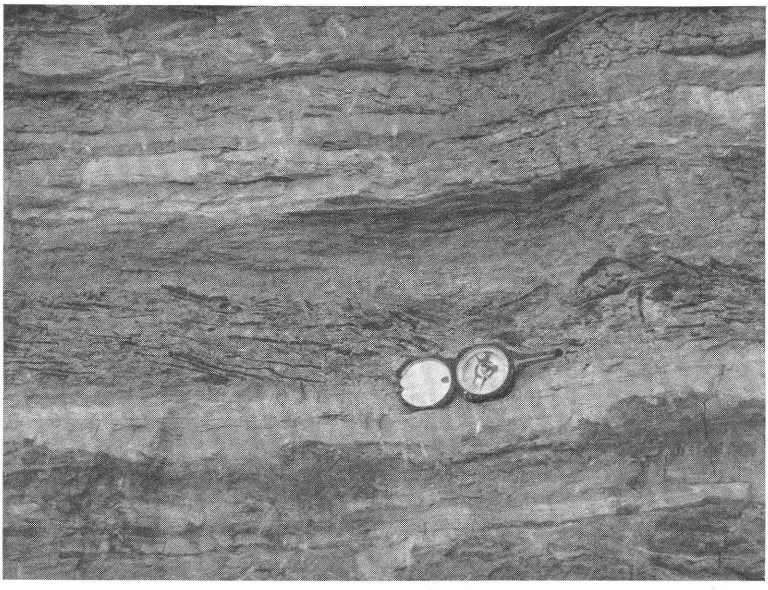


B. INTERLAMINATED SOOTY MANGANESE OXIDES, PINK CLAY, AND SANDY TUFF, INTERBEDDED WITH BROWN CLAY.

Haft of pick lies along a bedding plane in the clay. Note scour-and-fill surfaces and slaking of clay at left. See measured section page 28 for stratigraphic position.



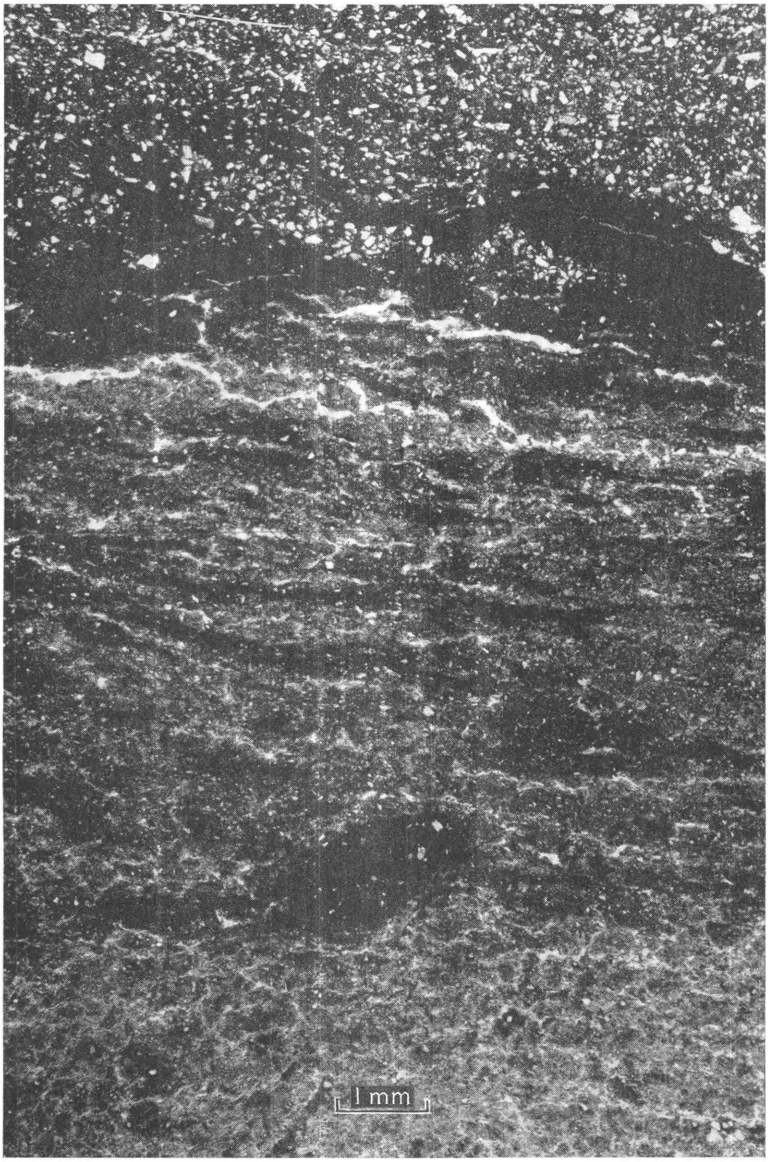
A



B

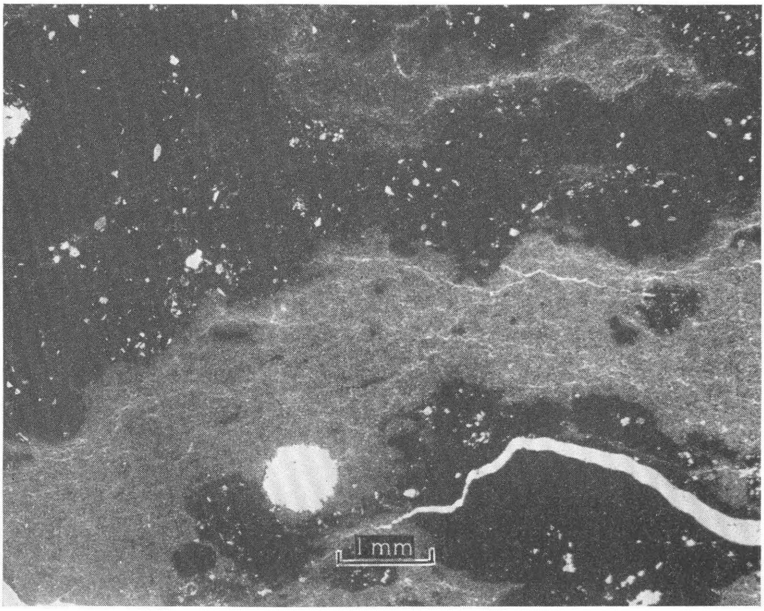
LAYER CONTAINING MUD FLAKES OF BLACK MANGANIFEROUS CLAY AND SOME FLAKES OF BARREN BROWN CLAY IN PINK SANDSTONE.

This layer is included in friable manganiferous sandstone below lowermost tuff member exposed in Chapin Wash. (See pl. 4.) *A* is close-up view of part of layer shown in *B*.



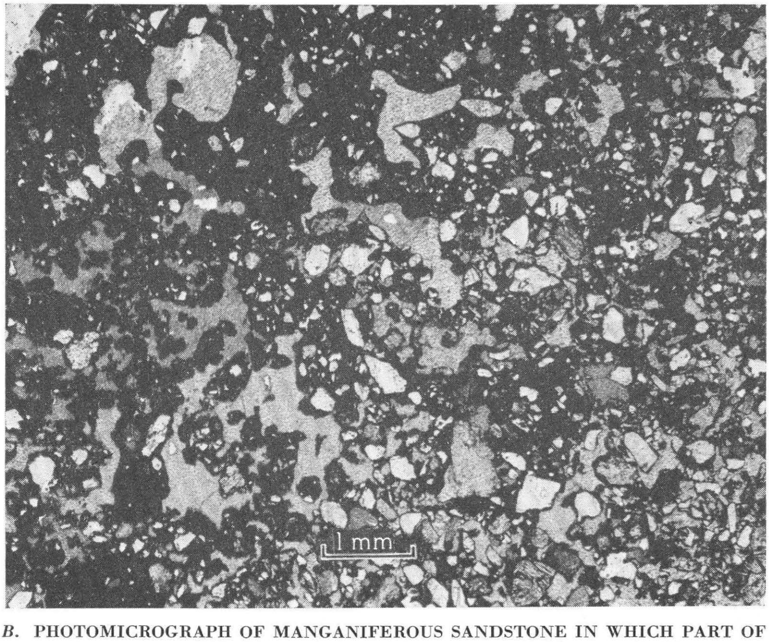
PHOTOMICROGRAPH OF MANGANIFEROUS CLAY AND SILT.

Upper part is silt with a matrix of iron and manganese oxides; middle part is clay with fine laminations of iron and manganese oxides; lower part is ordinary nonmanganiferous clay.



