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THE LAKES OF POTOSI

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THE lakes of Potosí have been rebuilt. Three and a half centuries after the beginning of work on this marvel among water-supply systems, one of the great engineering feats of its time, the lakes are to function again as in the days when they made possible the glory of the *Villa Imperial*. Construction of the system began in 1573 and was completed in 1621, with some thirty-two lakes furnishing the water to turn the wheels of the silver mills. Through the following years the fortunes of the city, one might say, rose and fell with the lakes. Does this rehabilitation of the lakes augur a new prosperity for the ancient city?

At the height of its prosperity Potosí had an accredited population of 160,000. Today the city numbers some 30,000 inhabitants. Its 200 blocks of houses stand in irregular rows of narrow, winding streets at the foot of the 15,680-foot cone of the Cerro Rico. Old churches and other old buildings in different degrees of preservation[1] link present-day Potosí with those traditional days when it sent to the Spanish crown the lion's share of the silver that played so large a part in shaping the course of the world's history. "There is no city in America that conserves its Spanishism with more love than Potosí."[2]

For a place of its size Potosí, at 13,780 feet (4200 meters), has no rival in altitude save Cerro de Pasco, at 14,200 feet, with a population of 20,000. The province of Frías, in which Potosí is situated, is well named. Recent figures[3] give the city an annual mean temperature of 7.8° C. (46° F.); the average winter temperature has a daily range from −16° C. (3° F.) to 7° C. (45° F.). The spring months,

[1] The Sociedad Geográfica de Potosí has taken a hand in the preservation of some of the old buildings, among them the Casa de Moneda, which however does not antedate the eighteenth century. A description of the Moneda, as it is today, appears in Hiram Bingham's article, "Potosí," *Bull. Amer. Geogr. Soc.*, Vol. 43, 1911, pp. 1–13.

[2] W. J. Molina: La Ciudad Unica, Buenos Aires, 1927.

[3] Luis Subieta Sagárnaga: Potosí Antigua y Moderno, Potosí, 1928, p. 2.

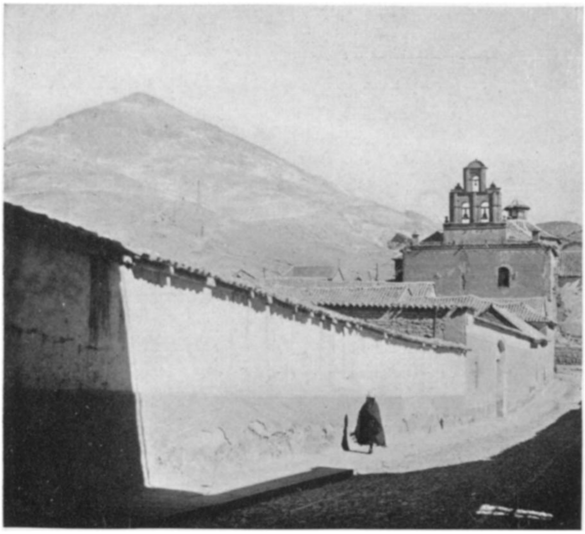

FIG. 1—The famous Cerro Rico dominates the scene in Potosí.

October to December, are usually warmer than the summer months, January to March, because of their bright sunshine, in contrast with the clouded skies of summer. After a residence of more than two years in Potosí the writer does not find the climate of the city itself any more inhospitable than that of Uyuni or Oruro or other cities of the altiplano proper, but early Spanish accounts all emphasize the rigors of the climate: "sumamente frío y seco," says an anonymous description of the city in 1603.[4] In his "Crónicas Potosinas"[5] Omiste records some disastrous storms of the early days; for instance, in August, 1557, snow fell continuously for 11 days to a depth of more than a vara (32 inches) and caused many deaths. In his "Anales de Potosí" Bartolomé Martínez y Vela[6] reports under date of 1640 that "the frightful storms, the terrible snows, and the insufferable cold" began to ameliorate.

However, the dryness of the climate is more pertinent to our present inquiry. The yearly precipitation at Potosí is about 25 inches, and most of it falls in the three summer months. From October to December there are occasional showers of hail, sleet, and snow, but it seldom rains at this season. Evaporation is great. The scarcity of water early offered an obstacle to the mining industry. "For silvers sake men desire a good yeere of raine in Potosi, as they doe in other places for bread."[7]

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[4] Relaciones geográficas de Indias: Perú, Vol. 2, Madrid, 1885.

[5] Modeste Omiste: Crónicas potosinas, Vol. 2, La Paz, 1919; see also Vicente G. Quesada: Crónicas potosinas, 2 vols., Paris, 1890, Vol. 1, pp. 251–253.

[6] Published in Archivo Boliviano, Vol. 1, Paris, 1872, pp. 282–490 (Quesada drew largely on this account for his Crónicas potosinas" and both were used by Bernard Moses for his chapter on Potosí in "The Spanish Dependencies in South America," 2 vols., New York and London, 1914, Vol. 2, pp. 1–26). Bartolomé Martínez y Vela was also the author of a larger work, for information on which we are indebted to Mr. Lewis Hanke of Harvard University. It is entitled "Historia de la villa imperial de Potosí, riquesas incomparables de su famoso cerro, grandesas de su población, sus guerras civíles, y casos memorables," and it was written about 1770. The manuscript is in the Biblioteca del Palacio Nacional (formerly the Royal Library) of Madrid and has not been published save for "Volume I," by Luis Subieta Sagárnaga in Potosí in 1925.—EDIT. NOTE.

[7] Joseph de Acosta: The Natural & Moral History of the Indies, reprinted from the English translated edition of Edward Grimston, 1604, 2 vols., *Hakluyt Soc. Publs.*, Ser. 1, Nos. 60 and 61, London, 1880, Vol. 1, p. 222.

The Creation of the Lakes


Fig. 2—A street in Potosí.

To the viceroy Francisco de Toledo is given credit for the project of the lakes of Potosí. The riches of the Cerro Rico had become known to the Spaniards in 1545, when the Indian Diego Gualca shared the secret of his discovery with his master Villarroel; but during the next two decades the ores ran so high in silver that only primitive smelting furnaces were needed to refine them. By 1566 these rich ores had been exhausted, and it became evident that other means must be found for treating less valuable ores if the demands of the Spanish crown and the greed of the individual miners were to be satisfied. It was perhaps the threatened decrease of silver shipments to Spain that prompted the viceroy's visit to Potosí in 1572, when he called a convention of the miners to consider the construction of ore-grinding mills operated by hydraulic power. The suggestion was greeted with enthusiasm, but unfortunately there was no permanent stream for furnishing such power closer than 15 kilometers. The inhabitants of the town depended on springs whose total flow amounted to some twenty or thirty liters a second during the dry season. Then it was that four prominent miners, Captains Illanes and Iñigo de Mendoza, Sebastián de Arlés, and Villafranca, offered to build at their own expense a lake to impound the summer rains so that there might be water the year round. The viceroy, by way of coöperation, offered to assign 20,000 Indians for building the waterworks and a force to maintain them in perpetuity. The offer was legalized by royal cedula dispatched by Philip II in 1574. A beginning was made with the lake Tabaco Nuño, later renamed Chalviri, 7 kilometers southeast of the Cerro of Potosí.

