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THE JOHNS HOPKINS UNIVERSITY
STUDIES IN GEOLOGY

No. 1

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EDWARD BENNETT MATHEWS

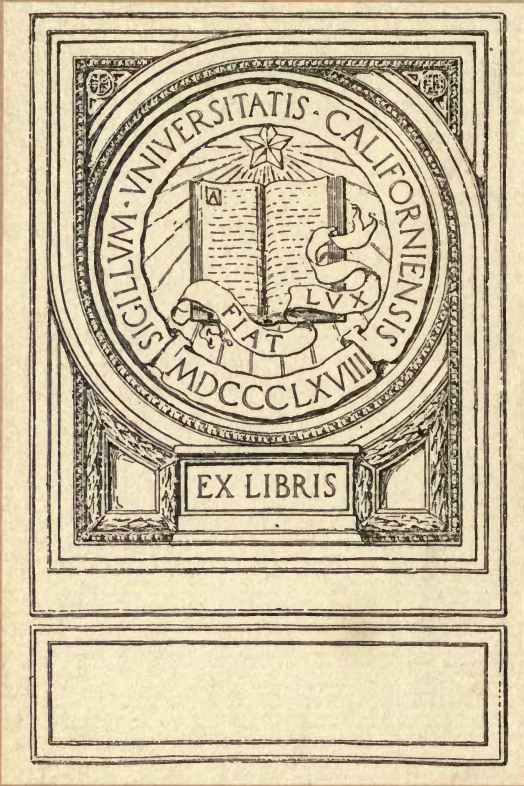
THE GEOLOGY OF THE
COROCORO COPPER DISTRICT
OF BOLIVIA

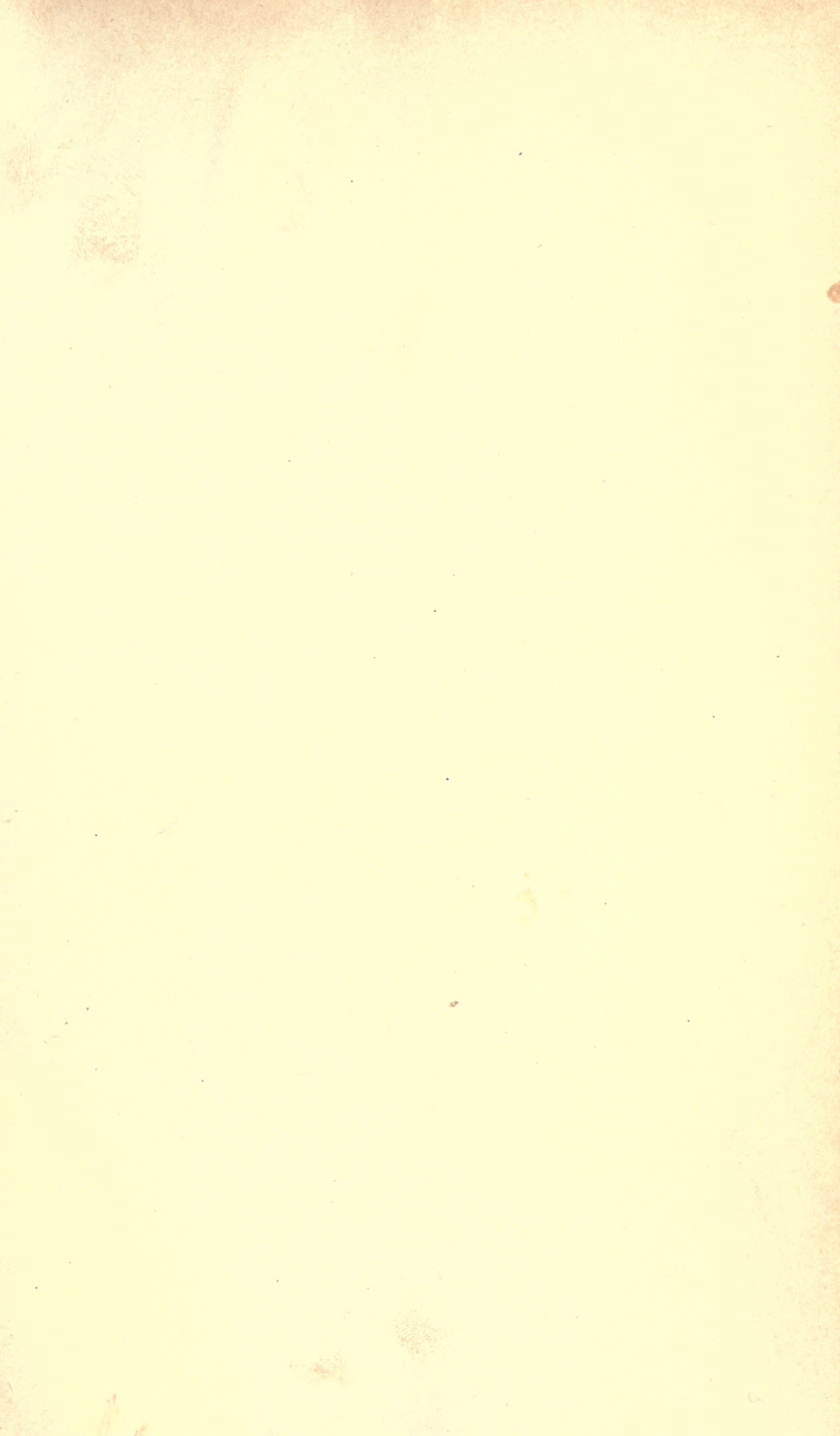
BY
JOSEPH T. SINGEWALD, JR.
AND
EDWARD W. BERRY

BALTIMORE
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THE GEOLOGY OF THE COROCORO COPPER DISTRICT
OF BOLIVIA

By JOSEPH T. SINGEWALD, JR. and EDWARD W. BERRY

C O N T E N T S

	PAGE
Introduction.	I
Location.	4
Geology.	6
Earlier descriptions.	6
The Vetás and Ramos series.....	13
The Vetás series.....	13
The Ramos series.....	28
Age of the Vetás and Ramos.....	35
The Vetás flora.....	39
Palentologic evidence of the age of the Ramos.....	43
Stratigraphic relations of the Vetás and Ramos.....	44
The Desaguadero series.....	49
Age of the Desaguadero series.....	50
Igenous rocks	53
Resumé of geologic history.....	55
The ore deposits.....	57
Earlier descriptions	57
Summary account of the ore deposits.....	66
Genesis of the Corocoro copper deposits.....	69
Genetic comparison with the Lake Superior deposits.....	76
Conclusions concerning genesis of the Corocoro deposits...	79
Mining operations	81
Treatment of the ore.....	82
Systematic account of the fossil plants.....	87
Bibliography	116

ILLUSTRATIONS

	PAGE
PLATE I. —Fig. 1. View looking North, showing the Vetas series on the West side of the valley....	11
—Fig. 2. View looking North, showing the Ramos series on the East side of the valley....	11
PLATE II. —Fig. 1. View looking South, showing principal mines on the Cerro Corocoro.....	19
—Fig. 2. View looking Southwest, showing the town, with the Vetas series on the right, and the southward extension of Cerro Corocoro in the left background.....	19
PLATE III. —Geological Map of the Corocoro District.....	32
PLATE IV. —Tufaceous shale showing abundance of plant material (<i>Calliandra obliqua</i> Engelh.).....	40
PLATE V. —Trails and mud cracks in the Desaguadero shales.	48
PLATE VI. —Edentate footprint from the Desaguadero series..	52
PLATE VII.—Fossil plants	115

THE GEOLOGY OF THE COROCORO COPPER DISTRICT OF BOLIVIA

INTRODUCTION

The history of the Corocoro copper deposits in Bolivia is quite prosaic in comparison with the story of the phenomenal riches that the bonanza silver districts, such as Potosi, Colquechaca, or Oruro yielded. Copper is a metal that was incapable of arousing the cupidity and imagination of the Spanish adventurers who first penetrated the bleak and inhospitable high altitudes of what is today Bolivia. Their quest was the precious metals. Consequently Corocoro does not share in the glamor and romance of the development of the silver districts during the Colonial period. The existence of Corocoro ores was by no means unknown, however, during this period, nor were the deposits entirely neglected. Upon the arrival of the Spaniards early in the Sixteenth Century they found the Indians working the oxidized outcrops of the ore bodies as a source of copper pigments. During the Colonial period the deposits were regularly worked by a Rodriguez family who furnished copper to the mint at Potosi for the national currency. Revolutionary movements led to a cessation of operations in 1781. A change in the character of the ore seems also to have been a contributory cause. The Rodriguez had mined the original outcrop ores and recovered the copper by smelting; and on encountering metallic copper ores beneath them, they were at a loss to know how to treat them.

A second period in the history of Corocoro was inaugurated in 1830 by Claudio Rivero who began working the native copper ores and who also, in that period, encountered much native silver. His success attracted attention to the

* George Huntington Williams Memorial Publication No. 10.

district, numerous mines were opened, and by 1846 there was an annual production of 35,000 quintals (46Kg) of barilla, or native copper concentrate. In 1850 the production had been increased to 88,000 quintals, but the average production since that year has been less. The total production from 1873 to 1912 was 200,000,000 pounds of copper. Besides leading to a regular and considerable production, this period is notable for the consolidation of the diversified ownerships of the mines under two strong companies. The *Compañía Corocoro de Bolivia*, a Chilean company, was organized in 1873; and the *Corocoro United Copper Mines, Ltd.*, an Anglo-French company, in 1909. All of the producing mines are now under the ownership of these two companies.

The completion of the Arica-La Paz railroad in 1912 marked a new era in the development of the district. From 1830 to 1912 the native metal ores were almost the sole object of attention. Owing to extremely adverse transportation facilities, only the high grade native copper concentrate could stand the freight charges; but, with the opening of the new railroad and the construction of the branch into Corocoro itself, the transportation situation was immensely improved, and it became profitable to export sulphide ores which hitherto had been avoided in mining or thrown on the dumps. This led to a sudden augmentation in the production of the district. In the latter part of 1914 the Chilean company was shipping at the rate of 1,500 tons monthly of hand-picked sulphide and oxidized ore averaging 18 per cent copper, and the European company 30 cars per month of the same kind of ore in addition to the usual amounts of native copper concentrates. Shortage of railroad equipment in 1915 and in subsequent years greatly reduced shipments from the district and compelled the lower grade sulphide and oxidized ores to give way to the higher grade metallic copper concentrates. To overcome this difficulty both companies experimented with flotation and in 1918 the Chilean company started in opera-

tion a flotation mill and in 1919 the European company. The grade of the sulphide ores is so much higher than that of the native copper ores, that concentration of the former is now the more profitable operation. The native copper ores are for the time being almost completely neglected and the district is primarily a producer of sulphide ores. In 1919 the production was about 9,000,000 pounds of copper, of which over four-fifths came from the sulphide ores and less than one-fifth from the native copper ores.