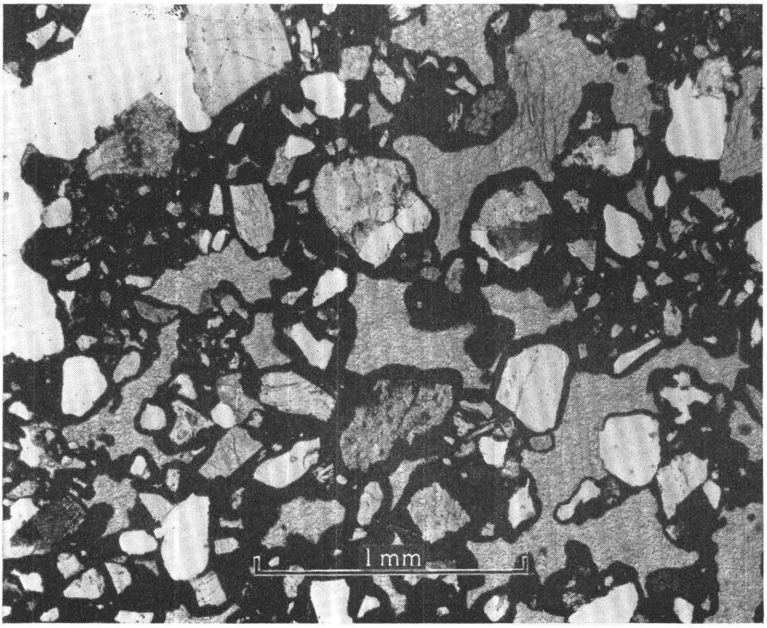
A. PHOTOMICROGRAPH OF TYPICAL MANGANIFEROUS CLAY.

Brown clay with flocculent blebs of red iron oxides, black manganese oxides, and mixtures of the two. All the oxides photograph black.

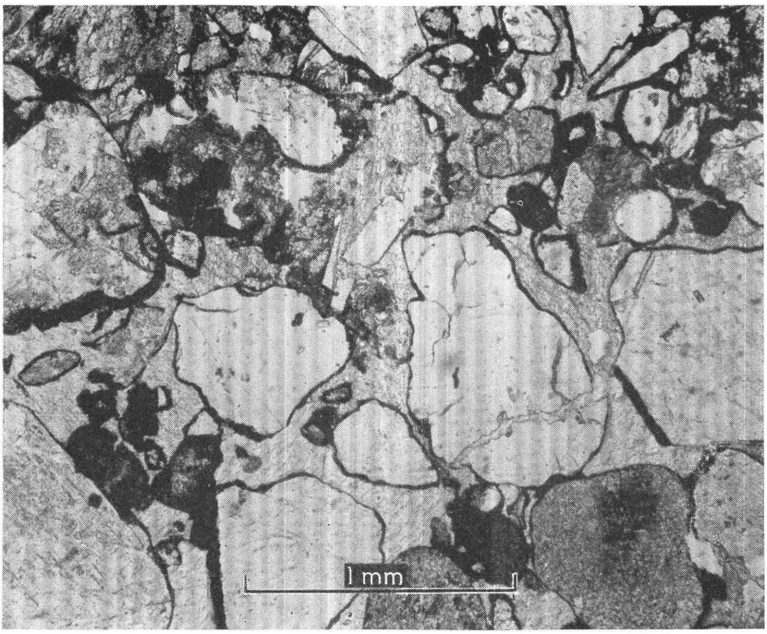


B. PHOTOMICROGRAPH OF MANGANIFEROUS SANDSTONE IN WHICH PART OF MATRIX HAS BEEN REPLACED BY CALCITE (MOTTLED GRAY).

Many patches of calcite unconnected in the plane of the photograph extinguish simultaneously. Compare with plate 18, *B*.



A



B

PHOTOMICROGRAPHS OF CALCITIZED MANGANIFEROUS SANDSTONE, ILLUSTRATING AN EARLY AND A MORE ADVANCED STAGE OF REPLACEMENT OF THE MATRIX BY CALCITE.

In *A* the manganese oxide (black) along the contacts with calcite consists partly of crystals of manganite. *B* illustrates almost complete replacement of the matrix and shows the layer of iron and manganese oxides that generally adheres to each sand grain.

HARD ORE

The hard ore is the supergene equivalent of the sandstone ore; that is, it is sandstone ore that has been altered by weathering agencies.

Compared to unaltered sandstone ore it is typically hard and resistant to weathering. It crops out most prominently in Maggie Canyon, where it forms a cliff that strikingly resembles the overlying cliffs of basalt. (See pl. 12*B*.) All the adits in Maggie Canyon shown on plate 2 are in this ore. A little of it crops out on the east side of Manganese Mesa, and it was cut in many of the drill holes through the basalt capping of Manganese Mesa. As cut by these drill holes, the hard ore has a maximum thickness of 56 feet and an average thickness of about 20 feet. (See pls. 24 and 25.)

Part of the hard ore consists of siltstone, sandstone, and conglomerate that sparkle with large crystals of "sand calcite." As seen in thin section, the calcite occupies the areas between the sand grains, and sharp tongues of calcite project into the manganese oxides and clay that cement these grains, suggesting that the calcite has replaced the cementing material. Typical sand-calcite relationships are shown on plates 22*B* and 23.

In some of the ore containing sand calcite the manganese oxides are crystallized here and there in contrast to the almost total absence of crystallized oxides in the unaltered sandstone ore. Thin sections of such material disclose a myriad of minute prismatic crystals of manganite along the contacts between the manganese oxides and the calcite. The contacts between manganese oxides and the sand grains are commonly as sharp as in the unaltered ore, though here and there minute irregularities suggest replacement by the oxides.

Some ore is cemented with opal in similar fashion, and in such ore most of the manganese oxide is crystalline. (See pls. 26 and 28*A*.) As in the calcitized ore, the contacts between sand grains and manganese oxides are sharply defined. Each sand grain has a crust of psilomelane, from which many manganite needles extend into the opal. At some places a band of manganite needles lies within the opal and parallel to the main opal contacts. (See pl. 26.) The opalized ore is highly porous, much of the opal simply forming a crust on the pore walls. (See pls. 27 and 28*A*.)

Much of the ore contains both opal and sand calcite, but much of it, too, is found on microscopic examination to contain neither, the grains being held together by psilomelane and manganite, the manganite forming velvety crusts on the pore walls. Brown spots in the opalized ore are found to contain much analcite, which is indistinguishable, however, from the opal in thin section.

The hard ore is generally somewhat blacker than equivalent sandstone ore of equal grade, though not so black as the sandstone ore containing much pyrolusite. Some reacts vigorously to hydrogen peroxide, some faintly, the vigor of the reaction apparently being inversely proportional to the degree of insulation of the manganese oxides by opal or sand calcite. This feature would have to be taken into account in designing any process to recover the manganese by chemical methods.

The tuff layers in the hard ore are similarly calcitized and opalized. (See pls. 16 and 27.) In some of the opalized tuff the manganese oxide occurs in tiny granules scattered throughout the rock, within the opal as well as crowded against the shards of glass. On high magnification most of these are seen to consist of tiny knots of prismatic crystals, presumably of manganite. The shards of glass are usually as uncorroded by calcite, opal, or manganese oxides as the sand grains in the sediments. A few of the richer manganiferous streaks in the tuffs cross the bedding laminations. Conversely, some highly manganiferous layers contain pockets of pure-white ash that cross the laminations; presumably these pockets consist of shards from which all cement had been removed.

At one place in the area some of the opalized, calcitized tuff contains small rosettes of barite plates.

Barren beds of both tuff and plastic rocks, as well as manganiferous beds, are opalized and calcitized.

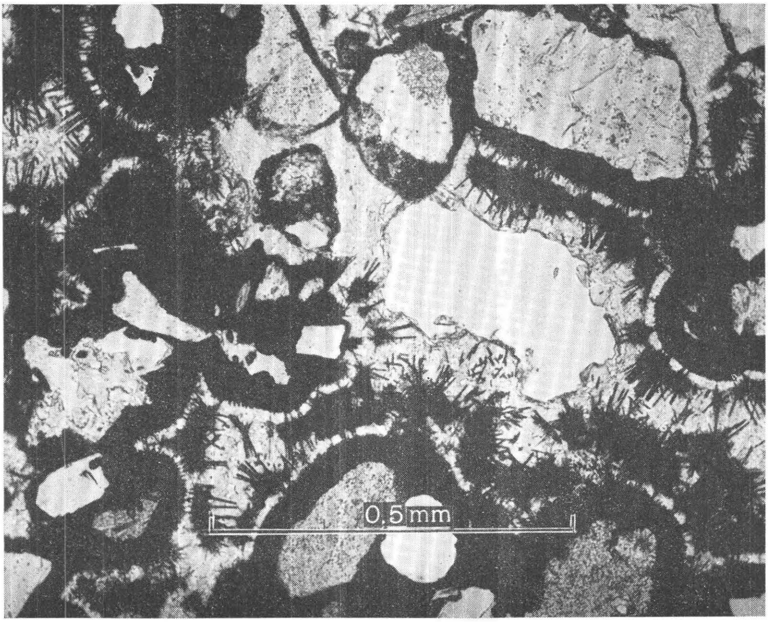
On the whole, the calcitized and opalized materials occur together and intimately associated, and they evidently were produced by equivalent or related processes. As they are the results of supergene alteration, the distribution of sand calcite and opal and the significance of the cementation and accompanying reconstitution of the manganese oxides are discussed in the section entitled "Modifications after original deposition" (pp. 73–75).