Completion of the Chalviri lake, far from solving the miners' problems, created new ones. Hardly had the lake water begun to function at the mills erected just below the lake than the difficulties of transportation became apparent. More than 2000 llamas were needed to carry the ore from the Cerro to the water. That it would be easier to bring the water to the ores soon became clear. Other

FIG. 3—Another view of the Cerro.

miners wished to construct mills near Potosí and to use the waters of Chalviri by building an aqueduct to the city. To this the four owners of the lake agreed on condition that mills be constructed for them near the Cerro to replace those built near Chalviri. So was the first water brought to Potosí.

The inauguration of its water supply marked the beginning of the great glory of Potosí. More lakes were built—according to some historians, a total of 32, with storage capacity of perhaps 6,000,000 metric tons. A channel, Ribera de la Vera Cruz de Potosí, as it was called by Corregidor Pereyra, was built through the city for dropping this water through a vertical height of 594 meters, to operate the 132 mills, *ingenios*.

FIG. 4—One of the *pilas* where the people of Potosí go for water.

FIG. 5—Scene along the Ribera, with one of the old bridges.

The average amount of water flowing in the Ribera may be estimated at about 250 liters a second. The summer rains served not only for filling the reservoirs but also for supplying the Ribera during the three rainy months. According to the writer's calculation, after April 1, when the lakes began to be drawn down, evaporation and seepage losses would be about compensated by the flow of feeders, which continues in some *quebradas* until July or August. Despite the low efficiency of the primitive wooden water wheels used by the Spaniards, it is likely that they generated a steady 600 horsepower at the mills. Each millowner was allowed the use of the waters of the Ribera to run his plant, but he was obligated to deliver this water at the proper level to his neighbor downstream.

FIG. 6—Looking down the Ribera; masonry canal (left of center) for turning water wheel.

Construction Methods of the Spaniards

The water-supply system of Potosí has met in remarkable manner the test of time. The engineers who planned and carried out the work were highly skilled. The product of their labors would have been well worthy of engineers of today. What background in water-

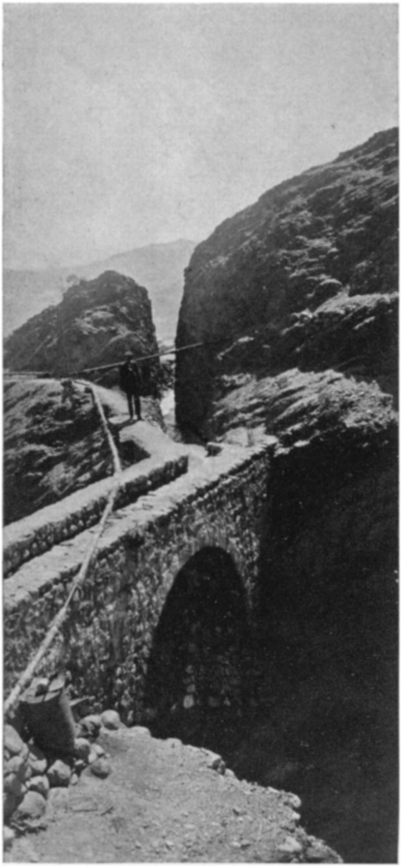

Fig. 7

Fig. 8

Fig. 7—A canal for using water of the Ribera to turn an old water wheel crosses the Ribera on an old bridge.
Fig. 8—Atop the Cerro Rico.

supply work did these colonial people have, to produce so remarkable a feat of engineering? Was it the Roman or Moorish heritage of arid Iberia? In any case they were called on to solve many new problems when they transferred their activities to the mountain region of South America.[8]

[8] Mr. Hanke remarks that the Spanish hydraulic engineers also encountered formidable problems in Mexico, for instance in the construction of the drainage system to protect Mexico City from floods.

The dams were built of earth and masonry. A transverse section of the higher dams—as at Chalviri, where the original height was 8 meters—shows five different layers, forming a total thickness of 10 to 12 meters. First, on the upstream face, to withstand wave action, is a dry wall of rock about 75 centimeters thick; next is a fill of clay; next a wall of stone in lime mortar, as thick as 2 meters at the greater depths; then another fill, of clay and sand; and a downstream wall of stone in lime mortar. The last two are not brought up to the full height of the dam. At less important dams, where the pressure of only 3 meters of water was to be resisted, there were upstream and downstream walls of masonry, some with mortar and many without, and a clay with earth filling between. It is not easy to distinguish between the original structures of the Spaniards and the repairs and embellishments of those who followed. The older historians give little information on this subject, treating the history of the lakes in too general a way to record details.

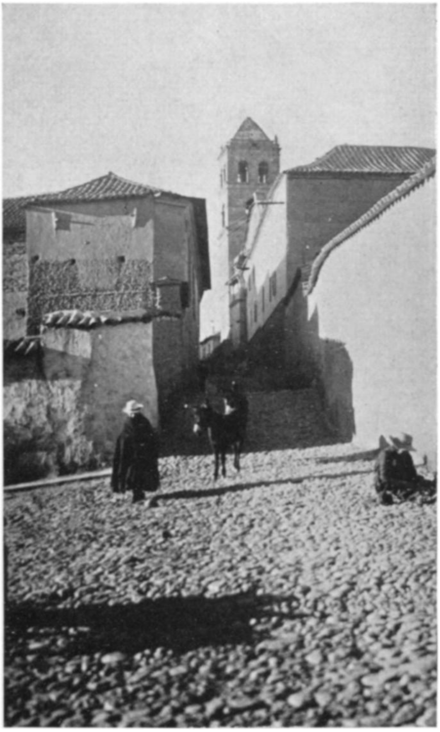

FIG. 9—A street in Potosí, showing the tower of San Francisco church.

An intricate system of aqueducts was built to convey waters from one lake group to another and, eventually, to the Ribera, which feeds the mills. The waters of all but the two northern groups flow by canals and cascades to Lake San Sebastian and from this lake enter the Ribera (Fig. 14). Yet there are indications that this was not the original idea. For instance, there are the remains of an old canal on the north slopes of the *quebrada* of Lobato, which drained Lake Ulistía at a much higher level than the Chalviri canal, into which these waters later flowed. Similar canals are found near Lake Muñiza and the defunct Lake San Lázaro.

The canals were built with walls of stone in lime mortar. They averaged about a meter in width and about 80 centimeters in depth; the main canals are inclined about 7 meters a kilometer, the subsidiary aqueducts 5 meters or less a kilometer. The canals wind along the slopes of the Karikari range; in places they are cut into the precipitous rock cliffs. Twice the canal from Chalviri passes through tunnels, once in rock, once in moraine 320 meters long. At one point the canal from San José is built upon a masonry wall 20 meters high. There are some six scenic cascades where the canals drop their water from a watershed divide to a lake or valley below.

The Ribera was also a work of magnitude. Five kilometers in

FIG. 10—Many old buildings in Potosí link the city with the days of its greatness.

length and eight meters in width, it was constructed with walls of rock in lime mortar, which time has destroyed. Over it 22 bridges furnished street crossings in the city.

