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TIN-BEARING PLACERS NEAR GUADALCAZAR, STATE OF SAN LUIS POTOSI, MEXICO

BY

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TIN-BEARING PLACERS NEAR GUADALCÁZAR, STATE OF SAN LUIS POTOSÍ, MEXICO

By Carl Fries, Jr., and Eduardo Schmitter

ABSTRACT

Large placers containing tin, mercury, and minor quantities of silver and gold are found near Guadalcázar, in the central part of the State of San Luis Potosi, Mexico. The village of Guadalcázar, which is centrally located in respect to the placers, is 96 kilometers by road northeast of the city of San Luis Potosí, the capitol of the State and a railroad center. The bedrock in the region consists mainly of Cretaceous limestone and shale, which, at a point about 4 kilometers northwest of Guadalcázar, is intruded by a small stock of porphyritic granite. This stock forms the highest part of the region and is surrounded by a limestone upland deeply dissected by steep-sided arroyos and characterized by numerous sinks. Two of the largest sinks, the Guadalcázar and Realejo Basins, contain large coalescing alluvial fans composed of granitic gravel—the placers—eroded from the stock. The metallic minerals in this gravel were originally deposited in veins and irregular mineralized zones in the granite and in the limestone near the granite contact.

The gravel deposits may be divided into three alluvial fans, each of which was derived from a separate part of the granite stock. The largest, the Papas fan, is estimated to contain 320,000,000 cubic meters of granite gravel. The next largest, the San Diego fan, contains about 214,000,000 cubic meters, and the small Santa Elena fan contains only 17,000,000 cubic meters. The gravel is poorly sorted and contains a high proportion of fine material, but there are few boulders larger than 0.6 meter across. Tests of drill cores from one large area have shown that, on the average, about 28 percent of the gravel is coarser than 16 mesh, 42 percent is finer than 16 mesh but coarser than 200 mesh, and 30 percent is finer than 200 mesh. Although the material is firmly compacted when dry, it disintegrates readily in water and could be mined with either power shovels or draglines.

The tin is in the mineral cassiterite, and the mercury is in cinnabar. Part of the silver is in sulfide minerals and a part may be alloyed with the placer gold, but most appears to be in very fine grained secondary minerals. The gold in the finer fractions is free, and that in the coarser fractions is chiefly in sulfide minerals and their oxidation products. Most of the metallic minerals in the fraction finer than about 35 mesh appear to be free from gangue, but most of those in the coarser fractions are attached to waste minerals, from which they could be freed only by grinding.

Assays of the metal content of a large block of material near the apex of the Papas fan gave an average of about 0.0084 percent of tin, 0.0015 percent of mercury, 9.44 grams of silver to the metric ton, and 0.058 of a gram of gold.

The rest of the Papas fan may be slightly leaner than the part tested, and the San Diego fan may be even more lean, but the small Santa Elena fan is apparently somewhat richer. The amounts of metal contained in the block tested, which represents 96,204,400 cubic meters (176,156,300 metric tons) of gravel, are 14,800 metric tons of tin, 2,640 tons of mercury, 1,662,920 kilograms of silver, and 10,220 kilograms of gold. The amounts of metal contained in the rest of the Papas fan may be somewhat greater than those in the part tested. The amounts in the San Diego and Santa Elena fans combined, however, are probably considerably smaller than those in the entire Papas fan. These amounts of metal could not be recovered, however, for recovery losses would be high.

Tests made by investigators using different methods have given widely different recoveries. The most complete tests made, however, in which equipment designed for recovering cassiterite commercially from very fine gained material was used, indicate that it may be possible, in commercial practice, to recover at least 41 grams of tin, 5 grams of mercury, 0.25 of a gram of silver, and 0.008 of a gram of gold per metric ton of heads, in metal or high-grade marketable concentrates.

The placers contain no reserves, in the economic sense of the term, inasmuch as they cannot be mined commercially at 1946 metal prices. Nevertheless, if tin and mercury attain twice this value, the placers might be mined at a profit. In that event, then, it would be possible to recover from the block tested perhaps 7,220 metric tons of tin, 880 tons of mercury, 44,040 kilograms of silver, and 1,410 kilograms of gold, amounts that may be considered to represent the "reserves" now known.

Owing to the low grade of the material, the placers would have to be mined on a very large scale to hold to a minimum the cost of treatment per metric ton. It has been estimated that, in order to treat 7,500 cubic meters of material a day, the consumption of new water—beyond what might be reclaimed from the tailings—would amount to about 18,900 liters a minute. How great a supply might be developed is not known, nor have any pumping tests been made. The region has no permanent streams, and storage of all runoff would provide only a small part of the new water required. The water table in the limestone appears to be at a depth from which it might not be feasible to pump. Although the gravel in the Guadalcázar Basin is apparently saturated, it may not yield as much water to pumps as might be expected, because of its relative impermeability. Some thin aquifers have been cut in shallow wells and in drill holes, and these and others like them would undoubtedly yield their water to pumps; but since the aquifers appear to be only small lenses of coarse material deposited in the beds of intermittent streams while the fans were being built, they may not yield large quantities of water. After a pit has been excavated, appreciable quantities may drain into it from aquifers and other less permeable beds. More water might be obtained, perhaps, from such a pit than from a series of wells. It would be much more difficult to develop a supply of water at Realejo than at Guadalcázar. Careful pumping tests should be made before the scale of mining is decided, in order to assure a supply of sufficient volume.

INTRODUCTION

LOCATION AND ACCESSIBILITY

Large gravel deposits containing small quantities of tin, mercury, gold, and silver occur near Guadalcázar, in the central part of the State of San Luis Potosí, Mexico (see fig. 11). They lie in two separate, enclosed basins. The village of Guadalcázar, which is in the larger of these two basins, can be reached by automobile over a narrow, rough, dirt road 18 kilometers long, which leaves the paved highway between the cities of San Luis Potosí and Antiguo Morelos at a point 78 kilometers from San Luis Potosí. This dirt road is in sufficiently good repair to be traveled by loaded small trucks, even during the rainy season; the trip each way requires about an hour and a half.

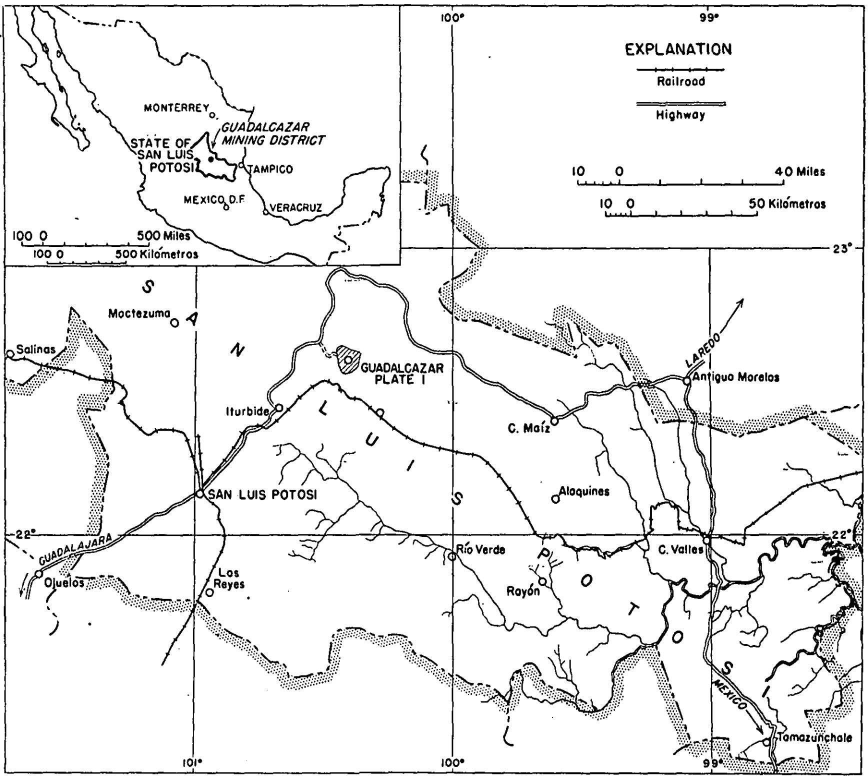

FIGURE 11.—Map of the State of San Luis Potosí showing location of the Guadalcázar region.

To drive from the road junction to the city of San Luis Potosí requires about an hour and a quarter. The village of Realejo, in the smaller basin, can be reached by automobile either from Guadalcázar, in about 50 minutes, over 11 kilometers of narrow mountain road, or directly from kilometer 83 on the paved highway, in about an hour over approximately 16 kilometers of dirt road with very steep grades. All parts of the gravel deposits could be made accessible by automobile at small cost. The nearest readily accessible shipping point is the city of San Luis Potosí, which is a rail center on the main line between Mexico City and Laredo, Tex. A branch of this line extends to Tampico, and another connects at Chicalote, in the State of Aguascalientes, with the main line between Mexico City and El Paso, Tex.

HISTORY OF EXPLORATION

Gold, silver, and mercury have been recovered on a small scale from arroyos in the gravel deposits by local miners for more than 50 years, but the amounts produced, though not definitely known, have undoubtedly been small. No attempt has yet been made to produce tin commercially. Near the close of the first World War a mining company tested recoveries of gold, silver, mercury, iron, and lead from the gravels, but no commercial operation resulted.[1] Although tin was reported in the Guadalcázar region as early as 1873,[2] the possibility of recovering it commercially was not recognized until 1927, when appreciable quantities were found in samples taken and sent for analysis by D. B. McAllister of San Luis Potosí. Shortly after this, the gravels near the village of Guadalcázar were briefly examined and sampled by the American Smelting & Refining Co., whose findings discouraged further study. In 1938 the Compañía Minera de Peñoles made a brief examination, the results of which did not seem to warrant the hope that the deposits could be mined profitably at that time. The London Tin Corp. carried on extensive studies in 1937–38, drilling five holes with a Banka drill and hand auger and assaying the samples thus obtained. This work was discontinued for political reasons before the entire sampling program had been completed.

In 1940, W. F. Foshag of the United States National Museum made a mineralogic study from samples sent to him by D. B. McAllister, of the heavy minerals in gravel from several of the arroyos in the region. In the spring of 1941 W. F. Foshag and Carl Fries, Jr., visited the deposits and collected samples representing not only large volumes of the gravel exposed in the walls of several arroyos near Guadalcázar and Realejo, but also the granite. These samples were subsequently studied by Carl Fries, Jr., and Miss Jewell J. Glass in the laboratories of the United States Geological Survey in Washington. The results of these studies in field and laboratory were briefly described by Foshag and Fries in 1942.[3]

During the spring of 1941 the Compañía Minera Guadalcázar, S. A., which then controlled the Guadalcázar placers, tested recoveries of the metallic minerals by means of a small power-operated jig. The method and equipment used were found to be inadequate for recovering the fine-grained minerals present, and work was discontinued

[1] Wittich, Ernesto and Ragotzy, F., Apuntes preliminares acerca de la zona minera de Guadalcázar, S. L. P.: Petróleo, vol. 13, no. 196, p. 6, April 1920.

[2] Anonymous, Guadalcázar: El Minero Mexicano, vol. 1, no. 21, p. 5, Aug. 28, 1873.

[3] Foshag, W. F., and Fries, Carl Jr., Tin deposits of the Republic of Mexico: U. S. Geol. Survey Bull, 935–C, pp. 107–117, 1942.

before the end of the summer of that year. In the fall of 1941, the San Luis Mining Co. excavated 16 test pits in the area previously investigated and took samples from them for determining the metal content of the material, as well as for testing recoveries by means of ordinary gravity-concentrating equipment. These preliminary tests were continued through the spring of that year, while the Panaminas Corp. briefly examined and tested the Realjo placers. In July of the same year the San Luis Mining Co. started a drilling program in order to obtain samples of the deeper-lying gravel for more comprehensive tests. The drill cores obtained were treated, under the direction of F. A. Beauchamp of Hamilton, Beauchamp & Woodworth, at Tecamachalco, D. F., in the experimental ore-dressing laboratory of Fomento Minero, an agency of the Mexican Government. These treatment tests were continued until February 1943, when it became apparent that the gravel could not be treated commercially by the methods of concentration used, and the San Luis Mining Co. decided against further investigation.