As inferred from the results of exploration up to the end of 1941, almost the only bodies of ore in the region that combine minable size with promising grade are composed of hard ore. Although perhaps a third of the hard ore has only about the same average manganese content as the unaltered sandstone ore (less than 5 percent) much of it contains at least 10 percent and some of it more than 20 percent. (See pl. 5, drill hole 3, and pls. 24 and 25.) Six samples specially analyzed for minor constituents showed the following content:

	Percent		*Percent*
Fe	1.3 –5.1	W	Trace
CuO	0.01–0.05	P_2O_5	0.08–0.27
PbO	0 – .59	BaO	.05–4.40
ZnO	.02– .10	SO_3	0 – .58

EXTENT AND THICKNESS

The manganiferous parts of the Chapin Wash formation crop out in two bands, one along the northeast side of the basin and the other



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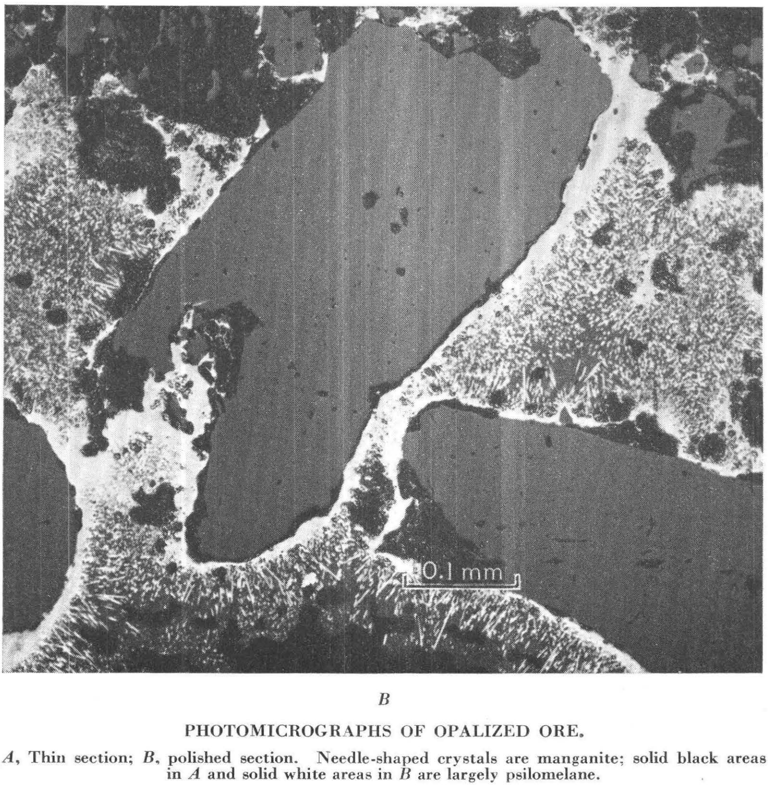

B

PHOTOMICROGRAPHS OF OPALIZED ORE.

A, Thin section; *B*, polished section. Needle-shaped crystals are manganite; solid black areas in *A* and solid white areas in *B* are largely psilomelane.

A

B

PHOTOMICROGRAPHS OF OPALIZED MANGANIFEROUS TUFFS.

B is enlarged view of part of plate 16, *B*, to show the clusters of manganite needles. *o*, Opal.

along the southwest side. (See pl. 1.) These outcrops belong to two manganiferous zones 750 to 1,000 feet apart stratigraphically (see p. 31). The relations between the two zones across the basin are interpreted in geologic sections *C–C′*, *D–D′*, and *E–E′*, plate 1. The two zones are described separately in the following pages. For the upper, more important zone, a general description is followed by an account of the features seen in each of the main blocks. For the lower zone, only a general description is given.

UPPER ZONE

The upper zone includes all the manganiferous exposures on the northeast side of the basin except the small cropping at the base of the Chapin Wash formation near the east edge of sec. 11, T. 11 N., R. 13 W. (See pl. 1.) The lens-shaped band in secs. 23 and 26, T. 11 N., R. 13 W., on the southwest side of the basin, and possibly some small outcrops in the northeast corner of sec. 19 in the same township, also belong to the upper zone. (See pl. 1, *C–C′*.) Plates 1 and 2 show the general distribution of the zone, and plates 5 and 10 show stratigraphic details and some variations in thickness and continuity.

The upper zone lies at or near the top of the Chapin Wash formation and comprises its full thickness where it pinches out against the Artillery formation in Burro Wash. The zone is continuously manganiferous for a stratigraphic thickness of fully 165 feet; at some places it is as much as 350 or 400 feet thick, but these thicker parts consist mainly of barren layers. Bands that are manganiferous throughout are traceable for as much as 3 miles along the strike, and the various exposures along the northeast side of the basin probably connect with one another below the surface to form a continuous zone twice that length. Outcrops and diamond-drill holes in the Maggie and Upper Chapin blocks indicate that some individual manganiferous beds are continuous for at least a mile down the dip.

MAGGIE BLOCK

The Maggie block lies between the Rudy and Manganese Mesa faults. (See p. 44.) The richest and most continuous exposures in this block are in the walls of Maggie Canyon. As judged from the exposures amid the slide rock, the manganiferous zone appears to be 75 to 100 feet thick in the main part of the canyon and to have a maximum thickness of about 200 feet. It fades out rapidly southwest of the Maggie tunnel, and toward the east and north it passes beneath the surface to reappear at a point 900 feet north (on the east side of Manganese Mesa) where 3 feet of manganiferous conglomerate crops out below some high alluvium. From that point the manganiferous zone can be traced northward about a mile to where it pinches out against the Miocene (?) volcanics. (See pl. 3*C*.) In that part of the block the manganiferous zone has a maximum thickness, at the outcrop, of only 17 feet (see pl. 5, measured sec. 1), and where it begins to thin out against the Miocene (?) rocks it consists of only a few dark streaks in a zone not more than 10 feet thick.

The many manganiferous beds on the east side of Manganese Mesa, between the basalt and the Manganese Mesa fault, seem to be part of a dip slope representing the west limb of a syncline displaced by the Manganese Mesa fault. (See pls. 2 and 10.) The beds in that area are largely concealed by basalt slide rock, but in some places the basalt boulders are covered with a strong shiny desert varnish of manganese oxide, a feature that was found to be an almost infallible indicator of a cropping of manganiferous beds nearby.

Diamond-drill holes show that the manganiferous beds underlie as much as 400 to 500 acres of the basalt south of Maggie Canyon and 150 to 200 acres under the basalt north of Maggie Canyon. (See pls. 10 and 24.) Some of the richest ore in the district was cut by these drill holes, as well as some of the thickest and most nearly continuous manganiferous zones. Hole No. 9 cut a 164-foot zone containing a total of only 16 feet of barren material, of which the thickest barren interval is 7 feet, and hole No. 3 cut 180 feet of manganiferous beds in a zone 285 feet thick.

As interpreted from drill logs and from surface exposures, the manganiferous zone in the Maggie block frays out into barren sediments roughly along the line indicated on plate 24. In the area south of Maggie Canyon this roughly coincides, in part, with the line along which the Sandtrap conglomerate begins to cut into the horizon of the manganiferous zone, but in general the manganiferous zone is limited by a fading out rather than by the unconformity.

UPPER CHAPIN BLOCK

The Upper Chapin block constitutes that part of the upper manganese zone that lies between the Manganese Mesa fault and the Plancha Mountain-Common Corner fault zone. It occupies the east flank and part of the trough of the syncline whose faulted west flank is the Maggie block. (See pl. 2.) The manganiferous beds crop out extensively along the walls of Chapin Wash and on the side slopes, and the most extensive and striking exposures in the district are in this block. (See pls. 4 and 6*B*.)

One diamond-drill hole in the Upper Chapin block cut a manganiferous zone as much as 200 feet thick, of which only 34 feet is barren, and one outcrop exposes a zone 110 feet thick, of which less than 30 feet is barren. An exposure of 85 feet that is manganiferous essentially throughout is shown on plate 4.

Some of the variations of stratigraphic continuity and thickness are shown on plate 5, measured sections 3, 4, and 5. The manganiferous zone begins to feather out northward at a point, covered by debris, somewhere southeast of the position of measured section 3, for near that section the thick zone of manganiferous clay crossed by measured section 4, to the southeast, is represented mostly by barren clay. Some manganiferous beds in the clay zone in the area of measured section 3 are as much as 3 feet thick, and some are of high grade, but they are not spaced closely enough to be minable. At the next exposure north, beyond the talus, the main part of the manganese zone averages only about 12 feet in thickness and consists wholly of sandstone ore that corresponds to either the top member in section 3 or the second manganiferous member from the top. Some of the underlying beds contain a few streaks, none more than 2 inches thick, of fairly pure sooty ore in limestone and in limy siltstone and clay; these streaks thin northward into paper-thin manganiferous partings.

The manganiferous zone frays out toward the south also, in the vicinity of the tunnel on the Chapin No. 2 claim in Chapin Wash, where it splits into three narrow members, composed mainly of sandstone, whose outcrops appear largely as vague dark bands. The underlying clay beds, which correspond to the clay ore so prominent in the exposures to the north, are here almost barren. (See pl. 5 measured sections 4 and 5.) At a shallow adit at the edge of the alluvium to the east the main manganiferous member, the upper one, is only 4 feet thick and contains only 2 percent of manganese. (See pl. 24.) Diamond-drill holes indicate that the manganese zone frays out in this general area at about the same rate down dip as along the strike. Hole 1 (pl. 24), for example, cut only 51 feet of weakly manganiferous beds in an over-all zone 165 feet thick; the manganiferous layers are mostly only 1 to 2 feet thick and, except in the top 10 feet of the zone, contain less than 1 percent of manganese. Hole 15 crossed only 20 feet of low-grade sandstone ore, corresponding to the top of the three members on the Chapin No. 2 claim mentioned above. Hole 16, south 800 feet from hole 15, explored 260 feet of beds below the Cobwebb basalt but penetrated only barren beds. The frayed edge of the manganiferous zone here, at the south edge of the Upper Chapin block, is an extension of the southwest border of the manganiferous zone in the Maggie block.