VILLA IMPERIAL

With the waters of the Ribera flowing constantly, Potosí flourished. Well deserved were the words that Charles V had placed upon its first coat of arms, "Soy el rico Potosí, del mundo soy el tesero, soy el rey de los montes y envidia soy de los reyes,"[9] and the more modest legend on the shield sent by Philip II, which is used to the present day, "Pro Cesaris potentia, pro regis prudentia iste excelsus mons et argenteus orbem debellare valet universum."[10] The fame of the *Villa Imperial* spread to all parts of the world. Martínez y Vela thus enumerates the products brought back by its exports of silver:

> . . . silks of all sorts and knitted goods from Granada; stockings and swords from Toledo; clothes from other parts of Spain; iron from Viscaya; rich linen and knitted goods from Portugal; textiles, embroideries of silk, gold, and silver, and felt hats from France; tapestries, mirrors, elaborate desks, embroideries, and laces from

[9] "I am the rich Potosí, the treasure of the world, the king of mountains and the envy of kings."

[10] Several different versions of the legend exist showing a text altered or corrupted in a number of places. The above text is supplied by Professor Frank G. Moore, of Columbia University, and Mr. Lewis Hanke. Professor Moore translates it thus: "For the powerful Emperor, for the wise King this lofty mountain of silver could conquer the whole world."

Flanders; cloth from Holland; swords and steel implements from Germany; paper from Genoa; silks from Calabria; stockings and textiles from Naples; satins from Florence; cloths, fine embroideries, and textiles of excellent quality from Tuscany; gold and silver braid and rich cloth from Milan; sacred paintings from Rome; hats and woolen textiles from England; crystal glass from Venice; white wax from Cyprus, Crete, and the African coast of the Mediterranean; grain, crystals, ivory, and precious stones from India; diamonds from Ceylon; perfume from Arabia; rugs from Persia,

FIG. 11—Ruins of old mills as the flood left them after the collapse of the San Ildefonso dam in 1626.

Cairo, and Turkey; all kinds of spices from the Malay Peninsula and Goa; white porcelain and silk cloths from China; negro slaves from the Cape Verde Islands and Angola; cochineal, dyes, vanilla, cocoa, and precious woods from Spanish America and the West Indies; pearls from Panama; rich cloths from Quito, Riobamba, Cuzco, and other provinces of the Indians; and various raw materials from Tucumán, Cochabamba, and Santa Cruz.[11]

Even in its earliest days the great fair of Potosí was famous. "I believe that no other fair in the world can be compared with it," said Cieza de Leon.[12] The proud inhabitants of the *Villa Imperial*, during those halcyon years of the first quarter of the seventeenth century, can have little dreamed that the same waters that brought fame to their city were also to take it away. On the fifteenth of March, 1626, the San Ildefonso dam broke, and in less than two hours' time its waters had destroyed the prosperity of 50 years' building. The tragic story of that terrible Sunday afternoon is still recounted in Potosí: how 126 of the city's 132 mills were destroyed (79 of them irreparably), along with 46 blocks of Spanish quarters, 370 houses of Spaniards, and 800 ranchos of Indians. The dead have been placed by some historians at more than 4000 (a census made by the Jesuits gives 3800), the loss of property at 12,000,000 *pesos fuertes*.

[11] Martínez y Vela, Anales de Potosí, pp. 411–413.

[12] Pedro de Cieza de Leon: The Second Part of the Chronicle of Peru, *Hakluyt Soc. Publs.*, Ser. 1, No. 68, London, 1883.

Potosí never completely recovered from the San Ildefonso disaster. The dam was quickly repaired, the lake was put back in service, and the more important of the *ingenios* were rebuilt. Other adventurers came from Spain to take the places of those who had drowned. As to the Indians, *qué importa?* Was there not an endless supply? But a certain morale had been lost. Miners are notoriously superstitious,

FIG. 12—The city of Potosí seen from the top of Cerro Rico.

and the catastrophe furnished ample cause for superstition in a city notorious for wealth and wickedness. The survivors saw in the event the visitation of divine retribution, and they were confirmed in this belief by the miracle of the San Francisco church, saved by the division of the waters, which left it unharmed, an island in the flood. Martínez y Vela records that at each gathering of clouds the townsfolk forsook their houses, to pray in the streets and plazas, thus publicly repenting their sins and pleading divine mercy.[13] When the ill-fated day had been forgotten, it was too late to restore the former level of prosperity.[14] The bulk of the silver was gone, and a long decline set in. Although from time to time hopes have been roused—by the discovery of a new vein or an improved process of recovering metal from the ore—silver has not been able to restore the former glory of the *Villa Imperial*. If the fortunes of Potosí are to be

[13] Omiste, *op. cit.*, Vol. 1, p. 190. Also Alberto de Villegas: La Campana de Plata, La Paz, 1925, p. 152.

[14] It is not implied that the water-supply system was of exclusive importance in the fortunes of Potosí. The introduction of the quicksilver amalgamation process (c. 1573) and the discovery of new veins, for instance, had an important relation to the amount of silver produced. Moreover, as Mr. Hanke points out, the fortunes of Potosí may not have fallen quite so suddenly as some of the chroniclers suggest; and he cites Humboldt's figures of silver production in the seventeenth century (Alexandre de Humboldt: Essai politique sur le royaume de la Nouvelle-Espagne, 2nd edit., Paris, 1827, Vol. 3, pp. 363–364). Complete statistics of the silver output of Potosí would be invaluable were they available.

rebuilt—and at last they have taken a definite upward trend—they will rest not on silver but on a baser metal, tin.

New Resources in Tin

Tin had been known about in the Cerro of Potosí almost back to the days of the discovery. One of the four rich silver veins dis-

Fig. 13—Looking at the backbone of the Karikari Range from the Cerro Rico. Lakes San Sebastian and Planilla are seen in the left center, with Lake San Ildefonso directly above.

covered about the middle of the sixteenth century was named Estaño. However, until the last decade of the nineteenth century the hill had been worked almost exclusively for silver, inasmuch as the tin commanded an extremely low value, 8 bolivianos per quintal smelted. However, in 1891 the United States government demonetized silver and adopted the gold standard. Immediately the Bolivian exchange dropped from 44 pence to 23 pence, at which exchange the silver mines could not continue operations. With the price of tin £52 sterling a ton (which represented nearly twice as many bolivianos as before the break in silver), the exploitation of tin was begun.[15]

Tin production increased rapidly. The product was smelted and shipped as bars until 1912, when, with the opening of the Potosí to Río Mulato railroad, it was possible to ship concentrates that weighed 40 per cent more. Despite severe fluctuation in the price of tin, its production at Potosí has increased steadily, and this trend of increase has been greatest during the past four or five years. Not only are veins being exploited for tin in the upper part of the hill, where the Spaniards found their wealth of silver, but mine development is being carried on at great depths, where there are no silver ores at

[15] The writer is here indebted to the unpublished notes of Luis Soux, a pioneer in the exploitation of tin minerals of Potosí.