Late in 1944, the Compañía Minera Guadalcázar obtained a 20-ton sample of placer material from north of the village of Guadalcázar and sent a small part of this for treatment tests to the Consolidated Mining & Smelting Co. of Canada, Ltd., which had been recovering tin commercially for several years from low-grade tailings after extraction of lead and zinc by flotation. As a result of the satisfactorily high recoveries obtained by the methods used in Canada, the Compañía Minera Guadalcázar made arrangements with the Banco de México of the Mexican Government, through its Department of Industrial Investigations, to assume the financial burden of further studies and, with the enthusiastic support of Engineer Gonzalo Robles and under the able direction of Wm. G. Kane, to carry the investigations to completion. The bank accordingly obtained the services of R. J. Quinstrom, a metallurgist of the Consolidated Mining & Smelting Co. of Canada, who erected a 25-ton pilot mill at Guadalcázar and established a small chemical laboratory for assaying both the material treated in the mill and the products. The plant was put into operation in June 1946 and continued to operate until the following December, when it became evident that in spite of the relatively high recoveries obtained from the very low-grade placer material, the average metal content of the placers was too low to permit mining the deposits commercially at the current metal prices.

FIELD WORK AND ACKNOWLEDGMENTS

As a result of the preliminary work in 1941 by W. F. Foshag and Carl Fries, Jr., arrangements were made between the United States

Geological Survey and the Instituto de Geología of the Universidad Nacional Autónoma de México, for a joint, detailed study of the Guadalcázar deposits, under the program for cooperation with the American Republics; sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation of the Department of State.

Detailed geologic and topographic maps were begun in March 1942, by the authors and Adán Pérez Peña of the Instituto de Geología, and were completed in June. These maps cover all the Realejo Basin (pl. 30) and most of the Guadalcázar Basin (pl. 29), which together contain virtually all the tin-bearing gravel in the region. The altitudes shown on the maps are approximate. They are based on an aneroid determination published by the Secretaría de Agricultura y Fomento, giving the altitude at the base of the tower of the main church in Guadalcázar as 1,673 meters above sea level.[4]

A general geologic map, without topography, of the entire region was also made. The mapping was controlled in part by a triangulation net made for the American Smelting & Refining Co. and partly by another net prepared by D. B. McAllister.

Further mineralogic studies of a small number of samples were made by the authors in the laboratories of the Instituto de Geología in Mexico and by Miss Jewell J. Glass in the laboratories of the U. S. Geological Survey in Washington. The results of the early tests of the gravels were made available by the Compañía Minera Guadalcázar, through D. B. McAllister; the San Luis Mining Co. generously communicated the results of its extensive and detailed investigations, carried on during 1941–43; and the Banco de México kindly furnished the results of its more recent tests made in the pilot plant at Guadalcázar during 1946.

For aid in field work the authors are indebted particularly to D. B. McAllister, who gave freely of his broad knowledge of the region. They gratefully acknowledge the many courtesies extended them by the mayor of Guadalcázar, Señor Tobías Tiburcio, and by the townspeople and farmers of the region. Señor Adán Pérez Peña, topographer of the Instituto de Geología, assisted in preparing maps and in many other ways during the period of field work. Living quarters in Guadalcázar were made available by Father Antonio Herrera, Curate of the Parroquia church. Valuable information on the results of the drilling program and treatment tests was obtained from the staff of the San Luis Mining Co. and from F. A. Beauchamp and J. Hunt of Hamilton, Beauchamp & Woodworth, consulting metallurgists to the San Luis Mining Co. The close cooperation of the Banco de México was of particular value in carrying the investigations to completion, and the writers are indebted for all data on the more recent

[4] Catálogo de datos numéricos, geográficos, y topográficos de la República mexicana: Secretaría de Agricultura y Fomento, pub. 8, p. 33, 1927.

studies to Wm. G. Kane, R. J. Quinstrom, and Wm. J. Shedwick, personnel of the Bank's Department of Industrial Investigations, under the able direction of Engineer Gonzalo Robles. Suggestions that helped the authors to interpret the geologic history of the region were generously made by W. F. Foshag of the Smithsonian Institution.

For critical, constructive review of the manuscript the authors express their gratitude to John Van N. Dorr 2d, F. C. Calkins, O. E. Meinzer, and J. B. Mertie, Jr., of the U. S. Geological Survey, and to Engineer Teodoro Flores, Acting Director of the Instituto de Geología, who actively supported the study on the part of the Mexican Government.

GEOLOGY

ROCK FORMATIONS

The oldest rocks in the Guadalcázar region are shale and limestone of Cretaceous age. In the area mapped (pl. 28), which represents only a small part of the region, the shale does not crop out. These sedimentary rocks are intruded by a small mass of porphyritic granite, whose age may be either late Cretaceous or early Tertiary. The youngest formations in the region comprise large deposits of granitic gravel, some small deposits of limestone gravel, and a few thin beds of rhyolitic volcanic ash. The old rocks form an extensive dissected upland, of which the granite occupies the highest part; this upland is surrounded by relatively low, broad, alluvium-filled valleys. Several small, isolated basins, such as those of Guadalcázar and Realejo, lie within the upland area and have no surface drainage connection with the surrounding lower country. Two of these basins contain the placer deposits that are the subject of this paper.

LIMESTONE

The limestone is a massive, dark-gray rock that gives off a fetid odor when broken and contains abundant but poorly preserved Cretaceous fossils. The bedding is well-preserved and obvious on the south side of the Guadalcázar Basin, but closer to the granite it is so massive that its attitude is almost nowhere apparent. In the past, the weathering of the limestone appears to have been largely the result of solution, for the alluvium in all the basins in the region contains large quantities of clay but only small quantities of limestone gravel, and sink holes and caves are numerous. All the basins seem, in fact, to have been formed by solution. The small ones are clearly nothing more than sink holes. The large ones, such as those of Guadalcázar and Realejo, resemble sink holes and presumably have the same origin. Under present climatic conditions the limestone is highly resistant to weathering. The soil mantle consists of moderately angular fragments in a matrix of caliche—principally calcium carbonate—and clay. It is thin, except locally where the topography allows the accumulation of debris washed from the slopes. The angular fragments in the soil mantle are most abundant near the base of the slopes and in and along the arroyos. The residue from the weathering of the limestone is a reddish, brown, or black clay containing a little quartz sand, chert, and a variable quantity of organic material.

GRANITE

A mass of intrusive igneous rock crops out in an oval area 2.4 kilometers long, lying between Guadalcázar and Realejo but nearer to Realejo (see pl. 28). Observed contacts with the limestone are nearly vertical, and the course of the contact is generally regular. The rock is a massive, light-gray, coarsely porphyritic granite, whose predominant minerals are quartz and potash feldspar, with biotite subordinate but everywhere present. The most abundant accessory minerals are zircon and magnetite. Small quantities of brookite, monazite, tourmaline, topaz, and fluorite are fairly widespread, and beryl and cassiterite occur locally. Much of the quartz forms doubly terminated bipyramidal crystals, and some of the feldspar consists of sanidine, the high-temperature variety of potash feldspar. The presence of quartz and sanidine, characteristic of extrusive rhyolitic rocks, and the porphyritic texture of the granite indicate that this mass of granitic magma was emplaced not far below the surface of the ground, where it cooled so rapidly as to prevent the sanidine from inverting to orthoclase, the variety of potash feldspar ordinarily found in granite.

The outer part of the granite mass is traversed by numerous fine-grained aplitic dikelets, which range in thickness from 6 millimeters to as much as 90 centimeters, but the central part is generally free from them. The aplite consists mainly of quartz and feldspar, with minor quantities of biotite, and appears to lack zircon, which is present in all the granite. It generally contains a little magnetite and tourmaline and in places cassiterite.

Pegmatite, also, forms a few small dikes in the granite, mainly in its outer part. The largest pegmatite dike observed is a well-defined and distinct band about 15 centimeters wide, but most are much smaller, and are apparent only on close inspection because they are very little coarser than the surrounding granite. Much of the pegmatite crops out in small oval areas, of which the largest observed was scarcely 20 centimeters in length. The pegmatite, like the aplite, apparently contains no zircon, but muscovite, tourmaline, topaz, and fluorite may be found in all parts of it; some parts contain beryl, molybdenite, scheelite, and cassiterite. The walls of some fractures in the granite are incrusted with thin rosettes of tourmaline, a mineral also found scattered through much of the granite without any apparent relation to fractures or veins.

The granite weathers largely by disintegration, forming a quartz-feldspar sand, although some of the feldspars are partly kaolinized and break down into silt and clay. Disintegration is particularly rapid in much of the outer part of the granite as the result of an earlier period of hydrothermal alteration, during which the feldspars were decomposed. The granite is most thoroughly altered along the south and west borders, where it has accordingly been most deeply eroded and is now well exposed.

ALLUVIAL DEPOSITS

Alluvial deposits occupy all the isolated basins in the region, but appreciable quantities of granitic gravel are found only in the large Guadalcázar and Realejo Basins. On the detailed maps in plates 29 and 30, the alluvium is divided into primary and secondary, or re-worked, granitic gravel, rhyolitic tuff, and gravel derived mainly from the limestone. The tuff, where present, lies between the primary and the secondary granitic gravel, and most of the limestone gravel corresponds in age to the secondary granitic gravel. All these deposits are of Pliocene age or younger.

Primary granitic gravel.—In the Guadalcázar Basin the primary or original granitic gravel forms two large fans, one extending out from Arroyo de las Papas and the other from Arroyo de San Diego (see pls. 28 and 29). These two fans coalesce and form a gently sloping plain that extends to the opposite edge of the basin. The surface drainage from the southwest is prevented from flowing northeastward beyond the village of Abrego by the San Diego fan, the higher of the two. This fan extends about a kilometer beyond the area mapped, into a southeastern arm of the Guadalcázar Basin, beyond Abrego. In the Realejo Basin the primary gravel forms a single alluvial apron sloping gently northwestward, away from the granite. (See pls. 29 and 30.) At the close of the period during which the fans were constructed, these alluvial deposits formed gently undulating plains that sloped 1° to 3° away from their source, but they are now partly dissected and have been further modified by slight faulting and subsidence. A large part of the Realejo Basin is now drained by Arroyo de Santa Elena, which leaves the northwest corner of the basin and enters the smaller Trinidad Basin, but there could have been no surface drainage out of the basin while the greater part of the primary gravel was being deposited.

The primary gravel is generally yellowish to reddish brown, moderately well bedded, compact when dry, and in some places weakly cemented. It consists mainly of granitic debris, which is accompanied by a much smaller proportion of clay and of chert pebbles derived from the limestone, as well as by a few pebbles of limestone. The relative scarcity of limestone pebbles apparently means that most of those that were formed were dissolved before they could be carried into the basins, although some small pebbles may have been dissolved after they were deposited. Bedding is generally visible, in many places because of slight differences in color between one bed and the next rather than because of differences in texture. Some beds, however, are much coarser than the average, and a few were observed that consist mainly of clay. The boulders in the coarsest beds rarely exceed 60 centimeters in diameter. The material in the individual beds is generally not well sorted. All the pebbles, cobbles, and boulders of granite in the primary gravel are more or less decomposed, the decomposition having occurred mainly after the gravel was deposited.

The topmost meter or so of the primary gravel is light gray and usually well cemented by caliche, calcium carbonate, where the surface has not been disturbed by cultivation; the campactness of the rest of the material is due to an abundance of fine silt and clay rather than to actual cementation, and the material readily disintegrates when saturated with water. Fractures are numerous in most surface exposures of the primary gravel, and are conspicuous because of narrow zones of light-gray, caliche-cemented material among them. This caliche was apparently deposited by surface waters, which, after first leaching out the soluble elements on passing downward, returned to the surface during dry periods and deposited calcium carbonate by evaporation.

According to Dr. Kirk Bryan, professor of physiography at Harvard University, a layer of caliche-cemented material occurs characteristically at or below the surface of the ground throughout the semiarid southwestern part of the United States and central Mexico. It was probably formed at some depth—from 1 to 3 meters—below the surface of the ground during an earlier period of even greater aridity than at present. Where it now occurs at the surface, it appears to have been exposed by a stripping of the original cover, and at such places it shows evidence of being removed by solution. Once formed, however, it is relatively stable and dissolves very slowly, unless rainfall is moderately abundant.