As an important producer of native copper ores for nearly a century, the Corocoro deposits ranked among the unusual copper deposits of the world. They share with the Lake Superior deposits of the United States, the distinction of being the only commercially important copper districts in which native copper is the principal form of occurrence of the ore. This unique geologic position of the deposits attracted the interest of geologists and mining engineers who have visited Bolivia with the result that the abundant literature listed in the bibliography at the end of this paper is now available, a striking contrast to the very scant literature covering many Bolivian mining districts with a more splendid and meteoric past. Notwithstanding the notable list of contributors to the geology of Corocoro, prior to 1917 little progress had been made in getting at the fundamental facts and explanations of the geologic phenomena of the district. Conclusions were hardly more than assumptions and had been based largely on hasty generalizations and unwarranted analogies, so that there was a wide divergence of opinion. The reader of the extensive literature was confused more than enlightened with respect to all but the most superficial facts concerning the geology and genesis of the deposits. In 1915, Singewald and Miller collected the first determinable fossils, in the shape of plants, from the Vetas formation on the basis of which Berry was enabled to determine definitely the age of those beds. The results of their work were published in 1917. In 1919, the authors of this paper visited Corocoro in the hope of further

unraveling some of the disputed and unsolved problems of its geology. That they can not contribute the last word they are fully aware; but their work has resulted in several distinct additions to the subject. These consist primarily in the first geologic map of Corocoro and vicinity, the first measured sections of the Vetás and Ramos formations, the recognition of the Desaguadero formation, and a more exhaustive study of the flora of the Vetás formation. Credit for whatever additions the authors may make to the geology of the district must be shared with the management of the two operating companies, as the work of 1915 and of 1919 was possible only through their aid and co-operation and the facilities furnished by them. It is only fair to say further, and with most enthusiastic appreciation, that credit is due particularly to Mr. Fernando Dorion, general manager of the Corocoro United Copper Mines, Ltd., and members of his staff, who were not only always ready to co-operate in and facilitate the work, but manifested an interest and expectation in the results in no wise less than that of the authors themselves.

LOCATION

The city of Corocoro is the capital of the province of Pacajes of the department of La Paz and has a population of about 10,000 inhabitants, almost exclusively Indian. Topographically, it is situated toward the western edge of the altiplanicie, or high plateau of Bolivia, in one of the numerous groups of low hills that rise above the level of the plain, at an altitude of a little over 13,000 feet. The houses are strung out along several small valleys and gulches at the foot of the north slope of the Cerro de Corocoro, and the mines are located on the hills immediately surrounding the town.

Until 1912 Corocoro was without railroad facilities. Access to the district was then by muleback or stage from La Paz, 100 km. to the northeast. Ingress and egress of

freight was even more cumbersome. The copper concentrates were packed on llamas and donkeys or carted from Corocoro to Nazacara on the Rio Desaguadero, a distance of 45 km. Low-draft river steamers or barges of 100 tons capacity carried the product a distance of 65 km. to Guaqui, the Bolivian port on Lake Titacaca, where it was transhipped to the lake steamers and transported to Puno, the port on the Peruvian side of the lake. Here it was transferred to the railroad and taken to the coast at Mollendo. Two more handlings were required to place the concentrates on the barges and from them on the ocean vessels which carried it to Europe or the United States. The freight charges from Corocoro to aboard ship at Mollendo amounted to over £ 3 per ton. The Arica-La Paz Railroad, which was placed in operation in 1912, passes within a few kilometers of Corocoro and a branch line, 6 km. in length, from Tarejra has been constructed to the very doors of the concentrating mills. Concentrates are now transported by a direct rail route of 340 km. from Corocoro to the coast at Arica at a rate of a little over £ 1. The effect of these greatly improved transportation facilities upon the development of the district has been described.

The climate of Corocoro is ideal. Owing to its high altitude radiation is rapid. The nights are always cold and during most of the year ice forms. The days of sunshine are delightfully warm. However, violent wind storms are frequent in the afternoon, often accompanied by snow or sleet squalls. Light snows or rains are frequent in summer. In other words, climatic conditions are those of a semi-arid climate at high altitude. The discomforts that one experiences in living there are due wholly to the lack of fuel and modern habitations. Owing to the dryness of the climate and the nature of the surficial geologic formations, the vicinity of Corocoro is almost devoid of vegetation, giving to its surroundings a bleak and desolate aspect.

GEOLOGY

EARLIER DESCRIPTIONS

Certain outstanding features of the geology of Corocoro have been recognized by all who have been there. There are two series of rocks having a strike west of north dipping away from a fault that runs parallel to the valley of the Corocoro River north of the city and lies on the west side of the valley. Both series of beds are prevailingly red in color and are made up of a thick sequence of shales, sandstones, and conglomerates. The series of westerly-dipping beds contains more sandstones and conglomerates than the series of easterly-dipping beds. Numerous beds of both series are impregnated with copper ores.

The copper-bearing beds of the westerly-dipping series are called "vetas" and those of the easterly-dipping beds "ramos," and as a matter of convenience, these names have also become attached to the rocks themselves. The term "veta" is Spanish for vein and "ramo" the Spanish for branch, terms that have neither genetic nor descriptive significance in this application. They have been so generally adopted, however, that it seems best to retain them as the names of the respective groups of ore bodies; and the series of rocks in which each occurs will, therefore, be called the Vetas series and the Ramos series, respectively. Since the sandstone beds are thicker and more prominent in the former series than in the latter, the vetas are said to average thicker than the ramos, a difference implied in the name.

Forbes (p. 42) describes the section of the Vetas formation from the Pontezuelo River eastward to the fault as follows:

"Starting from the westward, over a series of fine-grained red sandstones, we come upon some coarser and more gritty strata in which are embedded several seams containing copper . . . ; pebbly conglomerates are then passed over, some of which are also impregnated with copper; and we then arrive at the Veta de Buen Pastor, a fine-grained sandstone, impregnated not only with copper, but also with native silver. . . . The succeeding strata

are still coarse grits and fine conglomerates; and we come upon the Veta de Rejo, or Veta Copacabana. . . . Still lower in the same class of beds, the Veta Remacoia, or main seam of copper is encountered. . . . Below this metallic bed we find some gritty strata and then have a characteristic bed of fine-grained crumbly red sandstones of immense thickness, the upper edge of which is seen on the surface close to the line of fault."

His description of the Ramos formation from the fault eastward is the following: (p. 43)

"Crossing now over to the east side of the line of the fault we find an immense development of the same fine-grained sandstones as those composing the last bed met with on the surface to the westward of the fault; and in the lower part of this bed we find developed a series of metalliferous beds. . . . A considerable amount of gypsum is found in the form of strings or veins, also as small crystalline particles disseminated through the beds of red sandstone of this whole series."

The descriptions are good in recognizing the prominence of coarse sandstones and conglomerates in the Vetas formation and the occurrence of gypsum in the Ramos formation.

Reck says the rocks in the vicinity of Corocoro are prevailing sandstone beds in which the red color is less pronounced than in the same rocks farther north. Intercalated with them are shales of reddish-brown color and gypsum beds and stringers of gypsum and salt intersect the shales. He recognizes a westerly-dipping group of rocks which is dark brownish-red to reddish-gray in color and contains the ore-bearing beds and an easterly-dipping group of rocks which consist of red clay and an impure kaolinic clay which often enclose thin beds of a yellowish-green fine marly sandstone. The sandstones grade over into thin-bedded shaly sandstones. The series is not metalliferous. The rocks about Corocoro, he says, are also coarser than farther north and include conglomerates.

Mossbach adds little to the description of the stratigraphy of the Corocoro rocks. He says they consist of reddish, regularly stratified, not very hard sandstones with clay

cement. Intercalated in these are the ore beds which are of light-brown to greenish-blue color and somewhat harder.

L. Sundt saw more clearly the lithologic characteristics and differences between the two formations. He says in Corocoro are two distinct geologic formations, resting discordantly on each other. The older beds (the Vetas) extend to the north and west, strike N. 30° W. and dip W., are principally sandstones of yellow or red color, never contain beds of gypsum, and extend with great uniformity in strike and dip several kilometers to the west and north, having a thickness of more than 1000 meters. The sandstones are composed especially of rounded fragments of quartzites, which often have the size of a nut, forming conglomerates. Besides the quartzites, there are often small fragments of felsite, half kaolinized and not rounded, and also fragments of an eruptive rock composed of feldspar and hornblende. The other formation (the Ramos) rests on top of the former and surrounds it to the south and east and is composed of sandstones and conglomerates, often similar to those of the former, but usually of a darker color, chocolate and coffee. It is distinguished from the Vetas by its beds of red shale with intercalated beds of gypsum or aragonite. Besides the sandstones, conglomerates, shales, and gypsum, Sundt says there are encountered in the two formations of Corocoro, beds of tuffs and very characteristic trachytic conglomerates. In a white tuff are rounded fragments, up to the size of a fist, of trachyte composed of sanidine, black mica, and quartz. Small fragments of black mica, feldspar, and at times crystals of bipyramidal quartz also frequently form an integral part of the quartzitic sandstones.

Sundt's interpretation of the stratigraphic relation of the two formations will be disregarded at this point. It is evident that he clearly recognized the prominence of red shales and the presence of gypsum as distinguishing characteristics of the Ramos formation in contrast to the Vetas formation, and that the sandstones and conglomerates of

the Vetás formation tend to be lighter in color than those of the Ramos. Another important feature emphasized by him is the abundance of igneous material entering into the composition of these beds in the form of tuffaceous and conglomeratic material. Indeed, Sundt himself comments upon the fact that he is the first to recognize this.

Dereims merely says that the Corocoro beds belong to the Permian which extends over a great area on each bank of the Desaguadero, and that they are everywhere identical in mineralogical composition, consisting of rose-colored and red sandstones and red shale with gypsum and salt.