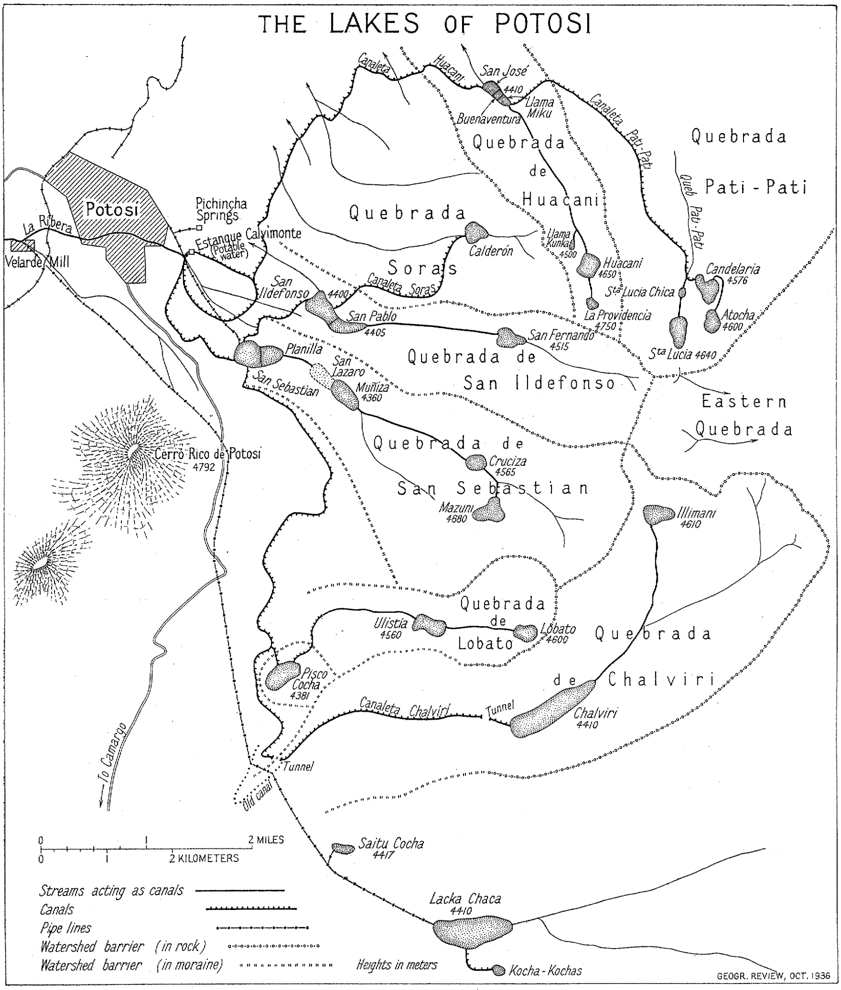

Fig. 14—Sketch map of the lake system of Potosí; scale approximately 1 : 115,000. The city is situated in 19° 34′ 18″ S. and 65° 34′ 25″ W.

all. The old discarded dumps of the Spaniards and the fills that they made in some of their tunnels are also being milled for tin.

Natural Foundation of the Lakes

The lakes of Potosí had their beginning many thousands of years before the arrival of the Spanish engineers. The Karikari range, which runs in a north-south direction east of Potosí, was formed as a huge batholith beneath a surface perhaps two kilometers higher than at present.[16] The mountain mass was eroded in the late Tertiary

[16] The quartz-porphyry plug at the center of Potosí hill, forming a volcanic neck within the older shales surrounding it, has been considered by some geologists to be a lateral valve of the formation of the Karikari batholith. As fossils of flora of the late Tertiary have been found among the volcanic tuffs in the upper part of the hill, the age of the mineralization of the hill has been established.

TABLE I—CAPACITIES AND OTHER DATA REGARDING THE LAKES

Name	*Metric Tons*	*Remarks*
Illimani	120,000	Narrow, low dam where trench was dug by Spaniards to drain original lake.
Chalviri	2,900,000	Dam 8½ m. high by 226 m. long, rebuilt in 1935 to 9.88 m. by 274 m.; lake perimeter when full 5½ km.
Lobato	200,000	Narrow, low dam where canal some 300 m. long was dug by Spaniards to drain original glacial lake.
Ulistía	360,000	Original name Patos ("ducks") well deserved judging from number of old stone arrowheads found about its shores. Main dam at west 5 m. by 188 m., small supplementary dam at southeast corner; lake perimeter 1800 m.
Pisco-Cocha	340,000	Tunnel 220 m. long cut by Spaniards through moraine to drain original lake.
Mazuni	55,000	Narrow, low dam where nearly one-half km. of trench in rock cut to drain original glacial lake.
Cruciza	47,000	Dam 6½ m. high originally, now less than 5 m.; 64 m. long; lake perimeter 2380 m.
Muñiza	175,000	Dam 5½ m. high, but 1½ m. of sediment has filled lake; dam 214 m. long; lake perimeter 1600 m.
Planilla	90,000	Originally named San Pedro. Dam 5½ m. by 105 m.; lake perimeter 1390 m.; depth of sediments about 1 m.
San Sebastian	300,000	Also known as San Salvador in early days. Dam 7 m. by 200 m.; lake perimeter 1750 m.
San Fernando	230,000	Low, narrow dam.
San Pablo	275,000	Originally named De la Reina. Dam 5½ m. by 235 m.; lake perimeter 1870 m.
San Ildefonso	430,000	Originally named Del Rey, also Karikari. Dam 8 m. by 500 m.; lake perimeter 2800 m.
Calderón	100,000	Original name unknown. Lake rediscovered in 1935 and rebuilt.
Providencia	85,000	Low, narrow dam. Tunnel in rock 40 m. long drains original glacial lake.
Huacani	315,000	Also known as Huancaní in colonial days. Dam 6½ m. by 100 m.; lake perimeter 1420 m.
Llama-kunka	11,000	Unimportant lake, perhaps work of Indians in recent years.
Llama-miku	40,000	Old dam found buried to top in mud, about 5 m. below surface; new dam 3 m. higher.
Buenaventura	12,000	Mere settling basin.
San José	12,000	Mere settling basin.
Atocha	180,000	Dam 3 m. by 90 m.; lake perimeter 1720 m.
Candelaria	45,000	Two low dams; unimportant lake.
Santa Lucia	130,000	Dam 3½ m. by 100 m.
Santa Lucia Chica	4,000	Unimportant settling basin.