As shown in plate 28, the source of the gravel in the Papas fan is distinct from that of the gravel in the San Diego and Santa Elena fans. Each of these fans consists of material eroded from a separate part of the granite. The maximum thickness of the primary gravel in the Guadalcázar Basin appears to be about 100 meters and occurs along the northeast-southwest (long) axis of the basin (see pl. 31), but at Realejo the thickness probably does not exceed 24 meters (see pl. 32). Most of the gravel may be of Pleistocene age, although a part of it may be as old as Pliocene.

Tuff.—Thin beds of fine-grained white rhyolitic tuff occur in several places distributed throughout the region. The most extensive deposit of tuff is found in the Guadalcázar basin, just south of the village, where a thin blanket of it overlies the primary gravel and is in part covered by secondary gravel, which is too thin to be shown in the sections in plate 31. There the maximum thickness of the tuff is about 4.5 meters, but in other places it is generally less than 1.5 meters. The pure tuff consists mainly of tiny shards of glass, with some broken crystals of quartz and feldspar; in some places it is mixed with a small proportion of sand and clay eroded from the primary gravel. A chemical analysis of pure tuff made for D. B. McAllister gave 73 percent of silica, about 19 percent of alumina, and minor percentages of oxides of potassium, sodium, and calcium. Small quantities of this tuff are used for scouring and cleaning in local homes.

The tuff was clearly brought into the region from some distance by the winds. Some of the beds appear to have been deposited directly from the air; others have undoubtedly been reworked by water. The tuff fell during relatively recent times, for it has been found in caves that had been occupied earlier by a prehistoric race of Indians. Fossil leaves were found by the authors in some of the beds near the Guadalcázar cemetery (see pl. 29), but owing to poor preservation only a few can be identified. According to Dr. Erling Dorf of Princeton University, who examined the material collected, the leaves are oak, juniper, and tejocote, all of which now grow in the region.

Secondary granitic gravel.—The secondary granitic gravel has been formed largely by reworking of the primary granitic gravel, but it also includes some gravel recently carried down from the granite area and, in many places, a small quantity of limestone gravel. It is pale yellow, very little compacted, and neither fractured nor caliche-cemented, thus differing noticeably from the primary gravel. It is not so distinctly bedded as the primary gravel but is much better sorted. In the higher parts of the basins this gravel is moderately coarse, having been washed nearly free from fine sand and silt; in the lower parts of the basins it consists largely of the fine sand and silt that was washed from the higher ground. Some boulders in the secondary gravel are as much as 1.5 meters across, although few are more than 60 centimeters in diameter. They are generally tough and hard, few being decomposed as in the primary gravel, and pebbles or boulders of limestone, which are rare in the primary gravel, can be found in all exposures of the coarser part of the secondary gravel.

The secondary gravel is somewhat more widespread than appears on the maps (pls. 29 and 30), for it was mapped separately only where it occurs in considerable quantity. The secondary gravel that occurs in the beds of all the small arroyos is generally not shown. Arroyo de Santa Elena, which now drains a large part of the Realejo Basin, has carried secondary gravel into the Trinidad Basin, west of Realejo and not shown on the maps. The amount and thickness of the gravel thus transported have not been measured, but they are probably small.

The thickness of the secondary gravel over much of the area shown on the Guadalcázar and Realejo maps is scarcely more than a meter, although its maximum thickness, is the lowest part of the Guadalcázar Basin, may exceed 9 meters. All the secondary gravel is of Recent age.

Limestone gravel.—Gravel consisting mainly of limestone debris is relatively scarce in the Guadalcázar and Realejo Basins. It may be found principally around the edges of the granitic gravel deposits and on the sides of the basins opposite the source of the granitic gravel. Most of the small alluvial deposits, however, are merely thick accumulations of heavy black or reddish loam that is composed largely of residue from solution of the limestone. A thin layer of the loam apparently underlies all the granitic gravel in the Guadalcázar and Realejo Basins, for such material was found in the bottoms of the drill holes that reached limestone bedrock, and it can be seen separating the granitic gravel from the limestone where the contacts are exposed on the surface. Some topographic forms that have the appearance of small fans composed of limestone gravel are really no more than pediment surfaces of limestone with a veneer of gravel. The thickest and most extensive deposit of limestone gravel occurs at the west end of the Guadalcázar Basin, where several large arroyos draining the limestone upland enter. This deposit may be as much as 15 meters thick, but the others are apparently much thinner. The limestone gravel appears to be in large part contemporaneous with the secondary granitic gravel, but is in part older, being interfingered with the younger part of the primary granitic gravel. At two places in the Guadalcázar Basin, arroyos have exposed thin beds of volcanic tuff interbedded with limestone gravel. This tuff is apparently the same as that between the primary and secondary granitic gravel and accordingly indicates that some of the limestone gravel is older than some of the secondary granitic gravel.

STRUCTURE

The limestone generally dips northward on the south side of the Guadalcázar Basin (see pl. 29), but closer to the granite intrusive the structure can rarely be determined, owing to the massive bedding of the limestone. The few dip readings obtained near the contact, where Arroyo de las Papas leaves the granite, show the limestone dipping steeply toward the nearly vertical contact between the limestone and the granite. These features indicate that the intrusive mass is not a laccolith, as has been believed by some observers,[5] but a stock. There seems to be no very close relation between the direction of the axes of the basins and the attitude of the limestone beds,

[5] Wittich, Ernesto and Ragotzy, F., Apuntes preliminares acerca de la zona minera de Guadalcázar, S. L. P.: Petróleo, vol. 13, no. 196, p. 5, April 1920.

although a few valleys entering the basins are nearly parallel to the strike of the beds.

The granitic gravel deposits, which are indistinctly bedded to moderately well bedded, generally dip away from the granite, at angles of less than 8°. A few dip readings as high as 20°, which apparently do not represent initial dips, were made along the northern side of the Guadalcázar Basin, but such high dips are rare. In detail the dips vary within short distances, both along and at right angles to the strike. These characteristics and the poor sorting of the material indicate that the granitic gravel was deposited in alluvial fans. The belief advanced by Tinoco[6] that the granitic material in Guadalcázar Basin largely represents a decomposed instrusive mass deeply weather in place is clearly untenable.

Local high dips and several small faults in the gravel in the Guadalcázar Basin appear to have been caused by the sinking of small areas into solution cavities formed in the underlying limestone after the gravel was deposited. The results of this process are well shown near the head of Arroyo de La Cieneguilla, nearly due north of the small settlement of San Nicolás (see pl. 29). There the gravel dips in all directions in an area about 300 meters in diameter, and a curved thrust fault occurs near the center. The tuffs south of the Guadalcázar cemetery are cut by a fault too small to be shown on the map in plate 29, on one side of which the dip changes sharply from 3° to 7° S. This disturbance was apparently caused by the enlargement of an underlying sink. Many other small faults occur in the gravel, but none appear to have had any large displacement.

In the Realejo Basin, also, several sinks have apparently been formed or enlarged since the primary gravel was deposited. The large depression partly shown in the upper left corner of the map in plate 30 does not contain primary granitic gravel, and, as the gravel could not have been removed after the depression was formed, either some barrier not now present prevented the primary gravel from entering the depression or the gravel was removed before the depression was formed. Since the possibility of faulting is remote, this depression seems clearly to be a sink formed after the primary gravel was deposited. The process whereby the large basins are believed to have been formed thus appears to have continued to operate after their formation and is probably still operating.

GEOLOGIC HISTORY

Remnants of an old erosion surface, of which the tops of the granite hills form a part, indicate that before the canyons and enclosed basins

[6] Tinoco, Manuel, Los Minerales de Guadalcázar, Santa María del Tecomate y Rincón de Petros: El Minero Mexicano, vol. 40, no. 13, p. 146, 1902.

were formed the region had relatively low relief. Probably there was normal surface drainage during that period, for apparently the gravels then eroded from the granite were transported out of the region, though to what place is not known. The canyons and sinks, which are now such prominent features in the region, were formed subsequently, possibly as a result of an uplift by faulting and the lowering of the water table, or by some change in climate. The large basins appear to have been broad shallow valleys before the surface drainage was interrupted by the development of sinks, but once the water ceased flowing on the surface, their further enlargement was effected entirely by solution.

The granitic gravel began to be deposited in the basins when the valleys were less deep and less steep-sided than they are at present, as evinced by remnants of high, broad, shallow valleys containing pebbles of granite, which can still be seen on the sides of Arroyo de las Papas and Arroyo de San Diego where these lie within the limestone. The basins were probably somewhat enlarged by solution during the deposition of the gravels. The absence of limestone pebbles in most of the fans of primary granitic gravel and their presence in the detritus now being brought into the basins by the main arroyos, which drain areas of both granite and limestone, suggest that the climate was more humid when the primary granitic fans were being deposited than it is at present. Precipitation may have been much greater then than now—perhaps more nearly 1,000 millimeters than the present 560 millimeters—and distributed more evenly through the year, though coming partly in periodic heavy rains. Such conditions would have facilitated removal of the limestone by solution and development of the sinks, yet would have permitted periodic removal and deposition of granitic detritus after heavy rains. There could not have been enough rainfall, however, to have maintained permanent streams, for stream-bed deposits are rare in the gravels. The surface water then, as now, drained into sinks in the limestone and was thus prevented from forming lakes. Late in the period of construction of the primary gravel fans, and even more since then, there may have been a gradual decrease in rainfall, particularly during a part of the year, until an even more arid climate than that now prevailing was attained, as evinced by the presence of caliche in the region. The climate then became somewhat more humid again. Now 80 percent of the rain falls in the period from May to October, inclusive, and virtually none falls during the winter months. Under these conditions little of the limestone is removed by solution, and the heavy summer rains give rise to floods that tear loose and carry down into the basins large quantities of limestone detritus.

The enormous amount of limestone that must have been removed by solution can be illustrated by the following example. The Guadalcázar basin contains about 534,000,000 cubic meters of granitic gravel but only a few million cubic meters of alluvium derived from the limestone, in spite of the fact that as much limestone as granite must have been eroded from the upland while the primary gravel was being deposited. (See pl. 28.) The scarcity of limestone alluvium in the basin clearly indicates that much of it must have been removed by solution, for limestone could not have been carried out of the region in the form of gravel without the removal of some of the granitic gravel as well. Apparently all the granitic gravel was retained, for if it were restored to its source—the granite-limestone contact being assumed to have continued upward with the same dip as that shown at the present surface—the summit of the restored block would stand about as high as the present summit of the highest peak, Cerro de San Cristóbal, an erosion remnant on the upland surface.

The poorly sorted character of the granitic gravel indicates that the gravel was transported and deposited by intermittent streams. The basins can never have been occupied by large lakes, for they contain no extrusive deposits of well-sorted and laminated sediments. Although a few clay beds were observed, these were probably deposited in small depressions or ponds between the shifting, aggrading streams that formed the fans. Certain relatively well-sorted sandy beds were presumably laid down in the changing channels of intermittent streams at times when they were not in flood. The lack of sorting in most of the gravel makes it likely that the heavy metallic minerals were deposited with comparative uniformity through the material; it seems unlikely that any large portions of the deposits should have been enriched to any appreciable extent, although the edges of the fans may have been impoverished slightly in relation to the apices.

At Guadalcázar the dissection of the primary gravel fan deposits appears to have been brought about in part by a change in climate and in part by the deepening of Arroyo de Las Papas and Arroyo de San Diego. At Realejo the dissection was caused mainly by the recent cutting, in the limestone, of the canyon through which Arroyo de Santa Elena now leaves the basin. Volcanic ash fell throughout the region during the period of dissection, but it now remains only where it could not be washed away by the rains, as in the lower parts of the basins and in the small sinks. Most of the ash has been eroded and mixed with the recent alluvium, consisting of limestone and granite, which in places also thinly covers uneroded ash.