Isolated exposures amid the talus on the slopes of Plancha Mountain indicate that some manganiferous beds, of unknown thickness and extent, underlie the talus and the basalt.

LOWER CHAPIN BLOCK

The principal exposures in the Lower Chapin block, between the Plancha Mountain and the Price faults, are along Chapin Wash east of Plancha Mountain. (See pls. 1 and 2.) The thickest exposures are at the tunnel in Chapin Wash at the northwest corner of the Minnesota No. 10 claim. Two black beds, the upper one 18 feet thick and the lower one 8 feet thick, separated by 12 feet of barren material, crop out there along the bottom and walls of an arroyo tributary to Chapin Wash, and several subordinate layers are exposed at higher horizons. (See pl. 5, measured section 6.) In general stratigraphic position the main beds seem to correspond to the deep-lying manganese beds cut by diamond-drill hole 3 in the Upper Chapin block.

The two thicker beds, with the barren interval between, extend northwestward along the arroyo for about 750 feet until overlapped by alluvium, beyond which they crop out again in Chapin Wash. At the place where the manganese zone reappears, 10½ feet of some of the richest bedded ore in the district is exposed, but at a point a few hundred feet to the north the zone consists only of two beds, each 2 to 3 feet thick, separated by a 10-foot barren interval. West of this point, in the south bank of Chapin Wash, an insignificant showing under the alluvium may represent this zone, though the beds cannot be traced to this exposure.

These exposures north of the alluvium are on the south flank of a small anticline. The manganiferous beds are eroded from the crest of the fold, but there are some poor exposures of them on the north flank, where they are cut off by the Common Corner fault.

The two main beds thin out southeastward from the tunnel on the Minnesota No. 10 claim. The lower one eventually pinches out completely against the Artillery formation (see pl. 2), and the upper one is not more than 3 feet thick at the line between sections 3 and 10, where the next higher manganese bed, which is 3 feet thick near the tunnel, has thinned down to 1 foot. Manganiferous beds crop out for another mile or more along the walls of Chapin Wash and on the south bank where they are not covered by pediment gravels, but in these outcrops they are thin and generally almost barren. Though there are some black streaks 1 to 1½ feet thick, at only a few places are they spaced closely enough to form a zone more than 3 feet thick. Other minor showings crop out east of Chapin Wash, in the southwest corner of sec. 12 where the Chapin Wash formation is cut off by the Price fault.

The down-dip extent of the manganiferous beds in the Lower Chapin block has been explored by a 50-foot tunnel on the Minnesota No. 10 claim and by two diamond-drill holes. Hole 18 (see pl. 24) cut the manganese zone about 600 feet down dip from the outcrops of the tunnel beds and crossed three manganiferous layers, in descending order 6, 12, and 10 feet thick, respectively. These beds correspond to the two beds at the tunnel and the first subordinate layer above. The other hole, No. 19, was drilled through to the Artillery formation, but the beds were barren throughout.

PRICE BLOCK

The principal exposures in the Price block extend along that part of Burro Wash in which the manganiferous zone occupies the full thickness of the Chapin Wash formation and wedges out between the Cobwebb basalt and the Artillery formation. (See pl. 1 and pl. 5, measured section 7.) The main beds are exposed along the nearly perpendicular walls of the wash for somewhat more than 2,000 feet downstream from the point where they begin to lap sharply against the old steep topography on the Artillery formation. Section 7, plate 5, (see index map, pl. 5, for location), was measured at the thickest part of the zone and shows an over-all thickness of 50 feet. Throughout the block the strongest and most uniform section of the zone is in the upper part of the formation, but some streaks in the lower part are fairly black locally and as much as 2 or 3 feet thick. A 50-foot tunnel in the west bank of Burro Wash, on the line of the measured section, prospects the bottom of the main manganiferous beds. (See pl. 19, *A*.)

Farther downstream in Burro Wash, at the place where the uppermost beds cross from the south to the north bank, the manganiferous zone includes only one 6-foot and one 2-foot bed of manganiferous sandstone, separated by 4 feet of barren clay and siltstone. A little farther downstream the manganese content fades out almost completely, the beds containing only rare black streaks. This last statement refers to the main part of the zone, directly under the Cobwebb basalt, for on the north side of the wash some manganiferous lenses in the basal conglomerate of the Chapin Wash formation crop out here and there through some high alluvium that covers the bench. From there east to the river the only showing of manganiferous sediments, aside from a stain on some parting planes, is at a small cropping through the high alluvium in the SW¼ of sec. 7.

In the angle between the two spurs of the Price fault at the west edge of sec. 12 and the east edge of sec. 11, particularly at the quarter corner, the conglomeratic sandstone (below the Cobwebb basalt) that on the line of measured section 7 is barren is at this place largely a manganiferous bouldery conglomerate 4 to 5 feet thick, and the beds below are barren.

Two manganiferous layers crop out in the sliver of Chapin Wash formation to the northwest in sec. 2, in the angle between the two main spurs of the Price fault. The lower layer is at or close to the base and seems to be mostly less than 1 foot thick; the upper one attains a maximum thickness of 3 feet.

SECS. 23 AND 26, T. 11 N., R. 13 W.

The manganiferous zone as exposed in secs. 23 and 26 is strongest in sec. 23 south of the road, where it is about 350 feet thick and includes 20 to 30 separate manganiferous beds 1 inch to 1 foot thick. Locally some manganiferous layers are spaced closely enough to form bands 4 to 5 feet thick.

The manganiferous zone extends southward toward the river until overlapped by the alluvium that covers the river bench. Nothing more than faint showings were found in the isolated exposures in the alluvium or in the bluffs along the river. Toward the northwest the zone seems to have about faded out where a broad area of high alluvium begins to obscure the bedrock.

LOWER ZONE

The lower zone includes all the manganiferous exposures along the southwest side of the basin except that in secs. 23 and 26, described above as part of the upper zone. It may include also the manganiferous beds at the base of the Chapin Wash formation exposed near the east edge of sec. 11 on the northeast side of the basin.

The lower zone is traceable along its strike for a little less than 4 miles. Its greatest exposed thickness, about 350 feet, is in sec. 21, and it thins out stratigraphically upward from there to the northwest, the lower layers being the ones that fade out. It is somewhat more than 100 feet thick in the western part of sec. 17, where it rests directly on and begins to feather out against the Artillery formation. Southeast of sec. 21 the full extent and thickness of the zone are hidden by alluvium.

In sec. 17 part of the lower zone is cut out by the Sandtrap conglomerate, which at one place may cut completely through the manganese beds. Except for insignificant places along Burro Wash, this is the only place in the Artillery region where the Sandtrap conglomerate can be seen in actual contact with manganiferous beds, and many of the manganiferous pebbles in the Sandtrap must have been derived from the lower zone at that place.

Most of the manganiferous beds of the lower zone are widely separated lenses ranging in thickness from less than an inch to, rarely, a foot and in length from a few feet to a few hundred feet, but in the western part of sec. 17 some of the manganiferous beds are 2 to 3 feet thick. In the eastern part of sec. 18 a prominent manganiferous bed reaches a thickness of about 15 feet and extends for 1,000 feet along the strike.

Up to 1941 no effort had been made to prospect the lower zone.

ORIGIN

Three problems are involved in the origin of the bedded deposits of the Chapin Wash formation: (1) The immediate origin of the deposits, that is, whether the manganese—other than that in the hard ore, which is a product of supergene alteration—was originally deposited with the sediments in which it lies (syngenetic) or was introduced later (epigenetic); (2) the source of the manganese; and (3) the mechanics and chemistry of its transportation and deposition.

The deposits are syngenetic, and the manganese oxides in them were transported and deposited largely by mechanical means in a playa basin, but the source of the manganese is less certain. Because other conceivable sources are quantitatively inadequate and evidence to the contrary is absent, it is assumed that the manganese was contributed primarily by hot springs associated with the volcanism of the time.

IMMEDIATE ORIGIN OF THE DEPOSITS

Jones[31] believed these deposits to be replacement bodies, but the more detailed studies made since his reconnaissance examination indicate a sedimentary origin. The deposits were first described as syngenetic by Hewett,[32] who included them in the small group of deposits that show "convincingly that [the manganese oxides] were laid down as part of the sedimentary rocks that contain them," for they "form persistent layers in the midst of several varieties of sediments."

This conclusion is abundantly corroborated by the evidence noted in the present examination. The field evidence is perhaps the most conclusive and may be summarized as follows from the detailed descriptions given in preceding pages:

(1) There is stratigraphic persistence not only of the manganiferous zones themselves, which seem traceable through most of the basin of deposition, but there is also persistence of individual layers at a constant stratigraphic level for as much as a mile or more.

(2) There is interstratification of barren and manganiferous beds, ranging from large-scale interbedding to minute interlamination, and pinching out of manganiferous beds among barren ones and of barren beds into manganiferous ones.