Steinmann considers both the Vetás and the Ramos series members of his Puca sandstone formation. He says that red sandstones are found in Bolivia ranging in age from Silurian to Quaternary, but the thickest series (several thousand meters) and most widely distributed is that which covers a larger part of the high plateau and the eastern range of the Andes. To this series he has given the name Puca sandstone, from the Quechua word *puca*, which means red. He describes the series of rocks as resembling very strikingly the German Buntsandstein. Aside from local intercalations of dark shales and dark, basic, porphyritic rocks, and still more local limestone intercalations, the prevailing rock, he states, is a red, medium to fine-grained, occasionally conglomeratic sandstone of light to brilliant red, but also dark-red or violet color. Cross-bedding is common and carnelian nodules are occasionally encountered.

“Almost everywhere the formation can be readily separated into three divisions: a lower, consisting entirely of sandstone; a middle, in which red shales, often associated with gypsum and occasionally with salt, prevail, and in the lower part of which the fossiliferous limestones occur; and an upper, which includes the greater part of the sandstone series.” (p. 341)

The Vetás formation Steinmann considers to be the lower member of his Puca sandstone and the Ramos formation the middle member. The age of the Puca sandstone as determined by the fossils from the limestones is Cretaceous.

Steinmann also recognizes a younger series of red beds of which he gives the following description: (pp. 342-343)

"Toward the end of the Pliocene and in early Quaternary red sandy rocks were again deposited over a wide area, not as marine sediments, but as continental deposits, and since the Puca sandstone in Pliocene time still covered almost the entire region, at least it was much more widespread than today, these younger continental sands and sandstones were derived chiefly through the destruction and reworking of the Puca sandstone; they are consequently very similar to it, both in general composition and in color. What, however, could not be repeated and was not repeated in the redeposited material was the regular recurring stratigraphic sequence of the Puca sandstone as well as the intercalations of limestone, gypsum and salt which it contained. Further, since the injection of granodioritic rocks and the effusion of trachytic-dacitic volcanic rocks took place at the close of the Tertiary and in the Quaternary, these younger sediments contain almost everywhere fragments and tuffs and even flows of the younger eruptive rocks. There are also local accumulations of pebbles of the old crystalline basement (granite, gneiss, etc.,) which are lacking in the Puca sandstone, and hence constitute another distinguishing characteristic. On the other hand, the oldest beds of these younger sandstones which I have separated from the youngest, certainly diluvial deposits, under the name of Jujuy beds, often overlie the Puca sandstone concordantly and have been folded with it."

Concerning the mineralogic and petrographic character and the stratigraphic sequence of the Ramos and Vetás formations Steinmann adds nothing to our previous knowledge, unless it be a greater emphasis upon the shaly character of the Ramos formation. He errs in limiting the fragments and tuffs of the younger grano-dioritic volcanics to his Jujuy beds, as they are found abundantly in the lowest-exposed beds of the Vetás formation. As we shall see later, he also is mistaken in correlating the Vetás and Ramos formations of Corocoro with the Puca sandstone of the eastern Andes.

Douglas (pp. 27-28) describes all the red rocks of Corocoro and the surrounding region as one series of red gypsiferous sandstones and marls, everywhere marked by abundant seams of gypsum, often of considerable thickness.



FIG. 1. View looking North, showing the Vetas series on the West side of the valley.



FIG. 2. View looking North, showing the Ramos series on the East side of the valley.

Singewald and Miller (pp. 171-172) state that:

"the country rock of the district consists of a thick series of prevailing red gypsum- and iron-bearing shales, sandstones, and conglomerates, the relative abundance of which ranges in the order named.

. The prominent characteristic of the series as exposed in this hill [the Vetas formation] is the abundance of sandstone beds ranging in thickness from one to several meters.

. . . . In the series of rocks out-cropping in this ridge [the Ramos formation] sandstones are less prominent and shales more abundant."

This brief description emphasizes the sandy character of the Vetas formation and the shaly character of the Ramos formation, but does not call attention to the gypsiferous character of the latter and the lack of gypsum in the former, nor to the presence of fragmental igneous and tuffaceous material in these sediments.

Lincoln's description of the Corocoro beds is limited to the statement that:

"Corocoro is situated in a group of low hills composed of shales, sandstones, and conglomerates ranging in age from Triassic to late Tertiary. These sediments have a general ferruginous color, and are also gypsiferous."

None of the distinctive features of either series of rocks is mentioned.

The foregoing descriptions of the Corocoro strata are generalized impressions of the various observers. There is considerable disparity in the emphasis laid upon the various characteristics of the beds as a whole and upon the distinctive features of the series of beds on each side of the main fault line. But a composite picture of all the descriptions gives a good general idea of what the two series of rocks are like. In order to present this information in more accurate and detailed form, the authors measured two sections of the Vetas beds, one with transit and stadia rod and the other by pacing, and one section of Ramos beds with transit and stadia rod.

THE VETAS AND RAMOS SERIES
THE VETAS SERIES

A section of the Vetás formation was measured with transit and stadia rod beginning at the fault plane in a small ravine 2 km. north of Corocoro and continuing in a direction S. 65° W. a distance of 2100 m. to the Pontezuelo River. The position of the section is shown on the map. The stratigraphic thickness of the beds in this section is 1,491 m. This represents only part of the Vetás formation, as it does not include the beds cut off by the fault below those of the section, nor the overlying beds in the valley of the Pontezuelo River, nor in the hills beyond which continue for a long distance westward with the same strike and dip and appear to be part of the same series.

SECTION OF PART OF VETAS FORMATION
NORTHWEST OF COROCORO

Meters

	Pontezuelo River flood plain
4.1	Coarse red sandstone
1.8	Red shale
1.2	Red sandstone
4.1	Red shale
3.5	Gray conglomeratic sandstone
5.9	Red sandstone with irregular shale bands
2.3	Red shale
2.3	Red sandstone
1.8	Shale
1.8	Coarse gray sandstone
4.1	Shale
1.8	Gray sandstone
20.5	Red shale
9.4	Gray sandstone
10.5	Shale
1.2	Gray sandstone
12.3	Shale
5.9	Gray sandstone
13.5	Shale
5.9	Sandstone
11.7	Shale

Meters .

2.3	Sandstone
8.8	Shale
4.7	Gray sandstone
2.9	Red shale
5.9	Coarse gravelly gray sandstone
8.8	Red shale
11.7	Gray sandstone
3.5	Red shale
1.8	Gray sandstone
4.1	Red shale
.6	Gray shale
2.3	Gray sandstone
2.3	Red shale
1.8	Gray sandstone
11.7	Red shale
1.2	Gray sandstone
2.9	Red shale
2.3	Gray sandstone
1.8	Red shale
2.3	Gray shale
4.7	Red sandstone with gravel bands
1.8	Red shale
1.8	Red sandstone
2.9	Gray sandstone
4.7	Gray shale
7.0	Gray sandstone
7.1	Red shale
2.0	Coarse gray sandstone
1.0	Gray shale
1.0	Gray sandstone
1.0	Gray shale
2.0	Gray sandstone
5.1	Red shale
2.0	Gray conglomerate, cross-bedded
2.5	Red shale
5.1	Gray pebbly conglomerate
1.0	Red shale
4.0	Gray sandstone
.5	Red shale
.5	Red sandstone
1.5	Gray sandstone, cross-bedded
1.5	Light shale
1.5	Gray sandstone

Meters

- 1.5 Red shale
- 1.5 Coarse gray sandstone
- 2.5 Sandy shale
- 2.5 Fine gray sandstone
- 1.0 Red sandstone
- 4.5 Red shale
- 2.5 Gray gravelly sandstone, cross-bedded
- 2.0 Sandy red shale
- 4.0 Coarse sandstone
- 1.5 Gray shale
- 2.0 Fine gray sandstone
- 3.0 Red shale
- 1.0 Fine gray sandstone
- 1.0 Red shale
- 2.0 Coarse gray pebbly sandstone
- 3.0 Fine gray sandstone, irregularly bedded, some shaly bands
- 1.1 Gray sandstone
- 1.6 Light shale
- 2.6 Gray sandstone
- 3.1 Red shale
- 3.1 Gray sandstone
- 12.1 Red shale
- 1.6 Gray sandstone
- 3.7 Red shale
- 2.1 Gray sandstone
- 1.1 Red sandstone
- 1.1 Shale
- 3.7 Gray sandstone, gravel at top
- 2.1 Red shale
- .5 Gray pebbly sandstone
- 2.6 Red shale
- 2.6 Coarse gray pebbly sandstone
- 4.7 Shale
- .5 Gray sandstone
- .5 Red shale
- 19.4 Gray pebbly sandstone
- 5.3 Red shale
- 7.4 Coarse sandstone, very irregularly bedded, two *copper* bands
- 11.0 Thin-bedded red sandstone with cross-bedded lenses
- 1.1 Red sandstone
- 8.9 Red shale
- 1.1 Gray sandstone
- 16.8 Red shale

Meters

- 3.2 Irregularly-bedded sandstone
- .5 Red shale
- 8.1 Gray and pinkish, irregularly-bedded, gravelly sandstone
- 2.5 Red shale
- 1.0 Gray sandstone
- 7.6 Red shale
- 3.1 Gray sandstone
- 4.6 Red shale
- 3.1 Gray sandstone
- 2.5 Pink shale
- 1.0 Gray shale
- 1.0 Gray sandstone
- 3.6 Shale
- 1.5 Pebbly gray sandstone
- 2.5 Shale
- 3.1 Gray sandstone
- 1.5 Shale
- 1.5 Gray sandstone with *copper*
- .5 Pink sandstone, thin-bedded
- .5 Gray sandstone
- .5 Red sandstone
- 4.0 Red shale with sandstone stringers
- .5 Red sandstone
- .5 Red shale
- 1.0 Red sandstone
- 3.1 Red shale
- 1.5 Gray pebbly sandstone
- 1.0 Red shale
- 2.0 Gray pebbly sandstone, irregularly-bedded
- 17.6 Shale with sandstone bands
- 7.8 Alternating coarser-bedded pinkish sandstone and shale
- 1.6 Red shale
- 2.1 Gray sandstone, *copper* at base, gravel at top
- 9.3 Red shale
- 1.6 Gray gravelly sandstone
- 3.1 Red shale
- .5 Red sandstone
- 8.8 Red shale
- 1.6 Gray pebbly sandstone
- 4.7 Red shale with stringers of sandstone
- 2.1 Gray sandstone
- 1.6 Gray pebbly sandstone
- 2.1 Reddish sandy shale