ORE DEPOSITS IN BEDROCK

Brief mention of the ore deposits in bedrock is made here to indicate the origin of the heavy minerals found in the gravel deposits. Many small ore deposits occur along the contact of the limestone and the granite, chiefly in the granite, beginning at a point east of the village of Realejo (see pl. 28), on the west side of the granite, and continuing around the south side to a point west of the San Diego adit, which is on the east side of the granite. No ore deposits are known to exist in Cerro de Las Piedras, in the northwestern part of the granite stock, and the core of the granite appears to be virtually barren. The individual mines are not shown on the map, except for a few of the largest and best-known adits and two deposits that, during the progress of the work, were found to contain small quantities of tungsten.

These ore deposits in bedrock were mined mainly for silver and gold, although they also yielded small quantities of zinc, antimony, lead, and mercury. The metallic minerals in which these metals chiefly occur are pyrite, sphalerite, galena, arsenopyrite, stibnite, tetrahedrite, argentite, polybasite, stephanite, cinnabar, and their various oxidation products. The gold is largely in the pyrite. The less well known and more recently discovered metallic minerals include the tin mineral, cassiterite; the tungsten minerals, scheelite and wolframite; and the molybdenite minerals, powellite and molybdenite. The deposits also contain many heavy nonmetallic minerals, of which the most abundant are lime-silicate minerals, such as garnet, wollastonite, tremolite, vesuvianite, and epidote, developed by reaction of the granite and its emanations with the limestone along the contact, as well as with detached blocks of limestone engulfed by the granite. Fluorine- and boron-bearing minerals, such as fluorite, topaz, danburite, axinite, dumortierite, and tourmaline, were formed, though less abundantly, in some of the ore deposits in the granite.

Cassiterite, although widely distributed in the granite, occurs chiefly in the outer portion of the southwestern half of the granite mass, the part from which the gravel in the Papas and Santa Elena fans was derived. This mineral appears to be more closely related to the pegmatitic phases of the granite than to the base-metal deposits, although it also occurs in granite that is free from pegmatites as well as from sulfide veins. It seems to be associated rather closely with topaz and beryl, and in places it accompanies tourmaline. No mass of bedrock has yet been found that could be mined commercially for cassiterite, however, even if tin were selling for many times its price in 1946. Moreover, no mass of bedrock was found in which the tin content is as high as that of the gravel in the Papas and Santa Elena fans, although a more detailed search in the granite might lead to the discovery of a greater concentration of cassiterite. Nevetheless, unless the tenor were about a hundred times that of the gravels, the bedrock could not be mined profitably because of the greater cost of hard-rock mining. It is possible that the granite eroded from the stock and deposited in the fans containing more cassiterite, on the average, than that now exposed at the surface. On the other hand, it could have been less than that in the apices of the fans sampled for there has undoubtedly been some enrichment there and a corresponding impoverishment in the outer part.

Cinnabar occurs in a northwest-trending belt extending from the northwest corner of the Guadalcázar Basin through San Antonio to Trinidad, a distance of more than 6.5 kilometers. This belt follows the southwestern edge of the granite (see pl. 28) and apparently extends into the granite, some samples of which contain mercury. All the deposits that have been mined solely for mercury, however, occur wholly within the limestone.

PLACER DEPOSITS

DISTRIBUTION AND SIZE

The granitic gravel in the region forms three distinct deposits, each representing the material eroded from a separate part of the granite stock. These deposits are the Papas and San Diego fans, in the Guadalcázar Basin, and the Santa Elena fan in the Realejo and Trinidad Basins. They are composed mainly of primary gravel and contain only about 6 percent of secondary or reworked gravel. All the known primary gravel is in the Guadalcázar and Realejo Basins; the Trinidad Basin contains only secondary gravel. All the gravel is shown on the maps (pls. 29 and 30) except that in the small Trinidad Basin, west of Realejo, and that in the southeastern part of the San Diego fan, which extends about 2 kilometers southeastward from the village of Abrego, in the Guadalcázar Basin.

TABLE 1.—*Volume of granitic gravel in the Guadalcázar region*

Location	Volume (million cubic meters)
In separate fans [1]	
Papas fan:	
Primary granitic gravel	300
Secondary granitic gravel	20
	320
San Diego fan:	
Primary granitic gravel mapped	162
Primary granitic gravel not mapped [2]	45
Total primary granitic gravel	207
Secondary granitic gravel mapped	2
Secondary granitic gravel not mapped [2]	5
Total secondary granitic gravel	7
Total granitic gravel in San Diego fan	214
Santa Elena fan:	
All granitic gravel in Realejo Basin (mainly primary)	15
All granitic gravel in Trinidad Basin (all secondary)	2
Total granitic gravel in Santa Elena fan	17
Total granitic gravel in region	551

See footnotes at end of table.

TABLE 1.—*Volume of granitic gravel in the Guadalcázar Region*—Continued

Location	Volume (million cubic meters)
In separate basins	
Guadalcázar Basin:	
Papas fan	320
San Diego fan	214
Total in Guadalcázar Basin	534
Realejo Basin	15
Trinidad Basin	2
Total granitic gravel in region	551
In accessible areas	
Gravel under area occupied by village of Guadalcázar	48
Gravel under area occupied by village of Abrego	10
Total gravel inaccessible	58

In areas bounded by intersecting section lines on maps

[See pls. 2 and 3]

Location	Volume (cubic meters)
Papas fan:	
½ EFMN[3]	304, 700
FGM	1, 335, 900
GHM	843, 000
HIM	625, 000
IJM	609, 400
JKM	1, 641, 300
KLM	2, 925, 000
½ EFMN	4, 766, 200
FGMN	13, 282, 500
GHMN	10, 937, 500
HIMN	9, 375, 000
IJMN	9, 845, 000
JKMN	10, 625, 000
KLMN	9, 220, 000
½ EFNO	9, 531, 200
FGNO	21, 720, 000
GHNO	19, 845, 000
HINO	16, 720, 000
IJNO	15, 157, 500
JKNO	13, 125, 000
KJNO	8, 437, 500
Papas fan—Continued	
½ EFOP	8, 672, 500
FGOP	18, 357, 500
GHOP	17, 812, 500
HIOP	15, 782, 500
IJOP	13, 750, 000
JKOP	10, 625, 000
KLOP	6, 250, 000
½ EFPQ	3, 906, 200
FGPQ	10, 782, 500
GHPQ	8, 718, 800
HIPQ	6, 329, 300
IJPQ	8, 125, 000
JKPQ	4, 921, 900
KLPQ	3, 750, 000
½ EFQ	140, 700
FGQ	1, 203, 100
GHQ	125, 000
IJQ	112, 500
Total	320, 236, 700
San Diego fan:	
½ EFM[3]	304, 700
BCMN	478, 100
CDMN	1, 718, 800
DEMN	3, 390, 600
½ EFMN	4, 766, 300
ABNO	3, 414, 100
BCNO	7, 746, 600
CDNO	12, 657, 500
DENO	14, 845, 000
½ EFNO	9, 531, 300
ABOP	12, 345, 000
BCOP	13, 907, 500
CDOP	14, 220, 000
½ EFOP	8, 672, 500
San Diego fan—Continued	
ABPQ	12, 97000, 0
BCPQ	10, 000, 000
CDPQ	4, 750, 000
DEPQ	4, 000, 000
EFPQ	3, 906, 300
ABQ	3, 261, 300
BCQ	1, 726, 600
½ EFQ	140, 600
Mapped	163, 502, 800
Not mapped	50, 000, 000
Total	213, 502, 800
Santa Elena fan:	
AB	1, 000, 500
BC	7, 401, 000
CD	6, 363, 000
	14, 764, 500
Santa Elena fan—Continued—	
Mapped	14, 764, 500
Not mapped	[2] 2, 000, 000
Total	16, 764, 500

[1] Each fan contains material eroded from a separate part of the granite stock. Volume was calculated from geologic evidence and sections shown in plates 31 and 32.
[2] Volume was estimated from field evidence.
[3] Letters refer to section lines on maps in plates 29 and 30.

The estimated volumes of gravel in the separate fans are given in table 1. Those of the deposits that were mapped were computed from the sections illustrated in plates 31 and 32; rough estimates are included of the material in the Trinidad Basin and in the part of the San Diego fan that was not mapped. Between the villages of Guadalcázar and Abrego the Papas and San Diego fans interfinger, but for the purpose of computing their separate volumes, they may be divided along a line midway between section lines EE′ and FF′, shown in plate 29. The geologic sections, representing the estimated subsurface geology of the basins, are better controlled at Realejo, where numerous outcrops of the underlying limestone are present, than they are at Guadalcázar. There the gravel is not deeply dissected, and no drill holes have yet been put down to bedrock near the center of the basin. A hole located in the northeastern part of the basin, at the east edge of the Papas fan, was put down 61 meters without reaching the underlying limestone. In preparing these sections, the slope of the limestone contact was assumed to flatten gradually away from the sides of the basin. Limestone outcrops and three drill holes that reached limestone (see pl. 33) served as partial control, and the intersections of two sets of sections at right angles served as further control. Although the Guadalcázar sections are not accurate in detail, they give a reasonably truthful generalized picture.

According to the authors' estimates, the total volume of granitic gravel in the region is 551,000,000 cubic meters, a volume that is believed to be correct within 10 percent. The largest part of this material is in the Papas fan, which contains 320,000,000 cubic meters of gravel (see table 1). The San Diego fan contains 214,000,000 cubic meters, and the small Santa Elena fan contains only 17,000,000 cubic meters. The Guadalcázar Basin contains 534,000,000 cubic meters, the Realejo Basin 15,000,000 cubic meters, and the Trinidad Basin 2,000,000 cubic meters. Some of this gravel would not, of course, be available for placer mining, because the villages of Guadalcázar, San Nicolás, Abrego, and Realejo are built on the fans. As shown in table 1, about 58,000,000 cubic meters of gravel underlie Guadalcázar and Abrego, in the Guadalcázar Basin. The volume underlying each area bounded by the intersecting section lines in plates 29 and 30 is given separately in the table, so that the reader may calculate the volume in any area.

PHYSICAL CHARACTER AND MINERAL COMPOSITION

The primary granitic gravel has very nearly the same general character wherever it is exposed, whether in the Papas, the San Diego, or the Santa Elena fan. It varies in color from nearly white to dark reddish brown, but it is predominantly of a reddish hue, which has caused the deposits to be known locally as "tierras coloradas." Most of it is firmly compacted, but little of it is cemented; as the cemented material occurs only at the surface, it would not interfere greatly with mining. The compact, uncemented material can be excavated easily with a power shovel or a dragline, and though hard when dry it disintegrates readily when saturated with water. As the pebbles and boulders are more or less decomposed, they can be crushed readily and milled, if milling the coarse material should be found desirable.

Although the primary gravel appears to be moderately well bedded, the individual beds, for the most part, differ but slightly in texture. A few beds consist of relatively course gravel, although the coarsest fragments, for the most part restricted to the apices of the fans, rarely exceed 60 centimeters in diameter; other beds consist almost entirely of material finer than 20-mesh. In general the material is not well-sorted, and even the coarse-grained beds contain a large proportion of very fine material. The beds containing only clean-washed, well-sorted sand or gravel appear to be lenses, and as such are undoubtedly of small extent or volume. The proportion of coarse material decreases toward the sides and fronts of the fans, with a corresponding increase in the percentage of fine material, but these differences are not marked.

A Tyler screen analysis made by the San Luis Mining Co. of a composite sample of the material excavated from sixteen 8-meter test pits (see pl. 33) gave 29.6 percent of material finer than 200-mesh, and the coarser material was found to be distributed almost uniformly through all the screen sizes used, including the 12.7-millimeter screen. (See table 2.) More complete analyses of the material from 22 drill holes, averaging 33.6 meters in depth, showed that, although in 3-meter segments the material differed considerably in its size distribution, the averages for the individual cores were not greatly different. Material finer than 200-mesh constituted 5 percent of one 3-meter segment and 55 percent of another; but in entire cores from 20 holes drilled to depths of 12 to 45 meters (see pl. 33 and table 2), the range was only from 25.9 to 34.0 percent. Material coarser than 200-mesh and finer than 16-mesh ranged from 34.9 to 46.1 percent of the total. For material coarser than 16-mesh the range was greater, however, one core containing only 21.7 percent and another as much as 36.7 percent of the total.