Total capacity of present system 6,456,000 metric tons.

and Pleistocene. Glaciation played a prominent part. Its activity centered about a point eight kilometers due east of the Cerro Rico. In the part of the Karikari nearest to Potosí are eight glacial troughs, all of which except the easternmost lent themselves to development of the water-supply system. Beginning clockwise from the south, these

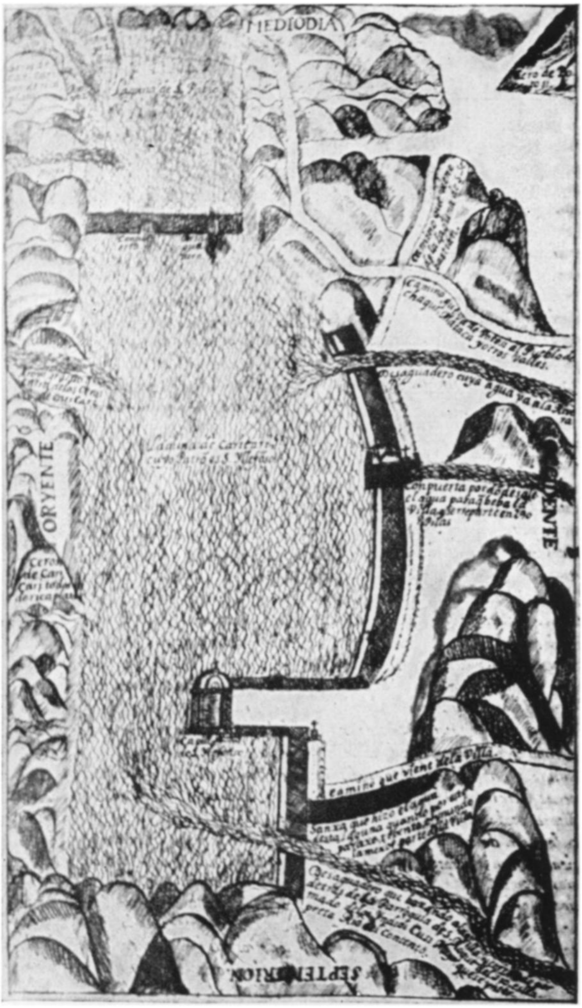

FIG. 15—An eighteenth-century drawing of a part of the lake system of Potosí. Lakes San Ildefonso and San Pablo are seen and the chapel of San Ildefonso, just west of which occurred the disastrous break in the dam in 1626. Reproduction on a reduced scale from the manuscript "Historia de la villa imperial de Potosí" by Bartolomé Martínez y Vela (see footnote 6). The opportunity of making this reproduction and that of Figure 16 is due to the kindness of Mr. Hanke.

quebradas with their present lakes are: (1) Quebrada de Chalviri or Tabaco-Ñuño (2 lakes), (2) Quebrada de Lobato (3 lakes), (3) Quebrada de San Sebastian (5 lakes), (4) Quebrada de San Ildefonso (3 lakes), (5) Soras Quebrada (1 lake), (6) Quebrada de Huacani (6 lakes), (7) Quebrada de Pati-Pati (4 lakes). The eighth quebrada, draining eastward, also contains lakes, but of these only the lakes Samasa and Talacocha are in condition. Yet there are remains of old dams in this quebrada, of construction similar to the early work of the Spaniards. They may have been built for irrigating land near Chaqui and Puna to grow foodstuffs for the vast number of workers engaged in the mines of Potosí.

In the cirques excavated in the hard crystalline rock at the head of the quebradas the Spaniards found lakes without outlets when they began their building program: Illimani, Chalviri, Lobato, Mazuni, Providencia, and Huacani are good examples. Use of this type of lake involved the building of a dam and the excavation of a ditch or tunnel to provide an exit for the waters. These lakes usually contain "dead water" below the level of the outlets. Farther down the quebradas the glacial debris was deposited as lateral and frontal moraines. The principal lateral moraines are shown upon the map; they evidently function as watershed barriers between quebradas where the solid-rock ridges cease to outcrop. Here the Spaniards found no natural lakes except Pisco-Cocha, which is entirely surrounded by moraines.

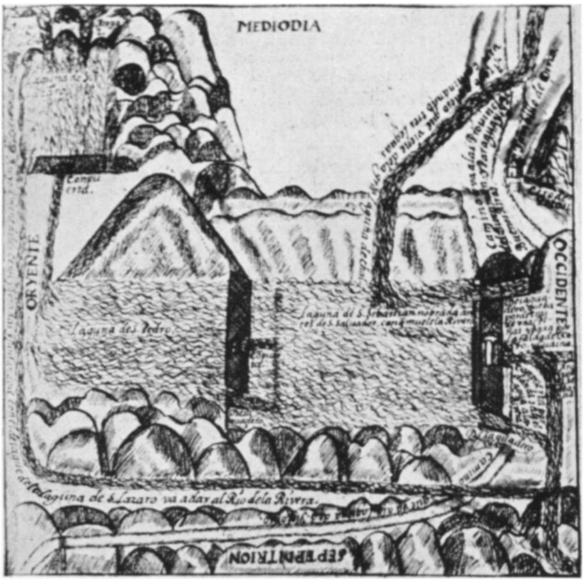

FIG. 16—Another part of the lake system of Potosí (see Fig. 15). This shows Lakes San Sebastian and San Pedro (Planilla).

The natural barriers of loose materials that the frontal moraines formed after the ice had melted were able to hold back water for only a relatively short time before erosion cut through and it drained off. But the Spaniards had only to rebuild the natural dams to reëstablish the lakes. San Ildefonso and Muñiza are lakes formed in this way, but the best example is Lacka Chaka, a new lake created during 1934 in one of the quebradas south of the Spanish system.

When the two types are compared, the first, or rock-bound, lakes offer most advantages. Filtration losses are small in rock formations, whereas the porosity of the moraines permits heavy seepage through the bottoms and sides of the lakes of the second type. Moreover, most of the actual seepage from the rock-bound lakes probably finds its way to other lakes and the canals; whereas seepage from the moraine-bound lakes sinks to deep levels, and even though it may appear at the surface elsewhere as springs, their level is too low to be used at Potosí. Evaporation losses are also much smaller in the rock-bound lakes; for, although the air is more rarefied at these higher altitudes, the lakes are sheltered from sun and wind, and temperatures are lower. Furthermore, the water entering the rock-bound lakes has flowed mainly over rock surfaces and carries only a small amount of sediment, whereas the streams traversing the loose moraines farther down the valleys carry a large amount of sediment and are gradually filling up their basins. Lake San Lázaro, for instance, is now completely filled with sediments and is permanently out of use; and Lake San Sebastian contains an average depth of

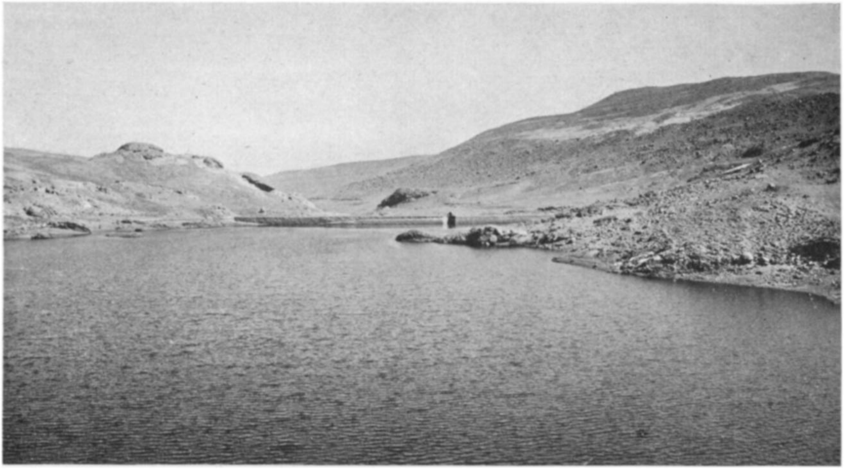

FIG. 17—Looking downstream toward old Chalviri dam, lake being half full. The canal is tunneled through the dark hill in rear of dam.