Meters

- 27.2 Gray sandstone, gravelly toward top
- 4.4 Shale
- 6.2 Gray sandstone
- 12.3 Shale
- 1.8 Gray conglomerate
- 2.6 Gray sandstone
- 1.8 Red sandstone
- 4.4 Red shale
- 4.4 Gray sandstone
- 6.2 Gray pebbly conglomerate
- 2.6 Gray sandstone
- 4.4 Red shale
- 1.8 Gray sandstone with gravel
- .9 Red sandstone
- 12.3 Coarse gray irregularly-bedded sandstone with bands and lenses of pebbles
 - .8 Gray sandstone with *copper*
- 4.2 Shale
- 2.9 Gray sandstone with bands of pebbles
- 5.9 Red shale
- 1.3 Gray sandstone
- .8 Conglomerate
- 1.7 Pale-red sandstone
- 5.9 Red shale
- 3.4 Gray pebbly conglomerate
- .8 Gray sandstone with *copper*
- 4.6 Red shale
- 13.0 Red sandstone with bands of gravel and shale
- 2.7 Red shale
- .9 Gray sandstone
- 1.3 Red shale
- 1.3 Red sandstone and shale
- 1.3 Red shale
- 4.9 Gray pebbly sandstone with subordinate shale bands
- 1.3 Red Shale
- 6.7 Alternating red sandstone and gravel bands
- 2.2 Red sandstone
- 2.2 Red shale
- 2.7 Red sandstone
- 4.5 Red shale
- 7.2 Reddish sandstone
- 2.7 Gray pebbly conglomerate
- 5.8 Red shale

Meters

- 2.9 Gray pebbly conglomerate
- 1.2 Red sandstone
- 5.8 Red shale
- 2.9 Gray conglomerate grading to sandstone above
- 7.0 Red shale with bands of red sandstone
- 4.7 Gray sandstone with *copper* bands
- 8.7 Red shale
- 2.5 Red sandstone
- 2.5 Red shale
- 8.7 Red sandstone with subordinate shale bands
- 1.2 Gray pebbly conglomerate
- 11.2 Red shale with subordinate red sandstone bands
- .6 Red sandstone
- 1.2 Red shale
- 1.2 Red sandstone
- 3.1 Red shale
- 1.9 Gray sandstone
- 5.0 Red shale
- .6 Red sandstone
- 5.0 Red shale
- 3.7 Gray gravelly sandstone
- 4.4 Red shale
- 1.9 Red sandstone
- 5.0 Red shale
- 1.9 Red sandstone
- 39.3 Red shale
- 5.0 Gray pebbly conglomerate
- 13.7 Red sandstone with subordinate shale
- 6.2 Red shale
- 4.4 Gray pebbly conglomerate
- 8.7 Red shale
- 1.2 Red sandstone
- 6.9 Red shale
- 1.9 Red sandstone
- 1.2 Red shale
- .6 Red sandstone
- 6.2 Red shale
- 4.4 Coarse red sandstone
- 5.0 Red shale
- 5.0 Irregularly-bedded gray sandstone
- 1.2 Red shale
- .6 Red sandstone
- .6 Red shale



FIG. 1. View looking South, showing principal mines on the Cerro Corocoro.



FIG. 2. View looking Southwest, showing the town, with the Vetas series on the right, and the southward extension of the Cerro Corocoro in the left background.

Meters

- .6 Red sandstone
- 1.2 Red shale
- 1.2 Red sandstone
- 2.5 Red shale
- .6 Red sandstone
- 6.2 Red shale
- 1.9 Gray sandstone with gravel
- 3.7 Alternating sandstone and shale
- 8.7 Red shale
- .9 Gray pebbly conglomerate
- 1.9 Red shale
- 1.2 Sandstone with gravel
- 1.2 Red shale
- 1.6 Red sandstone
- .6 Red shale
- 5.6 Gray sandstone with *copper* becoming red toward top
- 1.2 Red shale
- 3.1 Red sandstone
- 4.4 Red shale
- 3.1 Cross-bedded gray sandstone, coarse and pebbly at top
and bottom
- 3.3 Red shale
- .6 Red sandstone
- 1.1 Red shale
- 1.7 Gray pebbly sandstone
- 3.3 Red shale
- .6 Brown sandstone with gravel
- 6.1 Red shale
- 2.2 Soft red sandstone with gravel
- 23.3 Red shale
- 6.1 Alternating gray sandstone and conglomerate
- 2.7 Red Shale
- .7 Red sandstone
- .7 Gray conglomerate
- 1.0 Red shale
- 1.7 Red sandstone
- 1.3 Red shale
- 1.0 Red sandstone
- 1.7 Red shale
- 1.0 Red sandstone
- 3.7 Red shale
- .3 Red sandstone
- 1.7 Red shale

Meters

- 4.0 Alternating gray sandstone and conglomerate
- .7 Red shale
- .7 Gray conglomerate
- 1.3 Red shale
- 2.3 Conglomeratic sandstone
- 4.0 Red shale
- 4.7 Conglomerate
- 4.0 Red shale
- 2.0 Conglomerate
- .3 Red shale
- 2.7 Red and gray sandstone with pebble beds
- 1.4 Conglomerate
- 2.7 Red shale
- 1.0 Conglomeratic sandstone
- .7 Red shale
- 3.0 Conglomerate
- 3.7 Red shale
- 1.4 Gray sandstone
- 1.4 Red shale
- 3.4 Conglomeratic sandstone
- 2.0 Red shale
- 1.3 Conglomerate
- 2.5 Red shale
- 3.6 Coarse, gray, friable sandstone, pebbly and irregularly-bedded in lower part
- 1.8 Bright red shale with inconspicuous narrow bands of reddish sandstone
- .4 Gray sandstone
- 23.5 Red shale with scarcely indurated red sandstone in middle
- 2.5 Gray sandstone with conglomeratic bands a few inches thick
- 2.7 Red shale
- 1.0 Gray sandstone with conglomerate beds
- 2.4 Red shale
- 2.2 Gray sandstone with conglomeratic bands
- .5 Red shale
- .7 Red sandstone
- 2.5 Red shale
- 5.4 Conglomerate
- 6.8 Red shale
- 1.1 Red shale
- 1.1 Conglomerate
- 5.3 Red shale
- .5 Conglomerate

Meters

- 2.7 Red shale
- 5.9 Red sandstone with pockets of conglomerate
- 3.6 Reddish conglomerate
- 7.6 Red shale
- 1.8 Red sandstone with gravel bands
- .7 Red shale
- .9 Red sandstone
- .9 Red shale
- 1.6 Red sandstone
- 3.1 Red shale
- 1.3 Red sandstone
- 4.9 Red shale
- 8.1 Reddish sandstone
- 1.8 Red shale
- 3.6 Conglomeratic irregularly-bedded sandstone
- 4.3 Coarse mostly light, irregularly and cross-bedded, conglomeratic sandstone with *copper* patches
- 3.2 Red shale
- 6.4 Sandstone with conglomerate beds 1 to 2 feet thick
- 5.3 Red shale
- 4.3 Conglomerate
- 14.7 Red sandstone
- 2.5 Red shale
- 4.6 Red sandstone
- 4.4 Red shale
- 53.7 Heavy-bedded, mostly coarse light sandstone with gravel bands and some reddish layers toward top
- 21.5 Alternating coarse and fine, light and dark sandstone ledges with numerous thin shale intercalations
- 5.4 Light sandstone, very coarse toward top, occasional pockets of *copper* stain
- 6.7 Reddish sandstone becoming lighter and with copper blotches toward top
- .4 Dark-stained conglomerate
- .5 Light coarse cross-bedded sandstone
- .6 Sandstone (*copper* stained somewhat shaly, plants)
- .6 Shale
- 1.0 Sandstone
- 1.0 Shale
- .8 Sandstone
- .6 Shale
- .6 Sandstone
- .4 Shale

Meters

.8	Sandstone
6.0	Shale
2.5	Sandstone
3.1	Shale
1.6	Sandstone
1.8	Shale
1.6	Sandstone
5.0	Shale
3.5	Sandstone
3.9	Shale
1.9	Sandstone
2.9	Shale
1.5	Black-stained sandstone
1.1	Shale
1.5	Pebbly sandstone
.5	Shale
1.5	Sandstone
5.5	Shale
1.3	Sandstone
.7	Sandstone
1.1	Sandstone
6.7	Red shale with thin sandstone bands
4.5	Reddish sandstone
5.6	Reddish shale
.5	Reddish sandstone
.5	Reddish shale
.9	Reddish sandstone
.9	Reddish shale
.9	Reddish sandstone
2.1	Red shale
.2	Sandstone
10.0	Shales
.3	Sandstone
26.0	Red shales
	Corocoro fault

In this section, shales constitute 52.7 per cent of the beds, sandstones 24.6 per cent, conglomeratic sandstones 18 per cent, and conglomerates 4.7 per cent. The shales are almost invariably red, but enclose no gypsum beds nor are they gypsiferous. A large part of the sandstone is also red in color, but much of it is gray, and the coarse and conglome-

atic beds are nearly all gray. All copper-stained horizons are in sandy beds, never in the shales; and they range over a stratigraphic thickness of 1110 m. from the fault.

Another section of the Vetás formation was measured, by pacing and by tying in to locations on the map, along the Pontezuelo River, 5 km. northwest of Corocoro beginning at the Corocoro fault on the north side of the river and following the river to a point which included 1058 m. of strata. The position of this section is shown on the map. It likewise represents only a part of the formation, not including the underlying beds that have been cut off by the fault, nor a great thickness of overlying beds that continue a long distance westward from the top of the section. Of the total measured thickness of 1058 m., only 534 m. was measured in detail. The description of the rest of the section, 239 m. at the base and 270 m. at the top, is generalized.