(3) The manganiferous beds include every kind of rock, from conglomerate to clay and fine-grained tuff, of whatever degree of compaction, strength, and permeability, that composes the Chapin Wash

[31] Jones, E. L., Jr., and Ransome, F. L., Deposits of manganese ore in Arizona: U. S. Geol. Survey Bull. 710-D, pp. 146-149, 1919.

[32] Hewett, D. F., in Ore deposits of the Western States (Lindgren volume), pp. 488-489, Am. Inst. Min. Met. Eng., 1933.

formation; and in all these respects any manganiferous bed that may be selected can be matched by some barren bed.

(4) Significant details of sedimentation are shown by the manganiferous beds, such as mud flakes (see pl. 20) and coarser intraformational conglomerates (see pl. 19 *A*), drying cracks filled with silt from the overlying layer, and scour-and-fill surfaces (see pl. 19 *B*).

(5) There is a general uniformity in the manganese content of the various beds, as well as throughout the unaltered part of the deposit as a whole. (See pl. 25.)

In addition to this field evidence, the fact that the ores show the same textures, or fabric, as the equivalent barren rocks and that the oxides of manganese and iron in the ore beds show the same relations to the sand grains and clay as the iron oxide of the barren beds, constitutes good evidence of syngenetic origin. The intimate association of manganese-oxides and iron-oxides suggests a similar origin for the two, particularly in view of the similarity in their chemical behavior; as iron hydroxide is a common primary cement in some sandstone [33] and a common primary constituent of some clays,[34] the manganese oxides mixed with it in the ores would seem to be primary also.

SOURCE OF THE MANGANESE

The source of the manganese is obscure. The most that can be done here is to discuss the problem, which is not simply to find a source of manganese but to find one that could have supplied the many millions of tons of manganese oxides in the deposits. The writer conceives of four possible sources: The breccia and vein deposits in the Artillery formation; the bedded deposits in the Artillery formation; the source rocks in general of the Chapin Wash formation, by decay; and hot springs.

Though some oxides were demonstrably obtained as detrital material from the breccia and vein deposits in the Artillery formation (see p. 51), such deposits could have contributed only a minute part of the total. The bedded deposits, also, in the Artillery formation must have contributed something, but unless they were many times larger than those now manifest, or unless vastly more abundant than there is any reason to suppose, they too must be considered inadequate. But even should it be assumed that the bedded deposits in the Artillery formation constituted the principal source, the problem of origin would still remain unsolved, for the ultimate source of the manganese would merely be moved one step farther into the past.

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[33] Clarke, F. W., Data of geochemistry: U. S. Geol. Survey Bull. 770, p. 543, 1924.

[34] Idem, p. 536. Twenhofel, W. H., and others, Treatise on sedimentation, 2d ed., p. 241, 1932.

Even the entire assemblage of rocks that rim the closed basin in which the Chapin Wash formation accumulated and that contributed sediments to that formation—the pre-Cambrian and Paleozoic(?) rocks and the Miocene(?) volcanics, as well as the Artillery formation—must be regarded as inadequate. These rocks presumably contain manganese in the usual proportions,[35] and the material derived from them that went to compose the Chapin Wash formation could have contained, statistically, enough manganese to form the bedded deposits. Unfortunately for the significance of any such calculation, however, the manganese in the source rocks could have become available only through chemical decomposition of the rock-making minerals that contained it, whereas the general freshness of the grains of feldspar and biotite throughout the Chapin Wash formation indicates that very little chemical decomposition took place. The same reasoning applies to the origin of the bedded deposits in the Artillery formation, for in those rocks too the feldspar and biotite are still fresh.

The remaining possible source is hot springs associated with the widespread Tertiary volcanic activity of the region.[36] Though Lindgren [37] has said that "apparently manganese is rarely deposited in large volume by hot springs," a source as closely related to igneous activity as hot springs associated with volcanism would seem to be reasonable, and considering the inadequacy of the other possible sources in the Artillery Mountains region it would seem to be the only logical alternative. This opinion is bolstered by the close association of manganese deposits and volcanic rocks in both the Artillery formation and the Chapin Wash formation. Nevertheless, even this view is not entirely satisfactory. Hot springs contributing material to a playa deposit must be located within the drainage basin of the playa, yet no evidence of hot springs has been found in the district. At first it was thought that the old vein and breccia deposits in the basement rocks were the sites of old hot springs, but later it was discovered that they antedate the Chapin Wash formation.

TRANSPORTATION AND DEPOSITION

In the absence of some conviction as to origin, it is possible to discuss the chemistry and mechanics of the transportation and deposition

[35] Clarke F. W., op. cit., p. 30, 439–455. Daly, R. A., Igneous rocks and their origin, pp. 19–26, McGraw-Hill Co., 1914. Hevesey, G. V., Merkel, A., and Wurstlen, A., Die Haufigkeit des Chroms und Mangans: Zeitschr. f. Anorg. u. Allg. Chem., vol. 219, pp. 192–196, 1934; abstracted by L. E. Steiner in Chem. Abstracts, vol. 28, p. 7214, 1934.

[36] Hewett, D. F., Manganese in sediments, in Twenhofel, W. H., and others, Treatise on sedimentation, 2d ed., pp. 568–569, 1932; Sedimentary manganese deposits in Ore deposits of the Western States (Lindgren volume), p. 489, Am. Inst. Min. Met. Eng., 1933.

[37] Lindgren, Waldemar, A recent deposit of a thermal spring in Bolivia: Econ. Geology, vol. 17, p. 305, 1922.

of the manganese only in general terms. Present knowledge suggests, however, that these processes were simple.

If the manganese now in the Chapin Wash formation was derived from the bedded deposits in the Artillery formation, it was already in the oxide form at its point of release. If derived from hot springs, the manganese either was precipitated by the spring waters directly as oxide or was soon converted to oxide by the weathering of some other manganese compound. Wad,[38] manganite,[39] psilomelane,[40] and pyrolusite[41] are all deposited by springs, and so both physically and chemically the manganese could have started on its journey to its present site in much the same condition whether it came from hot springs or from the older bedded deposits.

Each heavy rain or sheet flood on the slopes of the closed basin or bolson in which the deposits accumulated would carry the particles of manganese oxides, along with other debris, step by step toward the playa area. At each wetting some manganese oxide might temporarily go into solution, but, in the main, transportation would be mechanical. The manganese oxides, in the form of finely divided earthy particles, doubtless would act much like the clay fraction of the migrating debris, and thus, like the clay, would be distributed through all the rocks that compose the bolson deposit, from fanglomerates to the clay beds of the playa. Such a wide lithologic distribution is one of the outstanding features of the Artillery manganese deposits. Once in the playa area of the bolson, the manganese oxides and accompanying iron oxides would tend to settle with the silt and clay to form a manganiferous clay similar to clay ironstone,[42] but, as the writer (Lasky) has satisfied himself experimentally, some of the manganese oxide might stay suspended even longer than the clay, and, as it settled, might form laminae and blebs of relatively pure oxide that might be covered with more silt and clay after the next rain or wind storm. (See pls. 17*A*, 21, and 22*A*.)

Playa lakes may persist for some time during periods of unusual rainfall, and at such times the manganese oxides would have greater opportunity to go into solution and later form chemical precipitates. The layers and laminae of essentially pure manganese oxides in the Artillery ores were presumably formed in this way; they contain as much as 60 percent of manganese, which is equivalent to 90 percent or more of the usual manganese oxides, and such a clean separation of manganese from iron in the usual colloidal complexes in the ores can take place only chemically.[43] Whether the manganese-oxide pre-

[38] Hewett, D. F., Sedimentary manganese deposits, in Ore deposits of the Western States (Lindgren volume), pp. 489–490, Am. Inst. Min. Met. Eng., 1933.
[39] Allen, E. T., personal communication.
[40] Lindgren, Waldemar, op. cit., p. 305.
[41] Hendricks, T. A., personal communication.
[42] Clarke, F. W., Data of geochemistry: U. S. Geol. Survey Bull. 770, p. 536, 1924.
[43] Clarke, F. W., op. cit., pp. 539–541.

cipitate would settle so as to form relatively pure layers or blebs, or would become contaminated with clay and silt, would depend upon whether or not precipitation began while the water was still muddy, whether additional clay and silt were added to the playa before the manganese oxide mud became too compact for the new material to settle into it, and whether wave action stirred up and mixed the bottom sediments. The layers of sooty manganese oxides interlaminated with clay, silt, and tuff and bounded by scour-and-fill surfaces such as illustrated in plate 19*B*, would seem to indicate successive stages in a playa lake that persisted for some time.

MODIFICATIONS AFTER ORIGINAL DEPOSITION

The only significant modification of the manganiferous material after its original deposition is represented by the hard ore. It might be supposed with some confidence that the manganese compounds in each layer were modified as the layer dried and became covered and compacted by later sediments or while the layers were exposed to weathering under the conditions of bolson accumulation, but modifications due to such causes would be difficult to recognize, and therefore, for the purpose of this discussion, the material originally deposited is defined as that composing the ores at the end of the period in which they were laid down.