95 centimeters of soft sediments on its floor and has lost 85,000 metric tons of its capacity.

Why, then, did not the Spaniards build all their lakes within the rock formation? It is significant that they began with Chalviri, the best lake of all. Unfortunately other appropriate sites like Chalviri and Huacani for impounding large lakes within the rock formation were not to be found; all the other lakes of this type are small. On the other hand, there were numerous *vegas* of fair dimensions that could be utilized for lakes of the second type, and, although large dams were usually required at these locations, clay and sand were close at hand for building needs.

FIG. 18—Looking upstream toward Chalviri dam and outlet canal.

FIG. 20—Remains of dam of "lost" lake found by the writer in the Soras quebrada in 1935, and now put into service.

CHANGES IN THE LAKES

Many changes have occurred in the lake system since it was built. Some lakes have disappeared. The historians mention names for which we have no lakes today: San Lorenzo, San Joaquin, Estaño, Redondilla, Santa Barbara, Estanquilla, Cajoncilla. The original decree of the viceroy Francisco de Toledo called for the building of 18 lakes, but historians have recorded that there were as many as 32. There are now 24 in service; one other, San Lázaro, has become filled with sediments to the full height of its dam and is no longer utilizable.

Undoubtedly one of the lost lakes was in the San Sebastian quebrada at a narrow gorge a short distance above Lake Muñiza, where

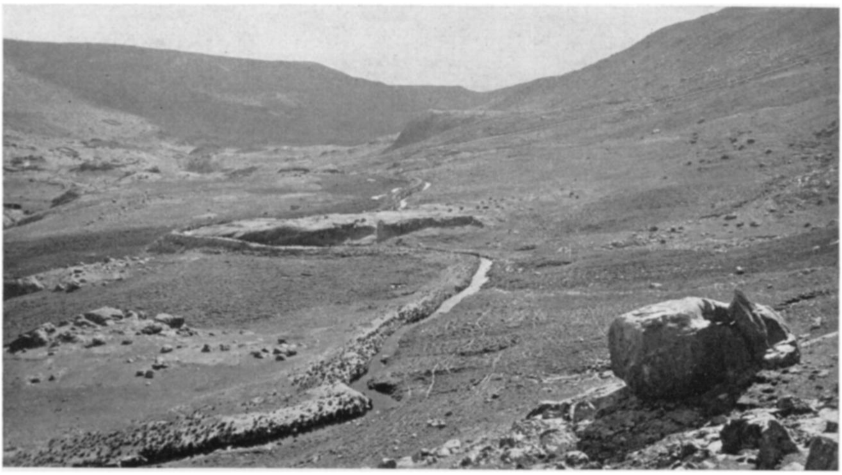

FIG. 19—The Chalviri aqueduct.

there is an excellent lake site, which the efficient Spanish engineers are not likely to have overlooked. There are two other sites in this quebrada and one in the San Ildefonso quebrada, which were probably used by the Spaniards. These lakes may have been destroyed by floods, though no remnants are left to tell the story. At San José there was probably a large lake covering most of the area now occupied by the three lakes San José, Buenaventura, and Llama-miku.

The writer was unable to learn the original names of two of the lakes shown on the map. The one in Quebrada Soras marked Calderón had been lost for half a century, until the writer discovered it during the course of his studies in 1935 and named it for Max Calderón, president of the City Council of Potosí, who has aided materially the project of rebuilding the lakes. The name of the remains of a small lake in the Pati-Pati quebrada was also lost; as this lake acts as a basin for diverting the waters of Lake Santa Lucia into the Pati-Pati canal, it is referred to as Lake Santa Lucia Chica.

The Chalviri canal has twice been rerouted. Originally the canal left the Chalviri quebrada by crossing a low place in the morainal ridge shown on the map. Later the canal was rebuilt on a steeper grade and was carried round the end of this moraine into the watershed to the north, this perhaps being part of the betterment program of Chalviri lake and canal executed by General Ortiz de Sotomayor during the years 1613 to 1616. Still later a tunnel was built through the ridge near the location of the original crossing, and a new canal was built to Potosí.

Upkeep of the Lakes

During the earlier days of operation a *lagunero* and a permanent crew of Indian slaves (*mitayos*) kept the dams and aqueducts in repair.[17] Two centuries later, by resolution of February 8, 1784, the work was accomplished through a roll of obligatory service, whereby each person had to contribute his labor on certain days or make a contribution of money. As the lakes filled with sediment, it became a question whether the practice of annual cleaning should be continued or whether the dams should be increased in height to maintain the capacities—a question that has not been resolved to the present day. Since the beginning of the Republic the administration of the lakes and also the distribution of water for domestic purposes have been in charge of various public officials, at first under the government and later under the City of Potosí.

Omiste writes of the annual sums set aside in the municipal budget for repairs and service of the lakes. He also mentions annual allotments of departmental funds to the city for this purpose, though funds seldom materialized because of constant deficit in the depart-

[17] Unpublished work of Vicente Cañete entitled "Guía Histórico."

mental treasury. During 1881 special taxes had to be levied on all consumers of water; for during that year the municipality had turned over its funds to the government for the necessities of the war with Chile. Furthermore, of the sums appropriated for the lakes, probably only a small percentage was actually used for that purpose.

With funds lacking for their proper upkeep, the lakes and canals inevitably deteriorated. A notation in the *Gaceta Municipal* corresponding to May 8, 1886, states that "in the year 1883 a repair to Chalviri dam was made with magnificent result, but unfortunately of short duration because of the poor quality of lime used." A report of the President of the municipality in 1887 states that a commission had inspected the lakes and after mature deliberation had presented an estimate of bolivianos 5596.00 for extensive repairs, but in the absence of funds repair work had been limited to a part of Chalviri dam, which cost bolivianos 862.05. To judge from its patched-up appearance in 1935, many cheap repairs of this sort had been made to Chalviri dam; none were worth their cost, for they merely diverted the leakage from one outlet to another.

The following pertinent excerpts are taken from the report of the municipality to the Minister of the Treasury in 1886.

> Lake San José is in a state of complete ruin at its dam and holds water only in the rainy season and then only for 8 days; Lake Santa Lucia does not exist, being filled with sand, its dam in complete ruin, and its greatest depth not reaching 50 centimeters; the aqueduct of San José loses half of its water in sandy places; Lake San Pablo has so many filtrations that its level is only equal with that of San Ildefonso, making a single lake rather than 2 lakes; San Fernando is full of sand and its dam a complete ruin; Mazuni and Cruciza are in complete ruins; Illimani has nothing remaining save remnants of a wall; Lobàto has completely disappeared; Ulistía is in lamentable state, not being able even in the rainy season to impound one meter's depth of water; Pisco-Cocha is out of service, its dam in deterioration and its tunnel completely destroyed; summary, 4 lakes in good service, 7 urgently requiring repairs, 9 completely useless.