TABLE 2.—*Size distribution of primary gravel in apex of Papas fan*

Screen-size fraction		Percent of total weight	Screen-size fraction		Percent of total weight
Passes through—	Retained on—		Passes through—	Retained on—	
In composite pit sample [1]					
	12.7 mm	4.46	28 mesh	35 mesh	4.85
12.7 mm	9.4 mm	1.52	35 mesh	48 mesh	5.06
9.4 mm	3 mesh	.90	48 mesh	65 mesh	5.46
3 mesh	4 mesh	1.71	65 mesh	100 mesh	4.96
4 mesh	6 mesh	3.87	100 mesh	150 mesh	4.06
6 mesh	8 mesh	5.28	150 mesh	200 mesh	3.97
8 mesh	10 mesh	7.06	200 mesh, "sand"		8.21
10 mesh	14 mesh	6.75	200 mesh, "slime"		21.37
14 mesh	20 mesh	5.49			
20 mesh	28 mesh	5.02			

Hole No.	Length of core (meters)	Weight of core (kilograms)	Retained on 16 mesh (percent)	Passes through 16 mesh but retained on 200 mesh (percent)	Passes through 200 mesh (percent)
In material from 22 drill cores [2]					
1	13.6	1,257	34.2	34.9	30.9
2	45	3,646	27.0	45.4	27.6
3	30.5	2,766	27.9	40.1	32.0
4	25.2	2,184	25.8	41.3	32.9
5	45	3,970	21.7	44.4	33.9
6	45	4,159	26.8	45.1	28.1
7	45	3,367	23.0	45.5	31.5
8	45	3,835	22.3	46.1	31.6
9	45	2,907	28.5	43.4	28.1
10	45	4,317	32.2	39.9	27.9
11	45	3,563	31.4	38.3	30.3
12	45	3,076	32.0	39.4	28.6
13	35	3,441	25.8	44.4	29.8
14	35	3,139	30.4	39.5	30.1
15 [3]	6	475	27.1	37.7	35.2
16	12	1,050	31.7	35.7	32.6
17 [3]	3	164	62.3	21.8	15.9
18	35	2,744	36.7	37.4	25.9
19	35	3,744	30.0	40.5	29.5
20	35	3,538	27.9	38.1	34.0
21	35	3,452	26.8	40.4	32.8
22	35	3,958	28.3	38.7	33.0
Total or average	740.3	64,752	[4] 28.13	[4] 41.53	[4] 30.34

Screen-size fraction		Composite pit sample,[1] percent of total weight	Material from 20 drill cores [2]		
Passes through—	Retained on—		Maximum percent [5]	Minimum percent [5]	Weighted average, percent [4]
Comparison of size distribution in different samples					
	16 mesh	33.4	36.7 (18)	21.7 (5)	28.13
16 mesh	200 mesh	37.0	46.1 (8)	34.9 (1)	41.53
200 mesh		29.6	34.0 (20)	25.9 (18)	30.34
		100.0			100.00

[1] Composite sample from sixteen 8-meter test pits (see pl. 33). Tests were made in 1942 by F. A. Beauchamp and J. Hunt, of Hamilton, Beauchamp & Woodworth, consulting metallurgists to the San Luis Mining Co.

[2] Drill holes shown and numbered in plate 33. Tests were made in 1943 by F. A. Beauchamp and J. Hunt, of Hamilton, Beauchamp & Woodworth, consulting metallurgists to the San Luis Mining Co.

[3] Hole not deep enough to give representative sample and not included in averages. Material consisted in large part of secondary gravel.

[4] Cores 15 and 17 not included. Averages were calculated by weighting each core in accordance with its length; the averages represent 731.3 meters of core.

[5] Figure in parentheses is the number of the drill core whose percentage is shown.

If it is assumed that the placers would have to be mined on a large scale, one of the most significant facts shown by these tests is that any minable part of the deposits can be expected to contain about 30 percent of material finer than 200-mesh, of which a large proportion is finer even than 500-mesh. This fine fraction would have to be treated to recover a high proportion of the metallic minerals contained in the gravel.

The secondary granitic gravel is light brownish yellow, generally somewhat loosely packed, and in large part better sorted than the primary gravel. In the beds of the arroyos it contains scarcely any silt or clay and in places is much coarser than any of the primary gravel, containing hard, tough boulders as large as 1.5 meters across. Over much of the area it consists only of soil washed into depressions or against stone fences, and in the lowermost parts of the basins, where it forms a thick cover over the coarser primary gravel, it is composed only of fine sand, silt, and clay. The deposits of secondary gravel are apparently not large enough nor rich enough to be mined separately, except perhaps on a very small, one-man basis, and are therefore of little commercial importance.

The principal minerals commonly found in the granitic gravel are the same in all parts of the deposits, although their relative abundance varies from place to place. Quartz, feldspar and its alteration products, and chert from the limestone constitute roughly 99 percent of the whole. The remainder consists mainly of mica, magnetite, hematite, specularite, limonite, and oxides of manganese; there are also small quantities of all the minerals that occur in the granite and in the ore deposits in bedrock. (See pp. 116 and 124.) Pyrite and the other sulfide minerals that occur in the bedrock deposits are generally found oxidized in the primary gravel, and are represented mainly by hematite and limonite, which may contain sulfide cores. The most abundant of the minor heavy minerals—those with a specific gravity greater than about 3—are tourmaline; titanium minerals, such as anatase, brookite, sphene, and rutile; zircon; cassiterite, partly in small crystals and partly as botryoidal wood tin; cinnabar; topaz; fluorite; and garnet. Among the rarer heavy minerals of possible commercial value are gold, minerals containing silver—mainly secondary minerals resulting from oxidation of the silver-bearing sulfides—and the tungsten minerals wolframite and scheelite.[7]

[7] For a more complete list of the minor and rarer heavy minerals in the deposits and a more detailed description of the minerals of possible commercial value, see Foshag, W. F. and Fries, Carl Jr., Tin deposits of the Republic of Mexico: U. S. Geol. Survey Bull. 935–C, pp. 113–116, 1942.

Dumortierite, a mineral of an intense dark-blue, forms many pebbles and boulders in a part of the San Diego fan, but is rarely present in the Papas and Santa Elena fans. It is derived from veinlets in the granite in the watershed of Arroyo de San Diego, just across the divide to the north of La Luzabit. (See pl. 28.) Although this mineral is mined commercially in certain localities in the world, it is probably not worth recovering at Guadalcázar because of its relative scarcity and its close association or intergrowth with quartz and feldspar. The presence of dumortierite serves, however, to distinguish the gravel of the San Diego fan from that of the Papas fan where the two fans interfinger. Only cassiterite, cinnabar, the silver-bearing minerals and gold appear to be present in sufficient quantities to warrant attempts to recover them commercially. Recovery of any other mineral, such as zircon, wolframite, or scheelite, even if possible and profitable, would add little to the value of the deposits.

The distribution of the metallic minerals in the separate size fractions of the gravel apparently differs widely in small samples, as indicated by tests made on the drill cores, but in the part of the Papas fan tested by the San Luis Mining Co., it was found to be rather closely correlated, in general, with the size distribution of the gravel. Assays of fractions from pit samples showed a slight concentration of tin and mercury in the fraction finer than 200-mesh (see table 3), and a marked concentration of silver and gold in the fraction finer than 200-mesh. (See table 3.) Assays of samples from drill cores showed a somewhat more uniform distribution of the metals in the different size fractions, although in these, too, the silver and gold were found to be concentrated to some degree in the finer material. But, as the sizing of the drill-core material into fractions finer and coarser than 200-mesh was done hydraulically, a part of the heavy minerals finer than 200-mesh may have remained with the coarser fraction. Consequently, this coarse fraction probably contained less of the metals than the quantities indicated by the assays, and the real distribution of the heavy minerals may not have been very different from that found to exist in the pit samples.

Although the tests were not conducted as accurately as they might have been to obtain all the information that the samples could yield, it seems reasonable to conclude that the metallic minerals in the fraction coarser than about 35-mesh are for the most part attached to gangue minerals and that most of those in the finer fractions are virtually free from gangue.

TABLE 3.—*Distribution of metals in separate size fractions of primary gravel in the apex of the Papas fan*

Size fraction		Percent of total weight	Metal content, in grams per metric ton				Percent distribution of metals			
Passes through—	Retained on—		Tin [1]	Mercury	Silver	Gold	Tin	Mercury	Silver	Gold [3]
Composite pit sample [2]										
	8 mesh	17.74	150	10	2.4	0.068	11.5	9.9	8.3	17.6
8 mesh	14 mesh	13.81	150	12	3.1	.068	9.0	9.3	8.5	13.7
14 mesh	28 mesh	10.51	200	15	3.1	Tr.	9.1	8.8	6.5	
28 mesh	48 mesh	9.91	270	11	4.1	.068	11.6	6.1	8.0	9.9
48 mesh	100 mesh	10.42	240	20	3.7	Tr.	10.9	11.7	7.6	
100 mesh	200 mesh	8.03	300	25	5.4	Tr.	10.5	11.3	8.6	
200 mesh, "sand"		8.21	270	15	7.5	.136	9.6	6.9	12.2	16.3
200 mesh, "slime"		21.37	300	30	9.5	.136	27.8	36.0	40.2	42.5
		100.00					100.0	100.0	100.0	100.0

Size fraction, in drill-core samples		Percent of total weight in drill-core samples [4]	Percent distribution of metals: 1, pit sample; 2, drill-core sample							
			Tin		Mercury		Silver		Gold	
Passes through—	Retained on—		1	2	1	2	1	2	1 [3]	2
Drill-core samples, [5] and comparison with pit sample										
	16 mesh	28.13	21.8	26.4	20.5	35.2	17.8	21.5	31.3	9.2
16 mesh	200 mesh	41.53	40.8	40.8	36.6	33.8	29.8	37.0	9.9	36.1
200 mesh		30.34	37.4	32.8	42.9	31.0	52.4	41.5	58.8	54.7
		100.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Tin assays are undoubtedly too high, but they can be used, without introducing a large error, for comparing the different fractions with each other.
[2] Composite sample from 16 test pits, from which several small samples were excluded because of insufficient material.
[3] Inaccurate because of "trace" assay reports.
[4] Average size distribution of material in 731.3 meters of drill core from 20 holes.
[5] Material from 740.3 meters of drill core taken from 22 holes in the Papas fan.

METAL CONTENT OF THE GRAVEL

Although the only part of the gravel deposits whose metal content has been fairly well determined is the apex of the Papas fan, north of the village of Guadalcázar (see pl. 33), rough tests have been made of other parts by taking channel samples from banks of primary gravel, ranging in height from 6 to 20 meters, along several arroyos eroded in the Papas, San Diego, and Santa Elena fans. These tests have afforded an idea of what some parts of the deposits might contain, but large volumes of gravel still remain untested. Because the quantities of tin and mercury in the gravel are very small, the early assays of the material, made by ordinary analytical methods, were erratic, and it was rightly suspected that many of them were too high. In order to obtain more reliable information, therefore, many samples were first concentrated by panning before they were assayed. The results thus obtained, even when the panning was done with extreme care, showed much smaller quantities of metal than were actually present, although they gave some idea of the minimum quantities that might be recovered by ordinary commercial methods of placer mining.

The most extensive tests made before 1941 were carried on by R. S. Botsford, who sampled a part of the Papas fan for the London Tin Corp., during the winter of 1937–38. Botsford drilled five holes, ranging in depth from 17.5 to 61 meters, with a 15-centimeter Banka drill and a 5-centimeter hand auger (see pls. 29 and 33). Because of the difficulty of recovering the cores intact and of obtaining accurate assays, the quantities of metal found in these cores cannot be considered characteristic of the deposits and accordingly are not quoted here. The tests showed, however, that the metal content differed but slightly from place to place, and that there was no significant increase in tenor with depth, even in the deepest hole, which is close to and 16 meters deeper than hole 9 drilled later by the San Luis Mining Co. (see pl. 33). Three of the holes drilled by Botsford were in the area tested later by the San Luis Mining Co., but the fourth was farther west and the fifth farther east.