SECTION OF PART OF VETAS FORMATION ALONG PONTEZUELO RIVER

Meters

- At top 1 meter of thin-bedded sandstone, *cupriferosus* and with plants
- 58.00 Gray and tan sandstones and conglomerates predominate
- 26.00 Gray and tan sandstones and conglomerates predominate
Two *copper* horizons with plants at top, lower one sandy and with very good plants
- 86.00 Gray and tan sandstones and conglomerates predominate
Cupriferosus horizons with plants at top. Casts of trunks of trees in green up to 6 inches in diameter, in some cases with pebbles within the casts
- 3.00 Gray conglomerate
- 60.00 Gray sandstones
- 1.50 Conglomerate
- 1.80 Red sandstone
- 2.40 Red shale
- 1.80 Red sandstone
- 3.00 Red shale
- 7.50 *Copper* band with many stem casts, conglomeratic sandstone
- 75.00 Interbedded sandstones and shales

Meters

- 7.50 Sandstones and shales
- 1.50 Conglomeratic sandstone
- 12.75 Red shales and interbedded sandstones
- 27.75 Gray to light-reddish sandstone ledges with some shale bands
- 4.50 Reddish shales
- 4.50 Pebble conglomerate
- 105.00 Grayish sandstones and shales to across the quebrada
- 1.80 Gray irregularly-bedded sandstone, *copper* stained for 2 to 3 feet, with many casts of plant stems
- 3.75 Reddish sandstone
- 2.25 Gray sandstone with black stained pockets
- 5.25 Shaly sandstone with non-persistent *copper* streak at top
- 3.00 Coarse friable light-brownish sandstone with black stained bands
- 3.00 Soft red shaly sandstone
- 6.57 Similar more massive sandstone, the upper 10 inches black
- 2.40 Becoming thin-bedded with narrow shaly bands *copper*-stained, no plants
- 4.50 Gray sandstone
- 1.50 Red shale
- 1.80—2.40 Gray cross-bedded hard sandstone with quartz gravel below
- 3.90 Red shale
- 1.20 Soft, black-stained sandstone
- 6.00 Red shale
- 1.20 Gray sandstone
- 2.40 Red shale
- .60 Gray sandstone
- 1.20 Red shale
- 3.00 Gray sandstone
- .15— .30 *Copper*-stained band with clay pellets, no determinable plants
- 2.10 Gray sandstone
- .20 Shale band
- 2.25 Gray sandstone
- 15.00 Red shale
- 6.00 Coarse pinkish-buff sandstone ledge
- 16.50 Interbedded red shales and sandstones
- .90 Thin-bedded gray sandstone, black along bedding planes
- .37 Compact gray sandstone
- .12 Hackly thin-bedded tufaceous sandstone with plant fragments

Meters

- .15 Compact gray sandstone
- NOTE.—The better plant material comes from this horizon and a thickness of 2 or 3 inches on either side of the plant layer is *copper*-stained
- .04 Plant layer
- .12 Gray shale layer, more compact in lower half
- .15 Gray cross-bedded coarse sandstone
- .62 Finer black stained sandstone
- 1.50 Light brownish coarse cross-bedded sandstone
- 1.00 Brownish sandy shale
- .40 Soft fine-grained banded sandstone
- 6.00 Red shale
- 70.50 Light reddish to gray sandstone with some shaly bands, in places showing regular 8- to 10-inch alternations of shaly and coarse materials becoming more distinctly thin-bedded near the top
- 8.25 Red shale with 6- to 8-inch bands of sandstone
- .60 Ledge of coarse red friable sandstone
- 9.75 Shaly hackly sandstone
- 3.00 Lighter gravelly sandstone
- .40 Brown sandstone
- .60 Light-brown irregularly-bedded very coarse sandstone with angular quartz gravel
- 3.00 Hackly argillaceous sandstone
- 8.25 Fine red shale (mudstone)
- .80 Coarse brownish gravelly sandstone
- .20 Fine-grained reddish sandstone N.22° W.55° W.
- .40 Coarse brownish sandstone with some fine gravel
- Red clay
- 239.00 Poorly exposed red shale and sandstone
- Corocoro fault

In the 534 m. of detailed section, shales constitute 38 per cent of the beds, sandstones 57 per cent, conglomeratic sandstones 3 per cent, and conglomerates 2 per cent. The shales are almost invariably red, but are not gypsiferous nor do they enclose beds of gypsum. Though much of the sandstone is red, the prevailing color is gray and as the sandstones and conglomerates make up such a large part of the section, the red color is less pronounced than the gray in the outcrops. All copper-stained beds are in sandy

horizons and usually also contain plant remains. Copper impregnations and plant-bearing beds range through the entire section of 1058m.

The sandstones and conglomerates of the Vetás formation vary much in mineralogical and petrographic composition. In the vicinity of Corocoro, quartz grains are more abundant than other constituents and are usually fairly well rounded and water worn. Associated with the quartz grains are subangular grains of feldspar, usually plagioclase, which in some instances are undergoing kaolinization, but frequently are perfectly fresh and glassy. The amount of feldspar varies greatly and in many places is in excess of the quartz. In the coarser rocks many of the grains and pebbles are fragments of igneous rocks, and most commonly of hornblende-andesite porphyry, or hornblende diorite porphyry, very much like the Mirikiri rock described in a subsequent section. The matrix of the sandstones is more feldspathic than the grains, and also includes considerable chlorite and frequently calcite. These beds are, consequently, always arkosic and often are really arkose rather than sandstones and conglomerates. Further, the more abundant the fragments of igneous rock, the less water-worn and more angular are the constituent grains, so that locally the beds represent but slightly water-sorted tuffs.

South of the Pontezuelo River no very coarse beds made up of fragments of igneous rocks were seen. North of that river, however, about 10 km. from Corocoro, and about 1 km. northwest of Ballivian station on the Arica-La Paz railroad, at the Carmen mine, a much coarser facies of the Vetás formation is encountered. Whereas the pebbles in the conglomerates about Corocoro include fragments of sandstone, quartzite and shales, at this locality they are made up of igneous rock varying from quartz porphyry, to andesite in composition. Large fragments of hornblende diorite porphyry, like that of Mirikiri, are particularly abundant. The fragments range in size up to pieces several inches in diameter. They are sufficiently subangular to show the

evidence of some water action and that the rocks are not volcanic breccias but rather are made up of slightly transported and water-deposited igneous material.

THE RAMOS SERIES

A section of the Ramos formation was measured with transit and stadia rod from the Corocoro fault to a thin white horizon at the Libertad mine, 3 km. north of Corocoro, including a thickness of 406 m. The white horizon is cut off by the Corocoro fault in the town of Corocoro. At this point the section was again taken up and measured in the direction N. 66° E., a distance of 3940 m. with transit and stadia rod, including an additional thickness of 3330 m. The total thickness of Ramos beds measured is, therefore, 3736 m. In the section are not included beds that have been cut by the fault beneath the lowest outcropping bed of the section nor a considerable thickness of beds east of the measured section which represent overlying beds. The total thickness of the Ramos formation is much more than 3736 m.

SECTION OF PART OF RAMOS FORMATION THREE KILOMETERS NORTH OF COROCORO

Meters

	Top of section measured at Libertad mine
.6	Light-green <i>copper</i> band
2.5	Brown sandstone
.3	Red shale
.9	Thin-bedded brown sandstone with shale laminae between beds
.9	Dark red shale
.1	<i>Copper</i> -stained
.4	White shale
.2	Red sandy shale
.2	Hackly drab shale
25.8	Red shale
.7	Greenish shaly sandstone
17.0	Red shale
1.4	Gray compact sandstone

Meters

- 27.2 Red shale
- 5.7 Greenish sandstone
- 4.0 Shale
- 2.5 Coarse reddish, irregularly-bedded sandstone
- 126.5 Badly weathered shale with occasional ledges of greenish-gray sandstone
- 1.3 Gray sandstone
- 5.0 Red shale
- 7.2 Friable gray sandstone with darker more indurated bands
- 19.8 Red shale
- 62.0 Red shale
- .8 Greenish sandstone
- 4.0 Red shale
- .4 Brown sandstone
- 24.3 Pale reddish, badly weathered shale
- 27.5 Buff and reddish-brown badly weathered shale with *copper* flakes and gypsum crystals
- 8.9 Red shale with courses of *copper* flakes and gypsum crystals
- .2 Friable gray sandstone
- 1.5 Much weathered pale reddish shale with *copper* flakes
- 5.7 Red shale
- 3.2 Dark-brown shale, surface covered with efflorescence of salts, some *copper* spots
- 7.2 Badly weathered red shale
- Corocoro fault

SECTION OF PART OF RAMOS FORMATION
AT COROCORO

Meters

- 114.6 Bright red clay shale
- 257.8 Concealed except for occasional outcrops of bright-red, soft sandy clay or argillaceous sandstone
- 3.0 Coarse red sandstone
- 39.4 Soft pink sandstone with intercalated shale
- 15.2 Fine red soft sandstone
- 193.4 Red shale
- 236.1 Alternating bright red sandstone and shale
- 256.1 Concealed
- 113.6 Concealed, mainly shale
- 258.1 Red shale with occasional ledges of scarcely indurated sandstone
- 2.0 Red sandstone