In 1935 the lake system was in truly pitiful state. When the writer made his investigation during April of that year, he found only six lakes usable: Chalviri, Muñiza, Planilla, San Sebastian, San Pablo, and San Ildefonso. Of these, Chalviri was losing one-quarter of its waters by filtration under the dam; the dam at Muñiza was leaking so badly as eventually to undermine the structure; the dam at Planilla was in questionable condition to resist full pressure, a portion of its upstream wall "shivering" and "dancing" when waves beat against it; the outlet valve at San Ildefonso could be neither opened nor closed; and there was so much leakage at San Pablo that its level was not more than 15 centimeters above that of San Ildefonso. Also there was so much leakage from the Chalviri canal that placer tin miners made a regular business of utilizing its waters; and although two other lakes, Huacani and San José were fit to impound water, their canal to Potosí was in such poor condition that no water arrived closer than 4 kilometers from the city.

Rebuilding of the Lakes

Appropriations large and small, special efforts on the part of the small miners and the Compañia Minera Unificada de Potosí, which represents 90 per cent of the mining interests of the Cerro, action of the municipal authorities, clamor of the pueblo had been without result; political differences, petty jealousies, and lack of understanding made any constructive effort for betterment well-nigh impossible. In 1934 the Compañia Unificada decided to safeguard its own interests by constructing an independent water supply, building a dam to impound 1,000,000 metric tons of water at Lacka Chaka, and laying 14 kilometers of pipe line to convey this water to its mill below the city.

Scant rainfall during the summer months of 1935 pointed to a crisis at hand. Even with the new lake in service there would not be enough water to supply even a greatly curtailed ration

FIG. 21—Lakes Llama-miku, Buenaventura, and San José, before rebuilding. Compare Figure 24.

FIG. 22—Lakes in lower San Sebastian quebrada. Left to right Muñiza, San Lázaro (extinct), Planilla, and San Sebastian.

FIG. 23—Dam of the sediment-filled lake San Lázaro.

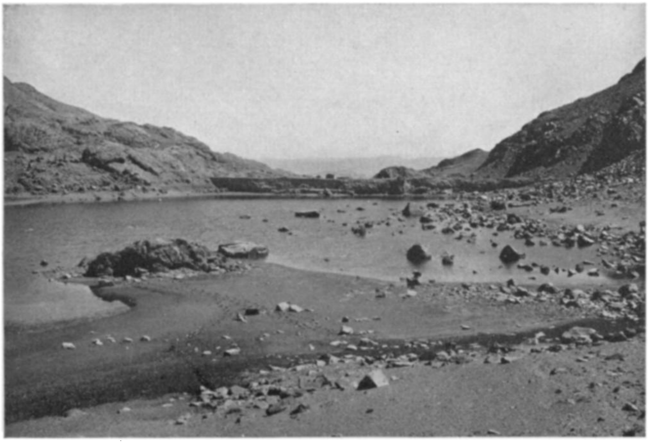

FIG. 24—Lakes Llama-miku, Buenaventura, and San José, after rebuilding. Compare Figure 21.

FIG. 25—Lake San Pablo (front) and Lake San Ildefonso, with its small chapel on the dam (rear). Compare Figure 15.

FIG. 26—Lake San Fernando before reconstruction.

throughout the year. At this point Dr. Mauricio Hochschild, head of the Compañia Unificada, offered the services of his engineering department for a study of the lakes. He also contributed toward the costs of reconstruction, met in part by an appropriation from the central government at La Paz. In September a construction force of 800 was set to work. It was indeed fortunate that the arrangements were completed in time to prepare 24 lakes for impounding water during the rainy season of 1936. Little precipitation actually fell during this summer—10.7 centimeters in January, 8.6 centimeters in February, 3.9 centimeters in March: a total of 23.2 centimeters, or 35 per cent of normal—and there would have been a severe water shortage throughout the year had the lakes not been refunctioning. As matters stand, there is enough water in the lakes at this time (June, 1936) to carry through to the next rainy season provided that care is used in distributing it.

The rebuilding of the lakes of Potosí involved the following operations: the construction of a new dam at Lake Chalviri and the repair of the old dams or the construction of new ones, as necessary, at the other lakes; the installing of new outlet pipes and adequate spillways at all lakes; the rebuilding of all the aqueducts; the reëstablishing of the lake and canal "lost" in the Quebrada Soras; the rebuilding of the outlet tunnels of Lakes Providencia and Pisco-Cocha, which had caved in; the draining of swampy meadows in the quebradas, where

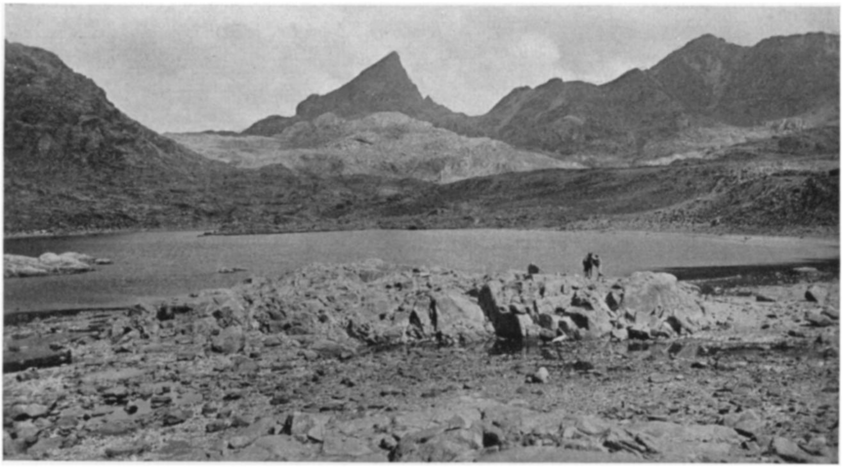

FIG. 27—Lake Atocha in the Pati-Pati Quebrada.

the waters spread out and evaporated and also became contaminated; the building of some thirty kilometers of motor roads to provide access to the lakes, which, except for San Ildefonso, formerly had been reached only by mule trails; the provision of houses for custodians at the principal groups of lakes; the construction of new intake boxes and iron pipe lines for making use of the springs of Pichincha as potable water supply for the city.

The main part of the operations for improving weak features of the old Spanish construction was directed toward three ends. The early dams had not been carried down to an adequate foundation, many being only 60 centimeters or less below the original surface. As a result, loss of water beneath the dams was heavy: filtration of as much as 80 liters a second has been reported at Chalviri in years when the lake was full. Two methods were used for rendering such dams more watertight. Where the lake was empty, excavation upstream of the dam was carried down one meter within rock or good clay, and a new, impervious masonry wall was built up beside the old dam from this depth. This was the procedure at Lakes Atocha and Ulistía. Where the lake contained water that could not be emptied without interrupting the water supply of the city, as at Chalviri, the new, impervious wall was carried into rock downstream of the old dam, and filling on both sides of the wall gave it support.