The first detailed tests in which analytical methods especially designed for ores of very low grade were used were those made during 1942 and 1943 under the direction of F. A. Beauchamp of Hamilton, Beauchamp & Woodworth, consulting metallurgists to the San Luis Mining Co. Beauchamp worked with material from hand-excavated pits and drill holes in the Papas fan north of the village of Guadalcázar. (See pl. 29 and pl. 33.) Probably a fair degree of accuracy was attained in the analyses for gold, silver, and mercury, and the quantities of these metals reported may be considered to indicate very nearly the true metal content of the material tested; but the quantities of tin shown by these analyses are considerably larger than those found in similar material by others who have had many years of experience in analyzing low-grade tin ores commercially, and the results for tin, therefore, probably are erroneous. A second series of detailed tests was made in 1943 under the direction of Wm. G. Kane and R. J. Quinstrom, consultants to the Banco de México. The tin analyses made during these tests probably are the most accurate of all that have been made of these placer deposits, because a careful study of the methods of analysis was made before the results were accepted with confidence. These assays checked closely with those obtained on identical samples assayed by the Consolidated Mining & Smelting Co. of Canada.

The first tests by the San Luis Mining Co., early in 1942, were made on samples obtained from channels cut in the sides of sixteen 8-meter test pits, excavated in an area 600 meters square, in which the pits were placed 200 meters apart, except where the terrain did not permit such exact spacing. (See pl. 33.) The total thickness of gravel tested was about 40 meters, this thickness being greater than the depth of the pits because of the uneven terrain. The weighted average content of metal in all the material, as calculated from assays of separate samples from each of the pits, was 0.0243 percent of tin, 0.0043 percent of mercury, 7.38 grams of silver and 0.018 grams of gold per metric ton. (See table 4.) The quantity of gold reported was undoubtedly less than that actually in the material, for many of the individual samples were reported to contain simply a "trace" of gold; the quantity of tin reported was undoubtedly high. Assays of a composite sample from which several individual samples were excluded for lack of material gave slightly lower average percentages, as shown in table 4. The material in the higher ground was found to be slightly richer, in general, than that in the lower ground close to the village, owing in part possibly to the larger proportion of low-grade, fine-grained secondary gravel in the lower pits.

Late in 1942 and early in 1943 the San Luis Mining Co. made further tests on material obtained from 22 drill holes from 3 to 45 meters deep, located in and around the area where the pits had earlier been dug (see pl. 33). Cores averaging about 20 centimeters in diameter were taken from the holes in 3-meter lengths by pressing a specially built pipe called a "biscuit cutter" into the firm gravel and removing each segment separately. The total length of core thus removed was 740.3 meters, and the weight of material when dried was 64.75 metric tons, all of which was used in many and varied tests. All but two of the holes were drilled in an area 1,400 meters long and about 900 meters wide, extending outward from the apex of the Pappas fan. The location of the other two holes increases the length of the area tested to 2,200 meters, the width remaining the same. The areas described extend from the outcrop of the contact between the gravel and limestone to lines 100 meters beyond and parallel to the outermost lines of holes. Only three of the holes, those nearest the contact between the fan gravel and the limestone, reached the limestone underlying the gravel deposit.

TABLE 4.—*Metal content of primary and secondary granitic gravel in parts of the Guadalcázar placer deposits*

Sample No.	Percent		Grams per metric ton			
	Tin	Mercury	Tin	Mercury	Silver	Gold
1	0.0243	0.0043	243	43	7.38	[1] 0.018
2	.024	.0032	240	32	7.02	[1] .033
3 [2]	.0403	.0015	403	15	9.44	.058
4	.043	.0075	430	75	7.16	.123
5 [3]	.0084	.0012	84	12	8.5	.034
6 [3]	.0085		85			
7	.005		50			
8	.016		160			
9	.016		160			
10	.0394		394			
11	.0219		219			
12	.0137		137			
13	.013		130			
14	.0086		86			
15	.0116		116			

[1] Less than actual gold content, owing to many individual samples being reported as a "trace."
[2] Best estimate of average metal content of the primary gravel in the apex of the Papas fan, with the exception of tin, which is undoubtedly too high.
[3] Best estimate of the average tin content of the primary gravel in the apex of the Papas fan.

1. Average metal content of material from sixteen 8-meter pit samples (see pl. 33), calculated from analyses of separate samples. Tests by Hamilton, Beauchamp & Woodworth, consulting metallurgists to the San Luis Mining Co.
2. Composite sample similar to 1, but from which several separate samples were excluded because of insufficient material.
3. Average metal content of 740.3 meters of drill core (64.75 dry metric tons) from 22 holes to a maximum depth of 45 meters in the Papas fan (see pl. 33), calculated from analyses of many separate samples. Tests by Hamilton, Beauchamp & Woodworth, consulting metallurgists to the San Luis Mining Co.
4. Small part of a 20-ton sample of primary and secondary gravel taken from banks along six arroyos in the Papas fan, north of the village of Guadalcázar. Tests by the Consolidated Mining & Smelting Co. of Canada, Ltd.
5. Average metal content of 30 metric tons of primary gravel from high banks along Arroyo del Roble and from a 17-meter pit near the old concentrating plant of the Compañía Minera Guadalcázar (see pl. 28), calculated from analyses of mill products. Tests by R. J. Quinstrom, consulting metallurgist to the Banco de México.
6. Weighted average tin content of material from 10 test pits, ranging in depth from 7.1 to 19.6 meters and totaling 138.2 meters, excavated in area of pits dug by the San Luis Mining Co. Tests by R. J. Quinstrom, consulting metallurgist to the Banco de México.
7. Tin content of a composite sample of primary gravel taken from many arroyo banks in the northeastern one-third of the Realejo Basin. Tests by R. J. Quinstrom.
8. Similar to 7, but from the central one-third of the Realejo Basin.
9. Similar to 7, but from the southwestern one-third of the Realejo Basin.
10. Average tin content of 12,600 metric tons of the richest secondary gravel in Arroyo del Roble and Arroyo del Pinal, north of the village of Guadalcázar. Tests by Wm. J. Shedwick and R. J. Quinstrom, for the Banco de México.
11. Average tin content of 55,900 metric tons of secondary gravel in the bed of Arroyo de las Papas. Tests by Wm. J. Shedwick and R. J. Quinstrom.
12. Average tin content of 99,500 metric tons of secondary gravel where small arroyos discharge their loads onto flats north of Guadalcázar. Tests by Wm. J. Shedwick and R. J. Quinstrom.
13. Average tin content of 138,000 metric tons of secondary gravel in bars along Arroyo de las Papas, northeast of Guadalcázar. Tests by Wm. J. Shedwick and R. J. Quinstrom.
14. Average tin content of 453,500 metric tons of secondary gravel on flats between arroyos north of Guadalcázar and south of samples 10–13. Tests by Wm. J. Shedwick and R. J. Quinstrom.
15. Weighted average tin content of 759,500 metric tons of secondary gravel (samples 10–14) from the area north of Guadalcázar, based on assays of samples from 49 pits. Tests by Wm. J. Shedwick and R. J. Quinstrom.

The average metal content of all the material removed from the drill holes, calculated from assays of several hundred samples, was 0.0403 percent of tin, 0.0015 percent of mercury, 9.44 grams of silver and 0.058 of a gram of gold to the metric ton. (See table 4.) As pointed out in a preceding paragraph, the tin content reported by the San Luis Mining Co. is undoubtedly high, but the content of the other metals is probably accurate. With the exception of the figure given for tin, then, these are the best estimates of the average metal content of the material in any one large block of the placer deposits. The metal content of the individual cores cannot be compared in detail here, for the assays of each core were not reported separately, but the differences were said to have been too erratic to indicate that any one part of the block tested was much richer or much leaner than the average. A small decrease in values seems to have been found away from the apex of the fan, but further tests of material more distant from the apex would be required to indicate whether this decrease is constant. Significantly, no progressive change in metal content was found with depth, and no marked concentration was found at the base of the deposit, in holes that reached the underlying limestone.

A small sample was tested late in 1944 by the Consolidated Mining & Smelting Co. of Canada, Ltd., in its laboratories at Trail, British Columbia. This sample was said to have been taken from banks along six of the arroyos north of the village of Guadalcázar. It weighed about 20 tons, but only 120 kilograms was submitted for testing. This sample was clearly not representative of the deposits as a whole, although it was said to have been taken over a broad area. The average metal content, as calculated from many assays of separate portions, was 0.043 percent of tin, 0.0075 percent of mercury, 7.61 grams of silver and 0.123 of a gram of gold to the metric ton. As the total metal content was even higher than that reported by the San Luis Mining Co. (see table 4), and as laboratory tests gave very high recoveries of the metallic minerals, further tests of much larger samples were thought to be justified and desirable, using the methods of concentration employed in Canada.

As a result of the encouraging data obtained in Canada, a pilot mill and chemical laboratory were constructed at Gauadalcázar during the spring of 1946, under the direction of Wm. G. Kane and R. J. Quinstrom and under the sponsorship of Engineer Gonzalo Robles of the Banco de México. Soon after the plant was put into operation in July of that year, it was found that the tin assays being made were erratic and tended to be high. In response to the urgent need for accurate tin determinations, a careful study of analytical methods and reagents was carried on over a period of nearly 5 months, until the results were finally judged to be trustworthy. Meanwhile, it had become clear that earlier tin assays by others were erroneous and could not be relied on to indicate the tin content of the deposits. Also, the sample tested in Canada was not representative of the primary granitic gravel, but was much richer even than most of the best secondary gravel. A new sampling program on a small scale was therefore undertaken, from October until December, and 10 pits were sunk by hand to depths of 7.1 meters to 19.6 meters in the area earlier sampled by the San Luis Mining Co. The average tin content of all the material from these pits did not exceed 0.0085 percent. (See tables 4 and 5.) This very low value discouraged any hope of mining the primary gravel commercially, and further investigation was thought unjustified.

TABLE 5.—*Tin content of material from 10 pits excavated in the apex of the Papas fan*[1]

Pit No.	Depth of pit (meters)	Tin (percent)
1	[2]0 - 1.5	.022
	1.5- 3.5	.005
	3.5- 5.5	.005
	5.5- 7.5	.003
	7.5- 9.5	.010
	9.5-11.5	.010
	11.5-13.0	.008
2	[2]0- 2	.025
	[2]2- 4	.022
	4- 6	.006
	6- 8	.008
	8-10	.006
	10-12	.007
	12-14	.006
	14-14.8	.007
3	[2]0- 2	.013
	2- 4	.006
	4- 6	.006
	6- 8	.006
	8-10	.006
4	0- 2	.009
	2- 4	.006
	4- 6	.006
	6- 8	.010
	8-10	.012
	10-12	.015
	12-14	.021
	14-16	.019
5	[2]0 - 1.3	.012
	1.3- 3.3	.009
	3.3- 5.3	.009
	5.3- 7.3	.006
	7.3- 9.3	.008
	9.3-11.3	.012
	11.3-13.3	.009
	13.3-15.0	.012
	15.0-17.0	.009
	17.0-19.0	.008
6	[2]0 - 1.6	.014
	1.6- 3.6	.009
	3.6- 5.6	.006
	5.6- 7.1	.015
7	0 - 2.8	.006
	2.8- 4.8	.004
	4.8- 6.8	.013
	6.8- 8.8	.012
	8.8-10.8	.012
	10.8-12.8	.008
	12.8-14.8	.013
	14.8-16.8	.003
	16.8-18.8	.003
	18.8-19.6	.003
[3]8	0- 2	.009
	2- 4	.005
	4- 6	.006
	6- 8	.014
	8-10	.009
	10-12	.009
	12-14	.005
	14-16	.009
	16-16.7	.012
[3]9	0- 2	.003
	2- 4	.004
	4- 6	.004
	6- 8	.005
	8-10	.006
	10-12.2	.006
[3]10	0 - 0.8	.004
	.8- 2.8	.008
	2.8- 4.8	.005
	4.8- 6.8	.002
	6.8- 8.8	.002
	8.8- 9.8	.002

[1] Pits excavated in area earlier tested by the San Luis Mining Co. Tests and assays by R. J. Quinstrom consultant to the Banco de México.
[2] Consists of secondary or reworked gravel.
[3] Pit reached underlying limestone bedrock.