Under this definition the clay and sandstone ores of the area represent the material originally deposited. The similarity of ore to barren sediments, particularly with respect to the manganese and iron oxides in them, has been cited as evidence that the deposits are syngenetic, which is equivalent to saying that this similarity is evidence that the ores are in the same condition as when originally deposited. Additional evidence lies in the fact that the manganese-bearing part—that is, the matrix or cement—in any kind of rock in any part of the formation is the same as in any other kind of rock in any other part. If the material should represent a modification of the manganese after original deposition, it would mean not only that the altering solutions penetrated every part of the deposit so completely as to preserve in minute perfection such delicate features of stratification as mud flakes and the intimate associations of barren and manganiferous laminae but also that they circulated as freely through the clay as through the sandstone and conglomerate.

Three periods have been recognized during which these original clay and sandstone ores could, conceivably, have been modified: (1) The erosion interval that preceded deposition of the Sandtrap conglomerate; (2) the erosion interval that preceded deposition of the Quaternary (?) basalt; and (3) the current cycle of erosion and weathering. Of these three possible periods, the second appears to have been the most significant and the third the next. Though the first period is theoretically possible, none of the altered ores can be unquestionably related to it; in fact, except for the uncertainties regarding the hard ore, as described below, there appears to have been no alteration of any significance at that time, for not only has altered ore not been found in obvious relationship to the pre-Sandtrap unconformity, but the manganiferous pebbles in the Sandtrap conglomerate are to all purposes identical with the material of the unaltered ores.

HARD ORE

The hard ore seems closely related to the early Pleistocene (?) erosion surface under the basalt of Manganese Mesa, and so the alteration that produced the hard ore is presumed to be most closely related to the second of the three periods named above, but some alteration may have taken place also during the pre-Sandtrap period and during the current cycle of erosion. As indicated in plate 25, the manganese beds prior to the eruption of the basalt were in part exposed at the surface on a flat dip slope and in part lay at relatively shallow depth below it. Under the semiarid conditions of the time, this situation would have been ideal for supergene alteration of the ores. On the other hand, the pre-Sandtrap surface reached very close to the manganese beds here and there in that area, and so there may have been some opportunity for alteration at that time as well as later.

The fact that the hard ore consists typically of altered sandstone and conglomerate ores suggests a close relationship between permeability and alteration, and this implied relationship has some significance with respect to alteration during the current cycle. Although the wide distribution of hard ore, as cut in the drill holes through the basalt of Manganese Mesa, indicates that the alteration in general can hardly be related to the present surface, yet surface waters may have gained access and penetrated for considerable distances along the more permeable beds when those beds formed the floors of Maggie Canyon and Chapin Wash. Water doubtless gained access to the manganese beds also along the base of the basalt, for such horizons are notoriously permeable.

The processes leading to formation of the hard ore included leaching, replacement by opal and calcite, and reconstitution of the original manganese oxides to manganite and psilomelane. Replacement of part of the matrix of the ores by opal and calcite means solution of the material replaced; moreover, since there are vugs crusted or filled with opal and some porous hard ore containing no opal or calcite at all there must have been some places where leaching or solution outstripped replacement or was unaccompanied by it. As alteration tended to produce material composed only of sand grains, calcite, opal, and the manganese oxides psilomelane and manganite, the material removed must have been chiefly the clay and iron oxide of the original cement. The spatial relation of the opal or calcite to the psilomelane-manganite crusts on the sand grains (see p. 59) suggests that, in the main, reconstitution of the manganese oxides preceded introduction of opal or calcite. Should the barite "roses" and concretions and the celestite nodules found locally prove to belong to this period of alteration instead of to a later one (see p. 74), it would imply that the process included a concentration of dispersed barium and strontium sulfate. The source of the opal is probably volcanic dust, both from the tuff interbedded with the ores at the general horizon of the hard ore and from that derived from the volcanic source rocks and distributed widely in the sediments. The clay matrix material that was dissolved and removed doubtless contained its proportionate content of volcanic material, whose fine grain size would have made it particularly soluble. In fact the presence of such material may be the reason why the clay cement was so readily dissolved. The relation of grain size to solubility is well recognized,[44] and it is illustrated in this particular area by the fact that in the opalized tuffs only the microcrystalline matrix is opalized, the larger shards being apparently uncorroded. (See pls. 16 and 27.)

The reconstitution of the manganese to psilomelane and manganite appears to be a result of solution and deposition rather than of simple hardening or crystallization of amorphous or colloidal oxides originally deposited. Several features indicate this. Particularly significant are the fact that the iron oxides have been removed from the reconstituted parts, which implies chemical separation, and the uniform age or space relation between the manganite and psilomelane. Pockets of friable white ash that cross bedding laminations in some specimens of rich opalized tuff ore, and rich streaks of oxides that cross laminations in other specimens of generally weak ore, also prove solution and migration of manganese. It seems clear that the relative richness of much of the hard ore, as compared with the average sandstone or clay ore, is due to enrichment by migration of manganese and by leaching of some of the valueless material.

MODIFICATIONS RELATED TO THE PRESENT CYCLE

Enrichment.—Here and there cliff exposures of hard ore have a crust of psilomelane, rarely more than an inch thick. Presumably this crust was formed by capillary migration of manganese in response to alternate wetting and drying. Doubtless the same process

[44] Murata, K. J., Volcanic ash as a source of silica for the silicification of wood: Am. Jour. Sci., vol. 238, No. 8, pp. 586–596, 1940. Gives a good summary of the chemical and physical properties of volcanic ash that make it a rich source of silica.

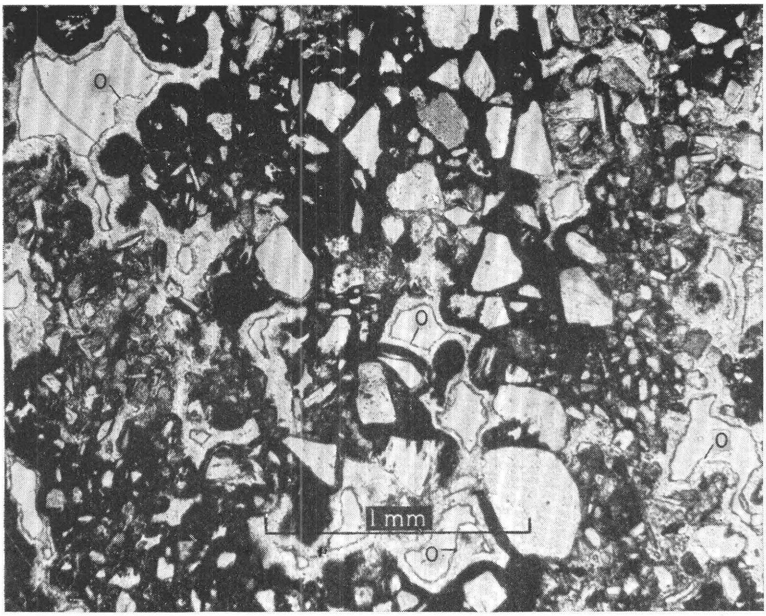
occurs also in the uncemented sandstone ores, and the absence, or at least apparent absence, of a similar enriched crust from exposures of such ore probably means that steep faces of uncemented ore tend to slough away before a crust of recognizable thickness can accumulate. At some places there has been residual enrichment where manganiferous beds form a dip slope.

There has also been some enrichment with psilomelane where the hard ores are cut by stringers of chalcedony. The walls of the chalcedony stringers are commonly replaced by psilomelane, and small threads of psilomelane extend into the adjacent ore. The chalcedony is commonly accompanied by calcite, locally in hexagonal-shaped crystals, and at the Maggie tunnel, in Maggie Canyon, the stringers contain also opal and barite. Some stringers contain barite interbanded with psilomelane and bordered by banded psilomelane walls as much as 2 or 3 inches thick; Hewett found concretion-like growths of interbanded psilomelane and microcrystalline barite in the ore at the Maggie tunnel.

The ore shipped from the Graham prospect (see p. 5) consisted of secondary (supergene) oxides that had replaced "sand-calcite" ore and other sedimentary ore along the west spur of the Common Corner fault. The secondary ore is largely massive psilomelane, which partly forms botryoidal growths in cavities. Some cavities are coated with a crust of quartz and filled with calcite. Scattered about the locality are nodules of celestite, none of which, however, were found in place. Because these nodules and the similar barite-psilomelane concretions at Maggie tunnel have been found only where supergene enrichment of the present cycle of erosion and weathering has occurred, they are presumed to represent a phase of the process that produced the crystalline barite of this cycle and the vein deposits in the Sandtrap conglomerate and Quaternary basalt.

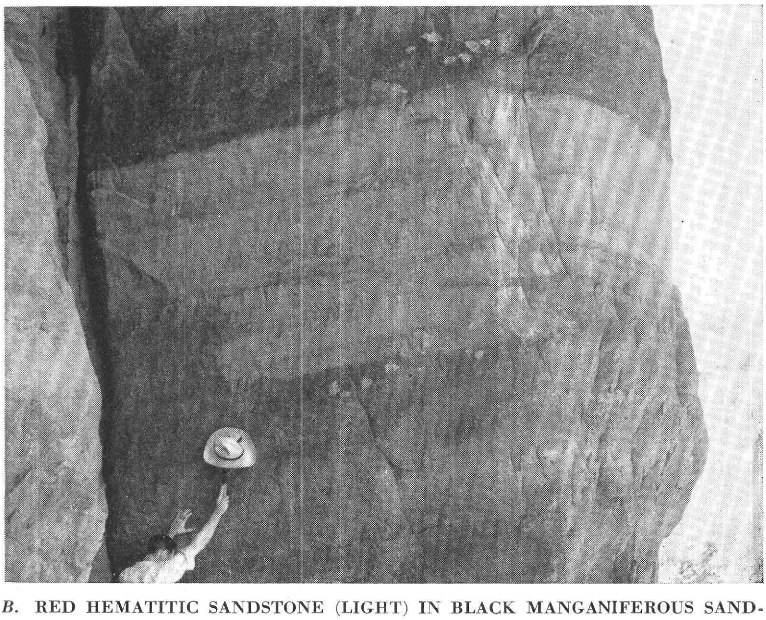
At no place is enriched ore unquestionably related to the present cycle sufficiently extensive to influence estimates of reserves.