The old outlet valves (*compuertas*) were crude and inadequate. Most of them could be neither completely opened nor completely closed, and at many of the lakes they had been removed or stolen. The *compuerta* was indeed the most vulnerable feature of the old Spanish construction. The Spaniards had used a large timber placed vertically within a well and reaching down to an outlet tunnel through

FIG. 28—Lake Providencia, highest of the lakes of Potosí, lies amid snow and cloud and can be reached only on foot.

the dam at its lowest point. A large beam was fastened to this timber at the top for raising or lowering it. The timber fitted into a small aperture within the outlet tunnel and thus could be adjusted to control the flow of water. Later this construction was replaced by an inverted cone of bronze attached to an iron rod or chain that could be raised or lowered from the top, to fit into a stone perforated in the same way. This delicate apparatus failed to function whenever the outlet aperture became blocked with stones or sand, and this was an inevitable occurrence. Efforts to remove the obstruction probably damaged the masonry of the outlet passages.

To provide a proper modern outlet, the old passages through the dams were cleaned out, and 12-inch iron pipe was laid and concreted within these passages. A barrel-shaped screen was placed at the upstream end of each pipe outlet as protection against clogging by stones. A gate valve was installed just below the dam and placed under lock so that the Indians of the region might not operate it to furnish wet pasture for their animals, as they had been accustomed to do with the old valves. Most of the old dams were without adequate spillways—a reason for the washing away of dams in floods.

The lakes now have a total capacity of about six and one-half million metric tons, as Table I shows (p. 541).

One of the reasons why it had been impossible to secure concerted effort for repairing the lakes was the fact that their ownership has never been definitely determined. They were built with some four million bolivianos provided by the miners and the labor of 20,000 Indians furnished by the Spanish crown. As time passed, the successors of the original miners represented by the large and small

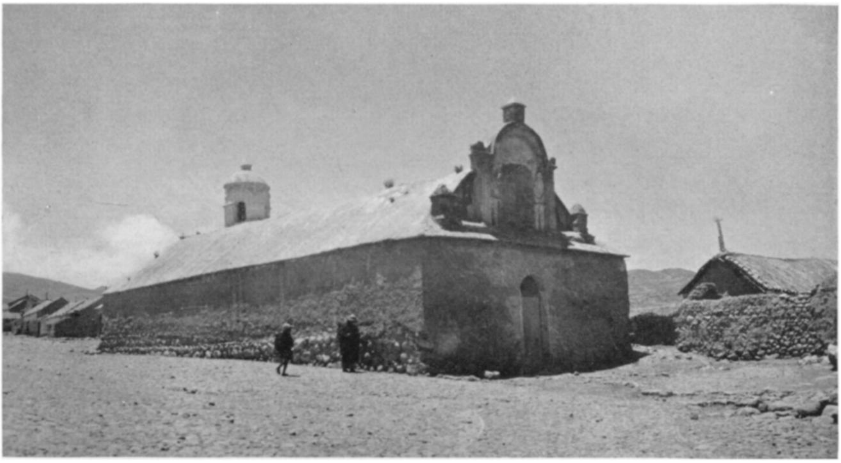

FIG. 29—Old Caja del Agua. Above the entrance door are the words: "Año 1775—El Señor Gobernador do Jaime Saint Just con el Ilustre Cabildo hicieron esta obra, con los fondos pios de esta Villa, siendo Procurador . . ."

mining companies of today claimed the lakes by virtue of these disbursements of their predecessors. The City of Potosí likewise claimed the lakes as the successor to the rights of the Spanish crown. The mining companies were wont to deny this claim on the ground that the goods of the crown could not have passed to the city at the birth of the Bolivian republic because the city as such did not exist at that time but was created some years later by the constitution of 1839.

The ownership of the lakes is still in doubt. The Compañia Unificada has permanently relinquished its claims to this water-supply system in consideration of being allowed the use of the three lakes Lobato, Ulistía, and Pisco-Cocha for a term of 50 years. The claim of the small miners still stands.

Potosi during Dry Years

Throughout all of Potosí's history there have been dry years. The normal rainfall, amounting to about 65 centimeters at Potosí and somewhat more at the lakes, is more than doubly sufficient to fill the lakes in summer, and it is likely that during the early colonial days, when the entire system of lakes and aqueducts was in good service, water was held over from year to year. However, by the latter half of the nineteenth century the lakes were in such poor condition that dry years were acutely felt. A municipal ordinance of March 13, 1878, decrees economy of water because of scarcity of rain in this year. An ordinance of March 31, 1885, limits water to the city *pilas* (hydrants for public use) because of the small quantity of water in the lakes—this being at the beginning of the dry season. The ordinance of May 14, 1892, implies low water, and that of February 13, 1897, devises ways and means for "passing through the abnormal conditions in which we find ourselves."

A number of resolutions dated late in the dry seasons of various years do not necessarily mean drought, since the water might have been wasted by careless administration. Among these are ordinances of November 20, 1909, and October 21, 1915. However, the resolution of August 26, 1916, cutting off water in the Ribera entirely from September 1 to the end of the year is a drastic measure that could have been necessary only during a dry year. During 1924 there was also shortage of water, though there are indications that in that year the lakes were in urgent need of repairs. During 1929 rainfall amounted to only 50 centimeters, or about 77 per cent of normal. During 1935 rainfall was somewhat low, and during 1936 exceptionally low.

There is a rather suggestive periodicity in these dates: between 1878, 1885, and 1892 are two intervals of 7 years each; between 1909 and 1915–1916 the same interval; between 1929 and 1935–1936 the same 7-year interval. It may be noted that the dry year 1929 fell about midway between the two wet years 1925 and 1932 of the South American west coast, when the southward-flowing El Niño Current replaced the normal northward-flowing Humboldt Current. The dry years 1935 and 1936 fall midway between the wet year 1932 and the year 1939, when the west-coast current is expected to reverse its flow again. Another dry year in 1937 would be a real calamity for the region; for the underground water resources have been much depleted by the successive dry years 1935 and 1936. However, Indians who predicted dry summers for both 1935 and 1936 and who arranged their planting programs according to this prediction expect a fairly wet year in 1937. This would be in harmony with a 7-year cycle, more humid conditions being indicated as the year 1939 is approached.

Looking into the Future

Potosí, however, should not want for water in 1937. No longer will it be necessary to cut off or even to curtail the supply to the mining industry and thus cause unemployment and distress, or to limit potable water for homes to three hours in the morning or less; no longer will the streets of Potosí be in darkness because of lack of water for power at its lighting plant or the city be without a sewerage system because of lack of water to operate it.

Already the Compañia Unificada has increased its capacity from 400 metric tons of tin ores treated a day to 800 metric tons, and further increase is under consideration. As this company is increasing its pay roll, so is Potosí's population increasing, and its housing facilities being extended.

As for the lakes that have been so intimately linked with the fortunes of the city, it is not likely that they will be permitted to fall into ruin again. The organization that rebuilt them is under obligation to maintain them until 1939, at which time they will be returned to the municipal authorities, when we may hope that a roused public interest will see to their preservation.