The gravel in the San Diego and Santa Elena fans also contains tin, mercury, silver, and gold but in what quantity is not accurately known. A few samples of material from these fans were taken in 1942 by the authors and Merle Guise of the Panaminas Corp., to test the relative difference between the metal content of these fans and that of the Papas fan. The samples were weighed and concentrated by

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hand panning in the field, and assays of the concentrates were made later. Owing to the method of sampling used, the results cannot be compared directly with those of the San Luis Mining Co., but a comparison can be made with results obtained on samples that were taken from the Papas fan and treated in the same way. Late in 1946 the Banco de México obtained three composite samples of primary gravel from the Realejo Basin, representing the northeastern, central, and southwestern sections of that basin. These were assayed while the pilot mill was still in operation at Guadalcázar. The composite sample from the northeastern section contained only 0.005 percent of tin, but those from the central and southwestern sections contained an average of 0.016 percent of tin each, or roughly twice the average tin content of the primary gravel in the apex of the Papas fan, as determined by the same chemist and using the same analytical method.

All these tests, then, indicate that tin and mercury are most abundant in the Santa Elena fan, less so in the Papas fan, and least abundant in the San Diego fan. The quantities of silver and gold were not determined and hence cannot be compared directly. Nevertheless, geologic evidence points to the conclusion that all the metals should be most abundant in the Santa Elena fan and least abundant in the San Diego fan (see pp. 123–125), owing to the concentration of the ore deposits in the granite around the southwest side of the stock. If two or three drill cores were obtained from the San Diego fan west of the village of Abrego, they would indicate how much leaner this fan is than the Papas fan, and such cores would give a reliable indication of the metal content of the rest of this fan. Although the outer parts of the Papas fan have not been sampled in detail, they seem to be leaner than the apex of the fan—the part that was drilled. The limestone gravel and alluvium northwest of the village of Guadalcázar (see pl. 29) may contain more mercury than the granitic gravel, owing to the abundance of small mercury deposits nearby, but they probably contain much less of the other metals.

The secondary gravel has been sampled in detail only in a small area north of the village of Guadalcázar, although samples taken from many other places have been roughly panned and the concentrates assayed. The detailed tests were carried on by the Banco de México during November and December 1946, on material from the same area in which the primary gravel was sampled. Some 49 pits were sunk to depths of 0.8 to 2.7 meters, through the secondary gravel in arroyo beds and sides, and on benches and terraces between arroyos. Assays of this material were made only for tin, which was found to be most abundant in the beds and sides of the present arroyos and least concentrated on the benches and terraces between them. The average tin content of the richest secondary gravel, whose tonnage amounted only to 12,600 metric tons, was 0.0394 percent of tin. The material on the benches, amounting to nearly half a million metric tons, was found to average only 0.0086 percent of tin. The gravel pockets in some of the arroyo beds have a tenor as high as 0.1 percent of tin, together with a nearly equal percentage of mercury and small quantities of silver and gold. It is doubtful, however, whether there is enough of this rich secondary gravel to support even a small mining operation, and in any large operation the primary gravel would also have to be mined and would determine the over-all grade. Much of the finer-grained secondary gravel in the lower parts of the basins may contain even less tin than the primary gravel.

RECOVERIES FROM THE GRAVEL

Concentration tests of the placer gravels were carried on both by the San Luis Mining Co. and the Banco de México. The quantities of metal obtained in concentrates made from the gravel tested indicate roughly what may be expected by way of recoveries in commercial practice. In the following discussion, it will be evident that, although the proportions of tin recovered by the two methods described differ greatly, when calculated on the basis of the head assays given by the two organizations testing the material, the actual quantities of tin recovered in the concentrates, per unit volume of heads, are much more nearly alike. This indicates strongly that the tin assays reported by the San Luis Mining Co. were much too high for the very low grade material assayed. The error was less significant, of course, in assays of the concentrates that were much richer in tin.

The first series of tests, which was made on drill-core samples taken by the San Luis Mining Co. during 1942 and early in 1943, was designed to indicate the recovery that might be obtained by means of ordinary gravity-concentrating equipment. The material was disintegrated with water in a small mill that served as a trommel and was fed to a 16-mesh screen. The oversize was sent to jigs, and the jig concentrates were crushed to pass 16-mesh and tabled; the undersize was fed to a group of small cones so adjusted as to separate the material hydraulically into fractions finer and coarser than about 200 mesh. The oversize from these cones was fed to a small Wilfley laboratory table, and the undersize was directed over a corduroy blanket to a storage tank. All the tailings from the tables were retabled. The concentrates, tailings, and other products from all the operations were weighed and assayed. The tests gave an average over-all recovery of only 7.3 percent of the tin shown by assay in the heads, 12.3 percent of the mercury, 4.3 percent of the silver, and 9.5 percent of the gold, in a low-grade concentrate from which, by further tests, it was found possible to recover at least 85 percent of these metals in marketable products, either in high-grade concentrates for smelting or in actual metal, as mercury and gold. These recoveries, per metric ton of heads, were equal to 24.8 grams of tin, 1.57 grams of mercury, 0.35 of a gram of silver, and 0.005 of a gram of gold.

The second series of tests, which was made by the Banco de México in the pilot plant at Guadalcázar in the fall of 1946, was designed to indicate the recoveries obtainable, in commercial practice, by means of special types of equipment designed for treating very low grade, fine-grained material. The tests were carried on by a metallurgist who had had several years of experience in recovering cassiterite commercially from very low grade tailings after extraction of lead and zinc by flotation. The most representative sample of primary gravel treated in the pilot mill was obtained partly from banks of primary gravel along Arroyo del Roble and partly from a 17-meter hole excavated near the old concentrating plant of the Compañía Minera Guadalcázar (pl. 30), amounting in all to about 30 metric tons. The fraction coarser than 4-mesh, averaging about 10 percent of the heads, was separated by wet screening in a trommel and discarded as waste. The portion finer than 4-mesh was then fed to a 35-mesh vibrating screen, from which the oversize was passed through a jig. The undersize was sent to a classifier to separate the portion finer than 325-mesh, which was discarded, and the oversize was fed to blanket-top tables, whose concentrates were further cleaned on a Wilfley table. The combined products from the jig and tables, including both concentrates and middlings, indicated that in these low-grade concentrates the recoveries amounted to 56.8 percent of the tin, 50.5 percent of the mercury, 3.3 percent of the silver, and 28.6 percent of the gold contained in the material treated, that is, in the fraction finer than 4-mesh and coarser than 325-mesh. The quantities of metal actually recovered in these low-grade concentrates were 48.1 grams of tin, 6.2 grams of mercury, 0.31 of a gram of silver, and 0.01 of a gram of gold per metric ton. Assuming that 10 percent of the original material was discarded as oversize—coarser than 4 mesh—and 25 percent was discarded as undersize—finer than 325 mesh—or 35 percent in all, the recoveries per metric ton of total heads amounted to 31.3 grams of tin, 4.0 grams of mercury, 0.20 of a gram of silver, and 0.0065 of a gram of gold.

The material coarser than 4-mesh probably could not be treated commercially by any method and would have to be discarded, but the fraction finer than 325-mesh could well be treated on the blanket-top tables. This was not done, however, for it had become evident that the tenor of the primary gravel was too low to permit the deposits to be mined commercially and there was no justification for continuing the work. From the results obtained by gravity concentration as practiced by the Consolidated Mining & Smelting Co. of Canada, Ltd., and from personal experience with these methods and with testing the Guadelcázar material, Quinstrom judged that recoveries from the fraction finer than 325-mesh would not be much lower, per metric ton of this material, than those he had obtained from the coarser fraction treated. The fine fraction was found by the San Luis Mining Co. to contain a relatively lager proportion of the metallic minerals than the coarser fractions. Inasmuch as it represents about 25 percent of the total, by weight, the proportion of metallic minerals contained in it is somewhat larger, though not the same for each mineral. (See table 3.) If it is assumed that the decrease in recoveries from this fraction would be more or less balanced by the greater proportion of metallic minerals contained, than the additional quantities recoverable from the fine fraction, per metric ton of total heads, would amount to 12.0 grams of tin, 1.6 grams of mercury, 0.08 of a gram of silver, and 0.0025 of a gram of gold. Adding these to the quantities obtainable from the coarser fraction, the total recoveries per metric ton of primary gravel, by treating all the material finer than 4-mesh, would be 43.3 grams of tin, 5.6 grams of mercury, 0.28 of a gram of silver, and 0.009 of a gram of gold. These quantities would be recovered in low-grade concentrates which would have to be reconcentrated.

Incomplete tests of the initial low-grade concentrates indicated that more than 95 percent of the tin could be recovered in a high-grade marketable product, and it was estimated that at least 90 percent of the other metals in these concentrates could be recovered. The preliminary concentrate could be prepared for electromagnetic separation by roasting, during which the mercury could be recovered as metal, and the roasted concentrate could then be separated electromagnetically. The magnetic portion would contain most of the gold and silver and could be smelted; the nonmagnetic portion would be passed over amalgam plates to catch the free gold and could then be retabled to raise the tin content to 65 or 70 percent. In any event, whatever the final flowsheet might be, separate concentrates suitable for smelting could be obtained with little extra expense and without any significant loss of the metals contained in the preliminary concentrate.

The minimum amounts of metal recoverable in marketable products, per metric ton of primary placer gravel, by gravity methods especially designed for recovering heavy minerals from very fine-grained materials, may be estimated as 41 grams of tin, 5 grams of mercury, 0.25 of a gram of silver, and 0.008 of a gram of gold. (See table 6.)

RESERVES

The Guadalcázar placers do not represent a metal reserve in the ordinary sense of the term, for at current metal prices (1946) the deposits cannot be mined profitably. In a broader sense, however, the placers do represent a reserve of tin, mercury, gold, and silver metals. These four metals could possibly be recovered commercially from the gravels if the prices of tin and mercury were double those obtaining in 1946. The only material for which it is possible to make any estimate of metal content is that in the apex of the Papas fan, as this is the only part of the deposits whose tenor has been quite well established. The body of gravel that was most thoroughly sampled—block A in plate 33—is 1,400 meters long, 800 meters wide, and 40 meters in average depth. Block B in plate 33, which includes block A and, in addition, the adjacent ground that was sampled sufficiently to indicate that its metal content per metric ton is about the same as that of Block A, is 2,200 meters long, about 900 meters wide, and as deep as the deposit, whose maximum depth in this block may be about 95 meters and whose average depth is estimated to be 48.6 meters. Block A contains 44,800,000 cubic meters of gravel, and block B contains about 96,207,700 cubic meters. It may be assumed that the average tin content of all this material is 84 grams to the metric ton, as found by the Banco de México in its tests at Guadalcázar (sample 5 in table 4), and that the mercury content is 15 grams to the metric ton, the silver content 9.44 grams, and the gold content 0.058 gram, as reported by the San Luis Mining Co. (sample 3 in table 4). On this assumption, block A contains, in round numbers, 6,890 metric tons of tin, 1,230 metric tons of mercury, 774,350 kilograms of silver and 4,760 kilograms of gold; and block B, which includes the amounts just cited, contains 14,800 metric tons of tin, 2,640 metric tons of mercury, 1,662,920 kilograms of silver, and 10,220 kilograms of gold (see table 6). The Papas fan as a whole may contain somewhat more than twice as much of these metals as block B and considerably more than the San Diego and Santa Elena fans combined.

The quantities given in the preceding paragraph are theoretical and cannot be considered as indicating what might be recovered from the blocks tested, because no method is known whereby more than 55 or 60 percent of the tin and mercury can be extracted with a smaller proportion of the gold and a very minor part of the silver. Although the exact proportion recoverable of each metal has not been definitely established, head assays being in error by as much as 25 percent, the pilot-mill tests have shown roughly what quantities may be expected to be recovered in commercial practice, per metric ton of primary placer gravel and in marketable products. In block B, they are 41 grams of tin, 5 grams of mercury, 0.25 of a gram of silver, and 0.008 of a gram of gold. Consequently, the amounts of recoverable metal—the "reserves" in the broader sense of the word—contained in the entire block sampled (block B) are, in round numbers, 7,220 metric tons of tin, 880 metric tons of mercury, 44,040 kilograms of silver, and 1,410 kilograms of gold. (See table 6.) The amounts of metal recoverable from the rest of the minable part of the Papas fan may be somewhat greater than those given for block B. The amounts recoverable from the San Diego and Santa Elena fans combined are probably much smaller than those recoverable from the Papas fan. As pointed out in a preceding paragraph, none of this material can be mined and treated at present metal prices (1946), but the gravel in block B might be mined commercially if the prices of tin and mercury were doubled.