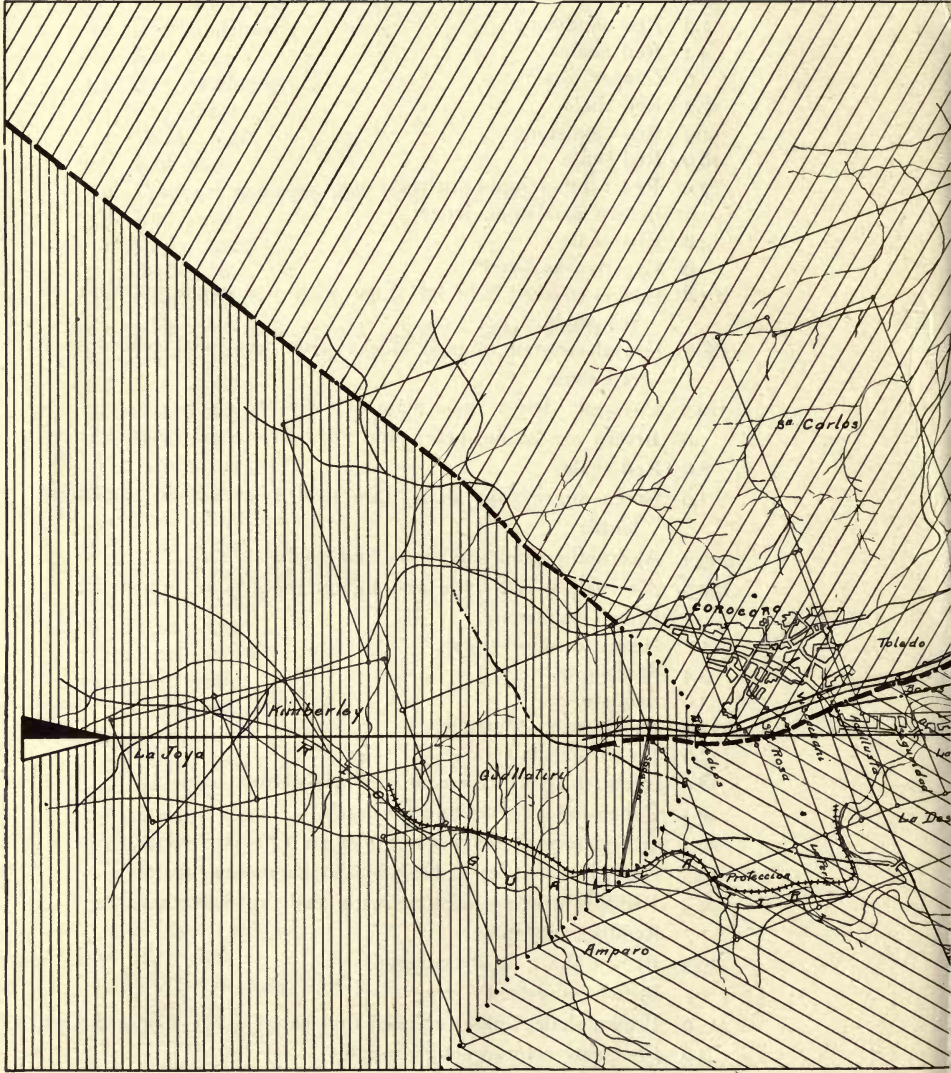
Meters

- 22.9 Red shale
- 2.0 Red sandstone
- .6 Red sandstone
- 6.4 Red shale
- 1.3 Red sandstone
- 15.4 Red shale
- .1 White band
- 3.2 Red shale
- 1.9 Compact red sandstone, softer in middle
- 3.8 Red shale
- .1 Green band
- 6.4 Red shale
- .3 Green band
- 16.0 Red shale with several 2.5 cm.—green bands
- 1.1 Green band
- 7.7 Red shale
- .6 Green band
- 5.8 Red shale
- .6 Green band
- 14.7 Red shale
- .3 Red sandstone
- 5.1 Red shale
- .8 Gypsiferous sandstone
- .4 Green band
- 6.4 Red shale
- .8 Green band
- 3.8 Red shale
- .3 Green band
- 8.3 Red shale
- .3 Green band
- 3.8 Red shale
- .6 *Copper* shale
- 9.6 Red shale
- 1.3 Cupriferous gypsiferous shale
- 3.8 Red shale
- .3 *Copper* shale
- 9.0 Red shale
- 1.3 *Copper*-stained shale
- 5.1 Red shale
- .1 *Copper* band
- 3.2 Red shale
- .1 *Copper* band
- 12.2 Red shale

Meters

- .6 *Copper* shale
- 5.8 Red shale
- 1.3 Red sandstone
- 4.4 Red shale
- .6 *Copper* shale
- 7.7 Red shale
- 1.9 Red sandstone
- 10.9 Red shale
- 7.9 Red sand, jointed with gypsum
- .6 Brown sandstone ledge
- 14.8 Red shale
- 2.6 Gypsiferous band
- 201.8 Gravel-covered alluvial slope with occasional outcrops of red shale
- 186.6 Gravel-covered alluvial slopes with occasional outcrops of red shale
- 320.5 Covered, River flood plain (chiefly red shale)
- .8 Brown sandstone, green and *cupriferous* in center
- 8.0 Red shale
- 1.0 Green *cupriferous* shale, thin-bedded, occasional sandstone lentils
- 39.4 Alternating red sandstone and shale
- 197.6 Alternating red shale and lighter-red friable sandstones
- .8 Brown sandstone
- 1.7 Heavy conglomerate
- 3.4 Sandstone
- 3.0 Sandstone
- 34.3 Poorly-exposed shale
- 17.6 Brownish shale
- 18.0 Greenish to whitish contorted gypsiferous shale
- 28.5 Concealed (dumps and quebrada)
- 20.4 Gypsiferous *cupriferous* sandstone (?) (mined)
- 39.3 Concealed except reddish-brown sandstone at top
- 24.4 Reddish-brown sandstone with shaly intercalations
- 1.7 Reddish sandstone
- 19.3 Brown shale, badly covered
- 1.7 Brown sandstone
- 15.0 Brown shale, lighter colored thin bands every 3 or 4 meters
- 2.6 Chocolate-colored conglomerates
- 7.5 Brown shale becoming sandy toward top
- 5.6 Brown shale

STUDIES IN GEOLOGY I



Meters

- .9 Brown shale grading into sandstone
- 2.8 Light gypsiferous sandy clay and brown sandstone
- 10.6 Reddish-brown shale
- .6 Sandstone
- 31.6 Brown hackly shale
- 2.5 Sandstone, brownish below, greenish and more gypsiferous above
- 3.4 Hackly brown clay, *copper* at base
- .5 Gypsiferous sandstone
- 23.4 Red shale, badly weathered
- 2.0 *Cupriferous* gypsum
- 21.7 Light-brown gypsiferous clay
- .35.0 Red gypsiferous shales with bands of gypsum at intervals
- .6 Contorted *cupriferous* gypsum
- 16.7 Red, very gypsiferous shale
- .3 *Copper* band
- 81.4 Red, gypsiferous shale
- 160.1 Covered in Corocoro valley across town
Bed at top of preceding section

The entire measured section of the Ramos beds includes 81 per cent shales, 18.7 per cent sandstones, 0.3 per cent conglomerates. The shales are light-red to dark-red in color and at some horizons grade into brown. Thin intercalations of green shale are abundant. The sandstones show the same range in color as the shales, except that near the fault are several horizons of gray sandstones similar to the gray sandstones of the Vetas formation. The color of the Ramos formation is, therefore, more pronounced red than that of the Vetas formation.

Gypsum is a prominent feature of the Ramos strata, occurring both as beds and as impregnations, veinlets, and stringers, through the rocks. North of Corocoro and south of the Pontezuelo River is a group of dull-gray to white hills called the Cerros Blancos, covering an area of 3 kilometers long from north to south and nearly 2 km. wide from east to west. The color of these hills is due to the abundance of gypsum in the rocks which seems to have grown by

accretion and forced apart the shales along the bedding planes and greatly disturbed their regular bedding. This effect is doubtless confined largely to the proximity of the surface and the underlying structure of the hills is in all probability essentially like that of their continuation along the strike to the south.

Cupriferous beds extend through 1700 m. of the section nearest the Corocoro fault but differ from those of the Vetas formation in that none of them are plant-bearing nor are they confined to the sandy layers. In the measured section are 14 cupriferous horizons in shale, 4 in sandstone, and 2 in gypsum.

AGE OF THE VETAS AND RAMOS

The age of the Vetas and Ramos beds of the Corocoro district has been placed in periods ranging from Carboniferous to Tertiary. Prior to 1915 these determinations were little more than guesses based on insecure lithologic correlations.

D'Orbigny (Translation p. 10) states that since he did not find any fossils in either series of rocks he is compelled from their general relationships to include them provisionally in the Carboniferous beds.

Forbes (pp. 37, 38) comments on the absence of satisfactory fossil evidence for determining the age of the strata, but believes the balance of evidence in favor of the Permian epoch. In this conclusion he is guided largely by their lithologic similarity to the Permian rocks of Russia. He was aware of the presence of plant remains but did not utilize them in his correlation. He says:

"Fossil plants are everywhere found in this formation; but generally they are very indistinct. In some places, as at Pontezuelo, large trunks of trees silicified are found in abundance."

Sections of two specimens of carbonized wood were too indistinct to permit of closer identification than that they were coniferous. The occurrence of carbonized fossil wood

in the Quimsa Cruz mine is mentioned (p. 47). The determination of the post-Pliocene *Macrauchenia boliviensis* by T. H. Huxley which was found in the Santa Rosa mine did not shake Forbes' faith in the Permian age of the Corocoro rocks for he remarks (p. 47) that it "appears only to be accounted for on the supposition that the animal had fallen into a fissure in these rocks."

Reck cites the presence of abundant plant impressions along the bedding planes and of petrified wood impregnated with copper and also of fossil bones that are petrified and the interiors of which are filled with native copper, but does not give determinations either of the forms or of their age. On the other hand, he says: (p. 95)

"I am indebted to the kindness of my friend Ph. Kröber, who lived a considerable time in Corocoro, for the opportunity of citing the occurrence in the metalliferous beds of *Terebratula elongata*, *Cyathocrinus ramosus*, and *Trotosaurus*, and the complete absence of fossils in the non-metalliferous beds."

The fossils indicate Rothliengendes or Zechstein, that is, Permian age. In view of our present knowledge of the Corocoro rocks it is certain that these forms did not come from them and that there is a mistake in the locality.

Nöggerath exhibited specimens from Corocoro showing flattened plant stems impregnated with metallic copper but made no use of them in his correlation of the rocks which, because they are lithologically similar to the Rothliengendes and the Buntsandstein and because they are copper-bearing, he considers certainly of Rothliengendes or Permian age.

Mossbach was doubtless merely following his predecessors in considering the Corocoro strata of Rothliengendes age. To the west, along the banks of the Desaguadero River, he says they are overlain by Triassic Buntsandstein beds. He mentions the occurrence of native copper replacing conifer wood in the Ramos and Vetas. (p. 96)

L. Sundt recognized the lack of scientific basis for the earlier correlations of the Corocoro rocks and arrived at more nearly correct conclusions though by a rather pre-

curious line of reasoning. He believed that the Ramos lie on top of the Vetas and surround them to the south and east and hence represent a younger series. He was the first to call attention to the trachytic material contained in the rocks and used it as a basis for arriving at their age. Trachytes, he says, have always been considered Tertiary in age and never older. Hence the rocks which include the trachytic fragments must be not older than Tertiary or there must be older than Tertiary trachytes. In support of the latter he cites examples of Cretaceous trachytes in Chili and Argentina. Consequently he concludes that the Vetas are either Cretaceous or Tertiary. Because of the thickness of the Vetas and because of their uplift, folding, and depression before the deposition of the Ramos, he considered the latter definitely Tertiary. He believed that the *Macrauchenia* skeleton was found in place, but doubted Huxley's post-Pliocene determination.

Dereims says he nowhere encountered fossils which permitted a scientific determination of the age of the Corocoro rocks, but he assigns them to the Permian on the basis of their petrologic facies and because he believed them to lie immediately above the Carboniferous. Their red color and cupriferous character are to him worldwide Permian characteristics.