Leaching.—In Chapin Wash, a few hundred feet downstream from the fault on the Minnesota No. 10 claim, the manganiferous sandstone of the upper of the two main manganiferous beds gives way for about 30 feet to a red hematite-cemented sandstone. The contacts between red and black sandstone partly follow and partly cross the bedding; they are remarkably sharp and cut across all details of lithologic character, even squarely across individual sandstone partings. Some of this material is typical hard ore cemented with sand-calcite, and some is typical friable sandstone. In thin section the red sandstone is seen to differ from the manganiferous counterpart in having a bright-red hematite pigment and cement. At one spot, high on the arroyo wall where it could not be examined closely, the reddening seems



A. PHOTOMICROGRAPH OF OPALIZED MANGANIFEROUS SANDSTONE.

Fuzzlike contacts between opal (*o*) and the manganese oxides (black) are due to crystals of manganite. (See pl. 26.)



B. RED HEMATITIC SANDSTONE (LIGHT) IN BLACK MANGANIFEROUS SANDSTONE (DARK).

Note manner in which contact between red and black sandstone crosses bedding and the tongues of black sandstone in red sandstone at edge of bluff to right. Interpreted as leaching of manganese from a sandstone originally uniformly manganiferous. Burro Wash, at north end of main manganese exposure.

to be related to a fissure. There is a similar and somewhat more extensive occurrence at the north end of the main exposure in Burro Wash, in the Price block, though all the material there is friable sandstone ore. (See pl. 28*B*.)

At both places one gets a strong impression that the manganese has been leached out, leaving behind the red iron-oxide component of the cementing material.

RESERVES

EXTENT OF EXPLORATION TO JUNE 1941

To June 1941 the only exploration of the bedded manganese deposits had been along the upper manganese zone on the Artillery Mountains side of the basin. The exploration openings consisted of surface cuts, shallow underground workings, and diamond-drill holes. Up to that time 43 vertical holes had been drilled, 15 of them by the United States Bureau of Mines. They ranged in depth from 180 feet to 805 feet and totaled about 13,400 feet. Their location is shown in plates 2 and 45. Thirty-five of the holes, 25 south of Maggie Canyon and 10 north of Maggie Canyon, had been drilled through the basalt of Manganese Mesa, to investigate the deposits in the Maggie block, 6 had been drilled in the Upper Chapin block, and 2 in the lower Chapin block. No drilling had been done in the Price block.

Of the holes that cut manganiferous beds, only two, No. 5 in the Maggie block and No. 19 in the lower Chapin block, were drilled completely through the manganese-bearing formation, so that the reserves in the area drilled are greater than has actually been demonstrated. (See pls. 10 and 25, particularly at holes 3, 11, and 12.)

For some of the earlier holes, drilled before it was recognized that degree of blackness is not a good indication of grade (see p. 55), only the cores from the darker beds were sampled, so that grade can be computed for only part of the known reserves.

BASIS OF ESTIMATES

The estimates of reserves are based on the diamond-drill data supplemented by 51 samples collected for this purpose by Lasky and on measurements of areal extent and thickness beyond the limits of the diamond-drilling, all interpreted in the light of the geologic investigations described in the preceding parts of this report. The position of 48 of Lasky's 51 samples is shown on plate 24; the other three were taken along Burro Wash in the Price block. The location of these samples represents a compromise between the desire to take samples at regular intervals and the necessity of taking them at satisfactory exposures. For the thicker and richer exposures an effort was made to cut a sample for each 10 feet of beds. The samples were analyzed in the laboratories of the Geological Survey.

A factor of 16 cubic feet per ton was used in estimating tonnages for all but the hard ore, for which a factor of 15 cubic feet per ton was used. These factors were obtained by averaging bulk specific-gravity determinations made on 32 samples of typical ore collected during the investigation.

It is assumed that no bed less than 5 feet thick can be mined, unless it is of extraordinary richness. It is also assumed, in view of the fact that the deposit is so low-grade that it must be mined by large-scale methods, that any barren layer less than 5 feet thick and lying between minable manganiferous beds would have to be extracted with the ore. For the beds of minable thickness, all material has been included that is obviously manganiferous. This is equivalent to taking a cut-off value of about 1.5 percent of manganese, but some material containing as little as 1 percent of manganese is included.

For the part of the Maggie block explored by the Bureau of Mines (see pl. 24), estimates of reserves containing 10 percent or more of manganese were made jointly by R. J. Sanford of the Bureau of Mines and Lasky and Vard Johnson of the Geological Survey. Estimates for the lower grades of material in that part of the Maggie block and estimates for the rest of the Maggie block and for the several other blocks were made by Lasky.

LOWER ZONE[45]

As the lower zone has not been explored, no estimate of its reserves can be made that would have any significance. Though many tens of thousands, and perhaps millions, of tons of manganese may be present in the aggregate, it is impossible to predict in advance of exploration whether it is sufficiently concentrated anywhere to constitute a reserve.

UPPER ZONE[46]

MAGGIE BLOCK

The probable limits of potential ore-bearing ground in the Maggie block, as explored to the spring of 1941, are indicated in plate 24. The average aggregate thickness of the manganese-bearing layers as indicated by the drill holes is 68 feet, and the average for the entire area, extrapolating beyond the drill holes, is about 65 feet.

The Maggie block is estimated to contain 80,000,000 tons of ore averaging 3.75 percent of manganese. Table 3 lists the grade and tonnage of the three kinds of ore that make up this total, and plate 25 indicates their general boundaries. The boundary between sandstone ore

[45] See p. 66 for definition of lower zone.
[46] See p. 61 for definition of upper zone.

and clay ore largely follows bedding planes, but no attempt was made to indicate this detail in the illustration. The apparent horizontal extent of the hard ore, which is the principal source of the higher grades of material, is indicated in plate 24. The thickness of this hard ore as cut in the drill holes ranges from 4 to 56 feet, and the average for the block is about 20 feet.

In addition to this 80,000,000 tons, there is about 40,000,000 tons representing the manganiferous beds cut in some drill holes but not sampled (see p. 75) and those too poorly exposed in Maggie Canyon to be sampled by the writer. This 40,000,000 tons is assumed to have an average grade approximating the combined average for sandstone and clay ores and thus to contain an average of about 3 percent of manganese.

Table 4 shows the apparent tonnages of various grades of ore by 5-percent increments. The breakdown of the gross tonnage into the various grades in the Maggie block is based primarily on drill-hole samples, each of which represents an interval of 5 feet or less (see pl. 25), and in this breakdown a scrupulous effort was made not to dilute the better-grade parts with underlying or overlying material of lower grade. The tonnages given for the various grades above 5 percent could be increased 3 to perhaps 6 times, by including lower-grade material, before the average grade would drop below the lower limit of the bracket.

UPPER CHAPIN BLOCK

The horizontal extent of the manganese-bearing zone in the Upper Chapin block is indicated in plate 24. The average aggregate thickness of manganiferous beds in this block is estimated to be about 65 feet.

The Upper Chapin block is estimated to contain about 35,000,000 tons of sampled material averaging 4 percent of manganese, and 15,000,000 tons of unsampled material. The grade and tonnage of the various classes of ore are shown in tables 3 and 4. The unsampled material consists largely of sandstone ore. As the ore below the outcrops has not been well prospected, the basic data for the Upper Chapin block, particularly as to grade of ore, are not quite so complete as for the Maggie block, but the order of magnitude of the figures given seems good. It is noteworthy that the average manganese content of the various kinds of ore, as well as the general average, is nearly the same for the two blocks.

LOWER CHAPIN BLOCK

The Lower Chapin block has been so little explored that no more than a tentative estimate of minimum reserves can be prepared. No attempt has been made by the owners of the property to investigate the continuity of ore between the two principal outcrops, and the only effort to investigate the extent of the deposit down dip from the outcrop is represented by two diamond-drill holes, each directly down dip from one of the two outcrops, and by a 50-foot tunnel.

The average thickness of what is exposed at the outcrops and cut in drill-hole No. 18 is about 20 feet, and the average manganese content of this material is about 7 percent. Inasmuch as each acre underlain by ore 20 feet thick would be equivalent to about 50,000 tons, a considerable amount of ore may be present. It is estimated that there is a minimum of about 2,000,000 tons. All this is probably sandstone ore, and, as in the other blocks, most of it probably contains less than 5 percent of manganese. (See tables 3 and 4.)

PRICE BLOCK

The most continuous part of the manganiferous zone in the Price block is 8 to about 35 feet thick and crops out for 2,000 feet. (See p. 65.) As the croppings of the same beds to the southwest beyond the Price fault zone are very weak, the ore body cannot safely be assumed to extend down dip any farther than the nearest fork of the fault, and the tonnage thus indicated is about 1,500,000.