TABLE 6.—*Quantities of metal contained in and recoverable from primary gravel in the apex of the Papas fan, per metric ton, and amounts recoverable from blocks sampled*

	Tin	Mercury	Silver	Gold
	Grams per metric ton			
Average metal content per metric ton of heads	[1] 84	[2] 15	[2] 9.44	[2] 0.058
Quantities of metal recoverable:				
Per metric ton of heads, in marketable products	[3] 24.8	1.57	.35	.005
Minimum estimates [4]	41	5	.25	.008
	Metric tons		Kilograms	
Amounts of metal contained in block A (82,028,800 metric tons)[5]	6,890	1,230	774,350	4,760
Amounts of metal recoverable from block A, in marketable products	3,360	410	20,510	660
Amounts of metal contained in block B (176,156,300 metric tons)[5]	14,800	2,640	1,662,920	10,220
Amounts of metal recoverable from block B, in marketable products	7,220	880	44,040	1,410

[1] Average tin content of 30 tons of primary gravel from area north of Guadalcázar, as determined by R. J. Quinstrom, consulting metallurgist to the Banco de México.
[2] Average mercury, silver, and gold content of 64.75 tons of primary gravel from 22 drill cores in the apex of the Papas fan, as determined by F. A. Beauchamp, consulting metallurgist to the San Luis Mining Co.
[3] Quantities recovered in tests by the San Luis Mining Co.
[4] Rough estimates, which may be considered as minima, of quantities recoverable by methods used by R. J. Quinstrom.
[5] See plate 33 for description of blocks A and B. Quantities of recoverable metal used to calculate amounts are those of Quinstrom (see 4, above).

WATER SUPPLY

The maximum rate at which the deposits can be mined depends upon the supply of water that can be developed. As that supply is probably small, the amount should be ascertained if and when a decision is made to mine the deposits. Because of the low grade of the material, large volumes of gravel would have to be treated daily in order to reduce the cost of treatment to a minimum, probably no less than 7,500 cubic meters a day and possibly as much as 15,000 cubic meters. Moreover, the high proportion of fine-grained material in the gravel requires a relatively high consumption of water. Tests made by the San Luis Mining Co. to determine the minimum dilution of the fine fraction showed that the common settling agents were ineffective and that the fraction finer than 200-mesh contained nearly six parts of water for each part of solids after settling for 6 days. The Consolidated Mining & Smelting Co. of Canada, Ltd., tested several settling agents, and although none was found to be very effective, aluminum sulfate gave the best results. The San Luis Mining Co. estimated that the total loss of water, beyond what might be reclaimed from the tailings, would amount to somewhat more than two parts by weight for each part of heads and that the consumption of new water in a plant treating 7,500 cubic meters a day would be about 18,900 liters a minute. At this rate, an annual consumption of about 10,000,000 cubic meters of new water would be required annually for handling 2,700,000 cubic meters of gravel. The findings of the Canadian company point to a lower consumption of water, but a further study of water consumption is necessary before any conclusion can be drawn.

How great a supply of water might be developed is not known, nor have tests been made to prove whether a supply sufficient to treat even 7,500 cubic meters a day might be developed in the Guadalcázar Basin. Consequently, water resources should be studied in detail by various methods, including drilling and pumping, to determine the scale at which mining might be carried on. The nearest station where records of precipitation have been maintained is at Cerritos, a town on the railroad about 25 kilometers southeast of Guadalcázar (see fig. 11). According to the Secretaría de Agricultura y Fomento the average annual rainfall for the years 1922 to 1932 was 558.7 millimeters. As the Guadalcázar district is perhaps 600 meters higher than Cerritos, the precipitation at Guadalcázar may be somewhat greater, probably about 635 millimeters. Nearly 80 percent of the annual total falls between May 1 and October 31, and 60 percent between June 1 and September 30. The driest month is February, with less than 2 percent of the yearly total, and the wettest months are June and September, each with about 20 percent of the total. Although much of the rainfall is gentle, a few very heavy rains fall during the summer and cause short-lived floods.

The southwestern part of the Guadalcázar Basin, which includes the Papas fan, forms a separate drainage basin whose surface area is about 34.5 square kilometers, of which 74 percent is occupied by limestone and limestone gravel, 23 percent by granitic gravel, and 3 percent by granite. (See pl. 28.) Assuming that the annual rainfall is 635 millimeters, the amount of water that falls on this area each year is 29,907,-500 cubic meters, more than twice the estimated amount of new water needed to treat 7,500 cubic meters of gravel a day. The amount of surface runoff that might be caught and stored in earth ponds or tanks is uncertain, but it is probably less than 5 percent, or only 10 percent of the water required. The rest of the water sinks into the gravel or drains off through fissures in the limestone. The runoff that reaches the lowest parts of the basin, where the gravel fill is at a level with the limestone-bedrock sides (see pl. 29), quickly disappears through sinks and fissures in the limestone, except where access to some of these outlets has been cut off by small earth dams. Other dams have been thrown up on the fan to catch runoff and hold it through the dry season for use by livestock. In areas occupied by limestone, water for domestic use is caught by small earth dams in places where an accumulation of silt and clay prevents it from escaping through fissures. Since these tanks, which catch only a part of the runoff, are almost completely sealed by silt and clay and lose hardly any water except by use and evaporation, much of the rest of the runoff could probably be caught in similar fashion and stored for mining use.

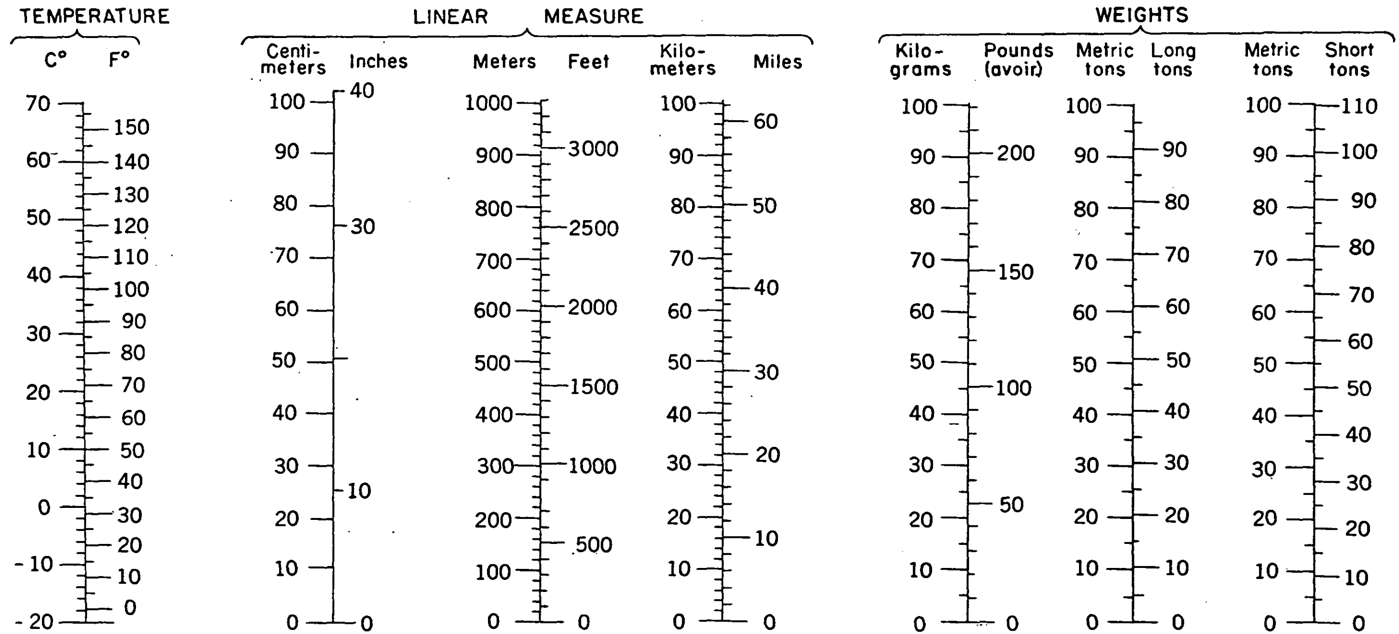
There are no permanent streams in the area, and the intermittent streams flow only after heavy rainstorms. It is said that there are large springs near Cerritos, in the front of the limestone range that forms the southeastern border of the Guadalcázar upland and faces the low valley followed by the railroad. As these springs are much lower than Guadalcázar, the water draining into the limestone in the higher area may sink to a considerable depth before reaching a permanent ground-water level. No deep wells have been drilled anywhere in the region, nor have even shallow wells been dug in the limestone. Small seeps occur at several places in the granite not far from its contact with the limestone, but the water yielded by them makes only a small contribution to domestic uses, and most of the seeps dry up during the dry season.

The gravel deposits, on the other hand, are apparently saturated with water, which seems to be held perched above the lower, permanent water table in the limestone by the relatively impermeable fan gravel or the clay between it and the limestone. Water seeps from under the rhyolitic tuff south of the village of Guadalcázar, where it is caught by an earth dam and stored for domestic use. (See pl. 29.) Shallow open wells in and around Guadalcázar, San Nicolás, and Abrego (see pl. 29.) reach water at depths of 1 to 8 meters; none is deeper than 12 meters, and none has ever been equipped with a mechanical pump. Most of them can be emptied with buckets in a few hours, although in two or three of them the water level is not lowered perceptibly by this slow withdrawal. It appears, therefore, that the flow of water into the wells in generally a mere seepage, except where a relatively coarse grained bed has been cut.

No tests of water flow were made by the San Luis Mining Co. when the drill cores were taken, but seepage into the holes was reported to be negligible or very slow, except into those that cut one or more of the relatively scarce, coarse-grained beds, which may be called aquifers. At such places the water rose suddenly in the holes, in some only a few meters but in others more than 20 meters. As these aquifers appear to be scattered lenses of material deposited in the beds of intermittent streams that existed during the building of the fan, they probably are not very large and do not contain a very large amount of water. When pumped, the aquifers would of course be slowly replenished from the less permeable material surrounding them, but at what rate is not known. Except from the small aquifers, little water is likely to be pumped from the greater part of the relatively impermeable fan gravel. If mining should be undertaken and pits excavated, appreciable quantities may drain into these pits from aquifers and other permeable beds, and more water might be obtained from such pits than from numerous wells.

The conditions in the eastern part of the Guadalcázar Basin—the part occupied by the San Diego fan—are similar to those in the southwestern part, except that the watershed covers a much larger surface area. Hence the amount of surface runoff that might be caught and stored may also be much larger. In the Realejo Basin, however, the conditions are very different; the surface area of the watershed is only 3.7 square kilometers, of which 44 percent is occupied by granitic gravel, 40 percent by limestone and limestone gravel, and 16 percent by granite. About one-third of this area is drained by Aroyo de Santa Elena, which carries the runoff into the Trinidad Basin, and the rest is drained by way of fissures in the limestone along the northern and western edges of the gravel deposit. (See pl. 30.) Most of the water for domestic use is obtained from seeps in the granite, but some of it is obtained from earth tanks erected in areas underlain by gravel and limestone. Even if all the runoff were caught in such tanks, however, the amount would be insignificant. Moreover, owing to the small volume and deep dissection of the gravel in the Realejo Basin, the amount of water stored in this gravel must be small. The northeastern and southwestern parts of the deposit appear to be the only places where any significant quantities of water might possibly be found.

METRIC EQUIVALENTS



1 cm. = 0.3937 in.
1 in. = 2.5400 cm.

1 m. = 3.2808 ft
1 ft. = 0.3048 m.

1 km. = 0.6214 mile
1 mile = 1.6093 km.

1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100m.) = 2.47 acres
1 cu. m. (m3) = 1.31 cu. yd.

1 kg. = 2.2046 lb.
1 lb. = 0.4536 kg.

1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2,205 lb.
1 long ton = 1.0161 metric ton
1 short ton = 0.9072 metric ton

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