Steinmann also fell into error through correlation on the basis of lithology. He mentions no fossils and says he was unable to substantiate the occurrence of carbonized conifer wood described by Forbes and others. He was aware of the fact that red sandstones were deposited in Bolivia at various periods from Silurian to Quaternary. The thickest and most widespread series of these, he says, are his Puca sandstone which he divides into three members. The lowermost member consists of sandstone; in the middle member red clays prevail, frequently associated with gypsum and often rock salt, and locally with limestones near the base; and the upper member is, like the lower, prevailing sandstone. Steinmann records Cretaceous fossils from the lime-

stones at Miraflores, a locality in the eastern Andes, 365 km. southeast of Corocoro. The authors likewise collected Cretaceous forms from these limestones at Miraflores and at other localities between Miraflores and Potosi and can substantiate Steinmann on this point. Both his description and age determinations of the Puca sandstone apply to the red rocks of the eastern range of the Bolivian Andes, but they do not apply to the Corocoro rocks. He states further that at the end of the Pliocene and in Quaternary thin red sandstones were again deposited as continental deposits out of the Puca sandstone and hence are similar to it in composition and color. And since the period of the close of the Tertiary and the Quaternary is that of the injection of granodiorites and flow of trachytic-dacitic rocks these younger red sandstones contain fragments, tuffs, and flows of the younger eruptives. This answers the description of the Corocoro rocks better than does that of the Puca sandstone and corresponds more nearly with their true age. The Corocoro rocks are not the equivalent of the Puca sandstone of the eastern Andes lithologically and are not of the same age.

Douglas (p. 28) because of the wide Cretaceous transgression over the older rocks which he observed in Peru where similar beds of red sandstone are occasionally interbedded with limestone, concluded that the red sandstone series of Bolivia might be regarded as a shallow-water facies of the fossiliferous Cretaceous limestones of the Peruvian sierras.

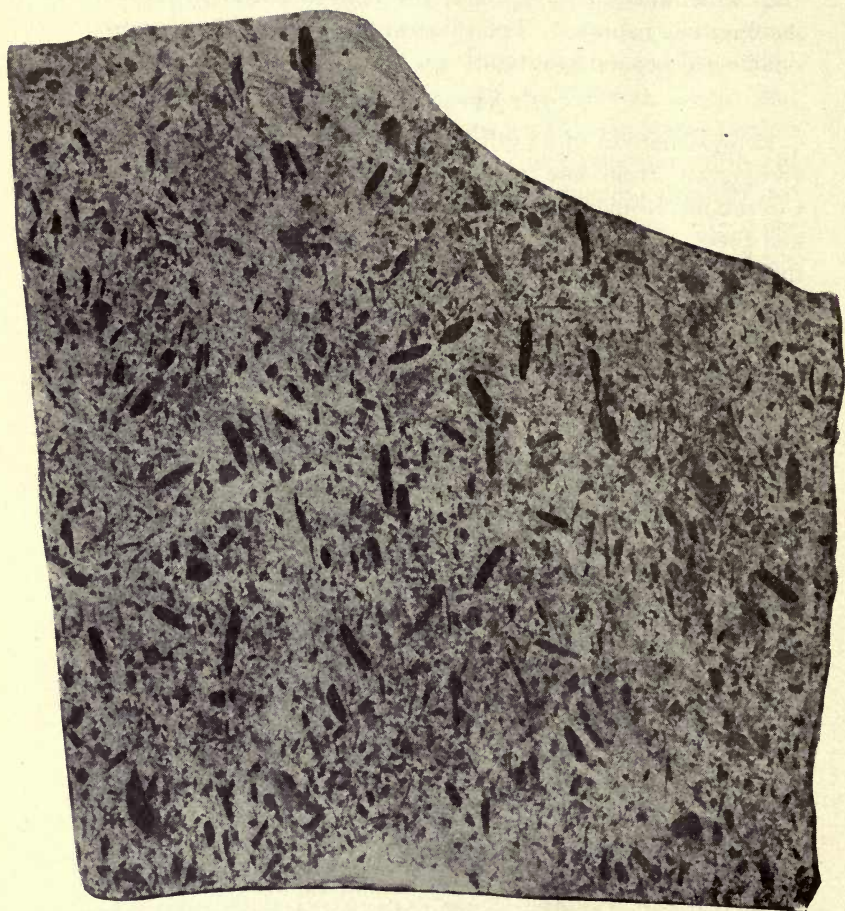
Singewald and Miller describe the occurrence of a ledge of plant-bearing sandstone in a gulch northwest of the city that was called to their attention by Mr. Fernando Dorion and from which they secured a collection of plants that were determined by Berry as Pliocene. As the locality is in the Vetas not far from the Corocoro fault, this flora fixes definitely the age of the Vetas.

In 1919 the authors examined the Corocoro rocks with some care for additional paleontologic evidence and found that the fossil plants occur at a number of horizons in the

Vetas and at many localities from the city of Corocoro north to the Pontezuelo River so that much larger collections were secured. Whereas the collection made by Singewald and Miller included 7 species, the new localities increased the flora to 23 species. The Pliocene age of the Vetas is now established beyond question.

THE VETAS FLORA

Representatives of 23 different species of plants have been recognized from the plant-bearing layers of the Vetas. Collections from the different horizons were kept separate and these demonstrate that there was no change in the flora during the interval of sedimentation, thus confirming the *a priori* conclusion that the rate of accumulation of the sediments was rapid and that the relatively great thickness of this and the overlying Ramos and Desaguadero series does not represent nearly as long an interval of time as comparable thicknesses of normal marine sediments would indicate. Among these 23 plants some are determined much more satisfactorily than others. Thus the *Carpolithus* may represent one of several genera of plants with drupaceous fruits; the *Rubiacites* one of several existing genera of the family *Rubiaceæ*; the reed which is not determined, even generically, is unmistakably monocotyledonous. The *Terminalia* is determined beyond any doubt, as are also the *Osteomeles*, *Polystichum*, *Ruprechtia*, *Dodonaea*, and most of the *Leguminosæ*, although there may be some duplication among the latter due to the variation and convergence among the leaflets of this alliance. Taking them as they stand and bearing in mind that nearly every form is represented by abundant and better preserved material from the finer grained Potosi tuffs, it may be noted that they represent a single fern, a single Gymnosperm, a single monocotyledon, and 20 dicotyledons. The last represent 19 genera, 10 families and 6 orders. By far the most abundant of these is the order *Rosales* with one member of the *Rosaceæ*, 5 of the *Mimosaceæ*, and 4 each of the *Cæsalpiniaceæ* and *Papilionaceæ*. The last three, or leguminous families, thus



Tuffaceous shale showing abundance of plant material
(*Calliandra obliqua* Engelh.)

constitute 13 of the 20 known dicotyledonous species, and they are also the most abundant individually, whole surfaces of the bedding planes being frequently covered with the leaflets of *Calliandra*.

Nineteen of the species recorded from Corocoro are represented in the Potosi tuffs and the two deposits are hence regarded as the same age. Since the Potosi flora is much more extensive than that found in the coarser matrix at Corocoro the conclusive evidence of the Pliocene age of the latter rests partially on the more complete analysis of the Potosi flora, which was given as fully as the evidence in hand permitted in 1917 and which has been much augmented in the field studies and from a study of the collections made by the authors around Potosi in 1919. This evidence will appear in connection with the authors' report on the Potosi district and need not be repeated in the present connection. Taken by itself the Corocoro flora offers intrinsic evidence of its late Tertiary age. Thus all of the plants, so far as they can be accurately determined, are of still existing genera which still survive at lower levels east of the Andes where they are represented by closely allied species. Most of them are arborescent forms that could not exist in the present-day altitude and semi-aridity of Corocoro. There are 5 fossil forms found at Corocoro whose modern representatives sometimes reach high altitudes, namely, *Polystichum*, *Podocarpus*, *Osteomeles*, *Amicia*, and *Vaccinium*. These reach variable elevations, greatest perhaps in the case of the *Osteomeles*, but they are overwhelmingly offset by the presence of such warm low-altitude types as *Terminalia*, *Copaifera*, *Dalbergia*, *Machærium*, *Enterolobium*, *Calliandra*, etc., and by the many additional types associated with these forms in the Potosi tuffs.

There is no doubt but that the Corocoro flora indicates a much lower altitude and a greater rainfall at the time it flourished, than obtains at the present time at Corocoro. This also has a bearing on the tectonic history of the mountain masses that bound the high plateau on the east

and west, but a consideration of this aspect is reserved until it can be discussed in the light of the geology and floras of the various localities in Bolivia where the authors made field observations and collections. The maximum altitude at which the fossil flora at Corocoro could exist is placed at about 6500 feet. The accompanying table will furnish such additional information as is pertinent to the present discussion.

Fossil species.	Corocoro.	Potosí.	Most closely related existing species.	Range.
<i>Polystichum bolivianum</i>	×	×	<i>Polystichum triangulum</i> (Linnæus) Fée.....	West Indies.
<i>Podocarpus fossilis</i>	×	×	<i>Podocarpus lamberti</i> Klotz.. <i>P. oleifolius</i> Descaïne.....	Brazil. Montaña, Peru and Bolivia.
<i>Ruprechtia braunii</i>	×	×	<i>Ruprechtia laurifolia</i> Mart..	Brazil.
<i>Osteomeles pliocenica</i>	×	×	<i>Osteomeles cuneata</i> (Lindl.)	Peruvian Andes.
<i>Acacia uninervifolia</i>	×	×	<i>Acacia paradoxa</i> D. C.	Amazon basin.
<i>Mimosa arcuatifolia</i>	×	×	{ <i>Mimosa invisa</i> Mart. <i>M. lupulina</i> Bentham....	Central America to Brazil. Brazil.
<i>Mimosites engelhardti</i>	×	×	<i>Mimosa</i> spp.	Bolivian Yungas.
<i>Calliandra obliqua</i>	×	×	<i>Calliandra macrocephala</i> Bentham	Brazil.
<i>Enterolobium grandifolium</i>	×	×	<i>Enterolobium timbouva</i> Mart.	Antilles to Eastern Bolivia.
<i>Cassia singewaldi</i>	×	×	<i>Cassia</i> spp.	Bolivian Yungas.
<i>Cassia ligustrinaformis</i>	×	×	<i>Cassia ligustrina</i> L.....	Amazon basin.
<i>Copaifera corocoriana</i>	×	×	<i>Copaifera</i> spp.	Amazon basin. (Bolivian Yungas).
<i>Peltophorum membranaceum</i>	×	×	<i>Peltophorum vogelianum</i> Bentham	Brazil.
<i>Amicia antiqua</i>	×	×	<i>Amicia lobbiana</i> Bentham...	Andean, Bolivia.
<i>Machaerium eriocarpoides</i> .	×	×	<i>Machaerium eriocarpum</i> Bentham	Eastern Bolivia and Brazil.
<i>Dalbergia antiqua</i>	×	×	<i>Dalbergia riparia</i> Bentham..	Amazon basin.
<i>Drepanocarpus franckei</i> ...	×	×	<i>Drepanocarpus lunatus</i> Meyer	Central America to Brazil.
<i>Dodonaea viscosaformis</i>	×	×	<i>Dodonaea viscosa</i> Linné....	All tropics, Bermuda to Eastern Bolivia
<i>Terminalia singewaldi</i>	×		<i>Terminalia</i> spp.	Tropical South America.
<i>Vaccinium ponzuelum</i>	×		<i>Vaccinium</i> spp.	Eastern Andean and Montaña.
<i>Rubiacites nummularioides</i> .	×	×	Rubiaceae	Montaña.
<i>Carpolithus baulti</i>	×			
Reed (not determinable)..	×			

PALEONTOLOGIC EVIDENCE OF THE AGE OF THE RAMOS

Careful examination of the measured section of the Ramos and of many other localities in those beds failed to yield any organic remains so that we are dependant on previous work for evidence concerning the age of these rocks.