Two groups of samples were taken, one representing 30 feet of beds at the 50-foot adit in Burro Wash, near the northern end of the exposure, and the other representing 15 feet of beds 750 feet downstream. The manganese content of these samples ranges from 0.81 to 2.41 percent and averages 1.6 percent, but samples taken by others are reported to have contained as much as 12 percent.[47] All is sandstone ore.

TOTAL RESERVES

Tables 3 and 4 below summarize the reserves of bedded manganese ores in the Artillery area as explored to June 1941. There appears to be a minimum of about 175,000,000 tons of manganiferous material, of which about 125,000,000 tons averages 3.5 to 4 percent of manganese and 50,000,000 tons is unsampled but is probably of similar grade. Of this total between 15,000,000 and 20,000,000 tons is estimated to contain 5 percent or more of manganese, and somewhat more than 2,000,000 tons is estimated to contain 10 percent or more.

Further drilling to delimit the ore body in the Lower Chapin block may reveal additional reserves. In addition, many square miles of new territory remain unexplored. It is probably safe to say that the area contains an assured minimum of 200,000,000 tons averaging 3 to 4 percent of manganese, of which about 20,000,000 tons contains 5

[47] Hewett, D. F., and others, Mineral resources of the region around Boulder Dam: U. S. Geol. Survey Bull. 871, p. 81, 1936.

percent or more of manganese and 2,000,000 to 3,000,000 tons contains 10 percent or more.

To what extent these deposits constitute a resource, for exploitation either in normal times or in times of acute national need only, is a metallurgical and economic problem. Beneficiation by simple gravity methods seems out of the question because of the physical nature of the ores, but in view of the enormous tonnage that is readily minable it may be expected that the manganese will be made available sooner or later, either by improvements in present flotation or hydrometallurgical technology or by new methods of treatment. The M. A. Hanna Co. conducted laboratory research from 1938 to 1941 on new methods of treatment, and the United States Bureau of Mines has recovered metallic manganese from the Artillery ores on a laboratory scale.[48] Further work, both by the M. A. Hanna Co. and by the Bureau of Mines, aimed at making these processes adaptable commercially, was in progress in July 1941.

[48] Shelton, S. M., Royer, M. B., and Towne, A. P., Electrolytic manganese: U. S. Bur. Mines Rept. Inv. 3406, p. 13, 1938.

TABLE 3.—*Reserves of manganese ore in the Artillery Mountains, Ariz., classified according to kind of ore*

[Estimates based on explorations to June 1941]

Kind of ore	Maggie block		Upper Chapin block [1]		Lower Chapin block		Price block		Totals	
	Tons	Manganese (percent)	Tons	Manganese (percent)	Tons	Manganese (percent)	Tons	Manganese (percent)	Tons	Manganese (percent)
Hard ore	15,000,000	6.5	400,000	8					[2] 15,500,000	6.5
Sandstone ore	40,000,000	3.0	20,000,000	4	2,000,000	7	1,500,000	1.5	[2] 65,000,000	3.5
Clay ore	25,000,000	3.5	15,000,000	4					40,000,000	3.5–4
Total sampled	80,000,000	3.75	[2] 35,000,000	4	2,000,000	7	1,500,000	1.5	[2] 120,000,000	3.5–4
Unsampled	40,000,000	[3] 3.0	15,000,000	[3] 4					55,000,000	3–3.5
Grand total	120,000,000	3.5	50,000,000	4	2,000,000	7	1,500,000	1.5	[2] 175,000,000	3.5–4

[1] Basic data not as good as for Maggie block, but estimates given are thought to be of right order of magnitude.
[2] Round numbers.
[3] Estimated.

TABLE 4.—*Reserves of manganese ore in the Artillery Mountains, Ariz., classified according to grade*

[Estimates based on explorations to June 1941]

Manganese (percent)	Maggie block: South of Maggie Canyon: Tons	South of Maggie Canyon: Cumulative totals: Tons [2]	South of Maggie Canyon: Cumulative totals: Manganese (percent)	North of Maggie Canyon [1]: Tons	North of Maggie Canyon [1]: Cumulative totals: Tons [2]	North of Maggie Canyon [1]: Cumulative totals: Manganese (percent)	Total Maggie block: Tons	Total Maggie block: Cumulative totals: Tons [2]	Total Maggie block: Cumulative totals: Manganese (percent)
Over 20	5,000	5,000	21.5	60,000	60,000	23.0	65,000	65,000	23.0
15–20	245,000	250,000	16.2	140,000	200,000	18.5	385,000	450,000	17.3
10–15	1,000,000	1,250,000	12.7	750,000	1,000,000	12.7	1,750,000	2,250,000	12.7
5–10	5,000,000	6,250,000	7.9	1,500,000	2,500,000	9.4	6,500,000	8,750,000	8.3
Under 5 sampled [3]							70,000,000	80,000,000	3.75
Total under 5							110,000,000	120,000,000	3.5

Manganese (percent)	Upper Chapin block [4]: Tons	Upper Chapin block [4]: Cumulative totals: Tons	Upper Chapin block [4]: Cumulative totals: Manganese (percent)	Lower Chapin block: Tons	Lower Chapin block: Cumulative totals (tons)	Price block: Tons	Price block: Cumulative totals (tons)	Grand totals [2] (tons)	Grand cumulative totals [2] (tons)
Over 20	5,000	5,000	22					70,000	70,000
15–20	5,000	10,000	20	500,000 (Over 20 to 5–10)				390,000	460,000
10–15	50,000	60,000	12					1,800,000	2,250,000
5–10	7,500,000	7,500,000	7		500,000			15,000,000	17,000,000
Under 5 sampled [3]	27,500,000	35,000,000	4	1,500,000	2,000,000	1,500,000	1,500,000	100,000,000	120,000,000
Total under 5	40,000,000 to 45,000,000	50,000,000	4	1,500,000	2,000,000	1,500,000	1,500,000	155,000,000	175,000,000

[1] Basic data not as good as for block south of Maggie Canyon.
[2] Round numbers.
[3] The lower cut-off value for this material is about 1.5 percent. See page 76.
[4] Basic data not as good as for Maggie block, but estimates given are thought to be of right order of magnitude.

RECOMMENDATIONS FOR FUTURE PROSPECTING

Further exploration in the Artillery area might have any one or all of three purposes—to obtain more data on known ore bodies, to investigate extensions of known ore bodies not yet fully delimited in either extent or thickness, and to seek new ore.

It seems clear that the Maggie block should be more closely drilled in order to determine the continuity of some of the higher-grade parts of the hard ore. (See pl. 24.)

The hard ore is the only material there is any chance of beneficiating by present methods, and before mining is started it would seem desirable that the tonnage, grade, spacing, and geometry (size, shape, and attitude in space) of the higher-grade shoots be determined more closely than can be done from data now available. Drilling by the United States Bureau of Mines has delimited the known higher-grade shoots south of Maggie Canyon closely enough to give a good idea of reserves and of the geometry of the deposits, but north of Maggie Canyon only enough drilling has been done to indicate that discontinuous shoots of relatively high grade are present.

Should mining ever be started on the Artillery manganese deposits and a method devised for treating the sandstone and clay ores, more complete data would be needed on the deposits of such ores in the Upper Chapin block.

There is a good chance that the hard ore may form a continuous band between the known shoots of hard ore in the Maggie Canyon area and the cropping of hard ore in the Upper Chapin block; large areas of this tract remain unexplored, for only two holes have been drilled between the two localities. (See pls. 5, measured section 4, and 24.)

Doubtless sooner or later the down-dip extension of the ore in the Lower Chapin block will be further explored, and if the Artillery manganese deposits are ever mined, ore in the Maggie block at horizons below those reached by present drill holes doubtless will be looked for. (See p. 75.)

The places in which new ore may best be sought include (a) Plancha Mountain, (b) the Price block, (c) the down-dip extension of the part of the upper zone that crops out in secs. 23 and 26, T. 11 N., R. 13 W., and (d) the area underlain by the lower zone.

At Plancha Mountain the possibility that ore underlies the basalt merits consideration because of the scattered croppings of manganiferous beds through the slide rock on its flanks. In the Price block some of the manganiferous beds below the main zone are as much as 2 or 3 feet thick and very black; they plunge out of sight below the level of Burro Wash, and their down-dip extension should be explored, for although the Chapin Wash formation is not very thick in that area it is thick enough to allow these beds to increase to minable size. The small exposure farther up Burro Wash may deserve at least one drill hole; the two manganiferous layers that crop out are thin and apparently of very low grade, but here too there is room down-dip for a body of commercial size.

The lower zone and the upper zone where exposed in secs. 23 and 26 are composed mainly of barren layers, but both zones are several hundred feet thick and may have parts that are more uniformly manganiferous. The chances of this being so and of the material being of good grade can be determined only by exploration, for there is no satisfactory geologic basis on which to form a judgment. Both zones are within reasonable drilling range (see pl. 1, geologic sections), and together they constitute many square miles of potential ore-bearing ground.

It should be added, however, that any new ore that may be found is likely to be similar to that already discovered, both in grade and kind. In view, therefore, of the great tonnages already known, new exploration, however likely it may be to disclose new ore, could well wait on improvements in methods of treatment.

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