Indefinite as to locality and uncertain as to identification is the statement by Forbes (p. 38) that he "was informed that a complete Saurian head had been extracted from the same beds by M. Ramon Due, but was not successful in obtaining it nor some fossil bones and teeth now in the museum of Avignon, in France, sent there by M. Grainier, of La Paz."

Whether the petrified bones, mentioned by Reck, came from the Ramos or not is unknown, but as he supplies no further information concerning them they are of no assistance in the problem at hand.

Mr. José Sossi, formerly owner of the Libertad mine, said that in 1910 he encountered at a depth of 360 feet in that mine a skeleton that he sent to the Dauelsberg Gesellschaft in Hamburg to be sold. Nothing more is known about it.

The Ramos shales often show mud-cracked surfaces and at certain horizons contain an abundance of cylindrical, imbricatedly - marked casts of what are apparently the burrows of some organism. One of these is figured on plate 5. Similar mud-cracked surfaces and burrow-like casts also occur in the Desaguadero series, notably at the small quarry along the railroad which furnished the Edentata footprint, thus serving to indicate the same general age of the two series of deposits.

The only direct paleontologic evidence of the age of the Ramos series is that furnished by the skeleton of *Macrauchenia boliviensis* described by Huxley. This was encountered during operations in the Santa Rosa mine in 1859, a long distance below the surface and in a normal consolidated matrix. The Haversian canals of the bones were for the

most part filled with threads of native copper and there is not the slightest doubt but that the remains were found in place in the Ramos beds, although Forbes, with his preconceived notion that these beds were of Permian age, is obliged to predicate that the *Macrauchenia* fell into a deep fissure which subsequently became thoroughly consolidated (p. 47.)

The genus *Macrauchenia* was formerly thought to represent an ancestral *Auchenia* type, but later studies, particularly of the rich Tertiary faunas of Argentina have demonstrated that it represents the last stage of evolution of the wholly extinct and exclusively South American mammalian order *Litopterna*. This genus, which is confined to the Pliocene and Pleistocene, spread in late Tertiary times from the Argentine plains over much of the Andean region. Closely related species are recorded from Tarija in southern Bolivia and from Ulloma on the Desaguadero River, 35 km. south of Corocoro, the latter occurrence in beds that are probably the same age as the Desaguadero series at Corocoro. The Tarija beds are considered by Scott as Upper Pliocene in age and correlated with the similar beds in the Argentine province of Catamarca which are involved in the Andean movements.

The paleontologic evidence of the age of the Ramos series, thus furnishes the strongest sort of evidence that these beds are of late Pliocene or Pleistocene age.

STRATIGRAPHIC RELATIONS OF VETAS AND RAMOS

The Ramos formation has generally been considered younger than the Vetás. But this interpretation has been either a mere guess or based on an erroneous conception of the geology of the district, and hence has not been supported by facts.

The meager paleontologic evidence indicates that the Vetás are Pliocene and the Ramos either Pliocene or Pleistocene. The former determination rests on floral evidence, the latter on a vertebrate form, hence no sharp comparison can be made as to relative age. That the Ramos are younger

than the Vetas is a more probable assumption than the reverse. Farther than this the paleontologic evidence does not carry us.

The relations between the two formations could be determined, therefore, with certainty only on structural grounds, but here again difficulties are encountered.

Forbes gives a cross-section and a ground-plan diagram (p. 41) to illustrate his conception of the relations of the Vetas and Ramos. According to his cross-section both series represent approximately the same horizon, being separated by a vertical fault plane with the downthrow on the Vetas side. The incorrectness of this stratigraphic interpretation is demonstrated by the descriptions of the measured sections. Although the cross-section shows the Vetas on the downthrow side of the fault, Forbes says the dip of the Ramos decreases rapidly from 80° at the fault plane to 30° a short distance away from it, "showing that a sort of bend or curve had taken place in the beds on settling down or coming to rest after the dislocation." This evidence would make a downthrow on the Ramos side the more probable. The ground plan shows the Vetas parallel to the strike of the fault and the Ramos diverging from the fault at a small angle but shows the divergence toward the south instead of toward the north. The latter is doubtless an inadvertent error for in the text he gives the strike of the Vetas ranging from N. 35° to 45° W. and the Ramos from N. 20° to 35° W.

Mossbach describes the edges of the Ramos upturned along the fault plane and believes the Vetas were pushed over the Ramos. The Vetas are considered the older and more consolidated beds and the Ramos the overlying and less consolidated beds of the same series of strata.

Sundt believed the Vetas an older series of rocks than the Ramos, because, as he says, the Ramos rest on top of the Vetas and surround them to the southeast, south, and west. These are the relations of the Desaguadero series which is described farther on to the Vetas and he has seemingly confused it with the Ramos.

Steinmann makes the Vetas equivalent to the lower member of his Puca sandstone and the Ramos to the middle member, and consequently the Ramos younger than the Vetas and on the downthrow side of the fault. The fault itself he considers an overthrust of the Vetas on the Ramos with a very steep westerly dip and to disappear to the south by passing over into a normal anticline. Since the Corocoro rocks are not his Puca sandstone, his conclusions are invalid.

Singewald and Miller state that the strike of the Vetas and the strike of the fault are the same, about N. 30° W., and that the dip of the fault is a little steeper to the west than that of the Vetas. The strike of the Ramos is a little more northerly than that of the fault and as they dip easterly, successively lower beds come to the surface northward along the fault plane. The Ramos have an upward drag close to the fault plane which steepens their dip in its proximity and indicates a downthrow on their side, or a reverse fault.

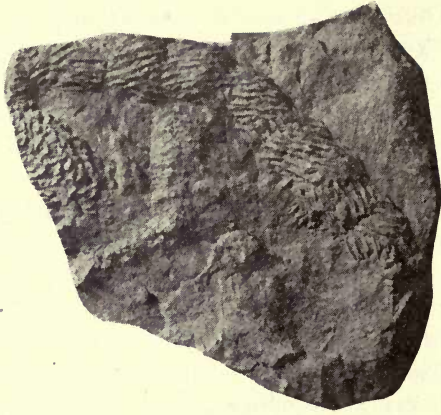
Lincoln says the Corocoro district consists of a faulted anticline with northerly strike and with the beds dipping away from the fault in both directions. The strike of the Vetas is nearly parallel to that of the fault, but the Ramos diverge from the fault going northward exposing successively younger beds. He thinks the two series of rocks are the severed portions of the same group of copper-bearing sandstones. The measured sections demonstrate the error of the last conclusion.

The Corocoro fault is first encountered on the surface west of the Santa Rosa shaft on the lower slope of Corocoro mountain above the town of Corocoro. Underground in the Cerro Corocoro it can be followed in the workings of the Remedios, Guallatiri Grande, and Challcoma mines, a distance of 1 km. to the south, that is, to the southern limit of the mine workings. It is covered at the surface over this stretch by the Desaguadero series. Northward from the Santa Rosa shaft the fault can be easily followed on the surface along the lower slope of the ridge paralleling the

Corocoro valley on its west side for a distance of $3\frac{1}{2}$ km. It is then covered by wash for over 2 km. to the Pontezuelo River, on the north banks of which it is again plainly discernible. The direction of the fault from Corocoro to the Pontezuelo River is N. 20° W. It continues in the same direction to the Carmen mine, on the Pizakeri River, 5 km. beyond the Pontezuelo River and 1 mile northwest of Ballivian on the Arica and La Paz Railway, and was traced 5 km. farther north to the Grau and Progreso claims.

That the strike of the Vetas is parallel to that of the fault is shown by the areal mapping of two of the principal ore beds, the Veta Yanabarra and the Veta Umacoaya, whose outcrops parallel that of the fault. On the other hand the divergence of the Ramos toward the north and the emergence of successively lower beds in that direction is shown by the mapping of several prominent ledges of the Ramos in the Corocoro valley. Between Corocoro and the Libertad mine, a distance of not quite 3 km., 406 m. of Ramos beds have come to the surface in that way. The Vetas and Ramos show considerable local variations of dip but the average dip of the Vetas is between 55° and 60° and the Ramos between 45° and 50° .

Three excellent exposures of the fault are at the north and south boundaries of the Vetillas claim, 2 km. north of Corocoro, and in the washout made by a branch of the Corocoro River near the middle point of the west boundary of the Quilinquilis claim, 3 km. north of Corocoro. At the south boundary of the Vetillas claim the fault plane has a dip of 73° W. The Vetas steepen as they approach it until they are parallel to it. The Ramos abut against the fault with unchanged dip of 47° . In a ravine on the north boundary, the fault plane shows a dip of 72° W. and the Vetas steepen to parallelism with it as they approach it. The Ramos have a dip of 47° which is unaffected by proximity to the fault plane. On the Quilinquilis claim the Vetas also steepen to 75° W. at the fault plane but the Ramos retain a dip of 49° . Immediately north of Corocoro for a distance of one-half a kilometer the Ramos are steeper, with dips



Trails and mudcracks in the Desaguadero shales.

as high as 85° and the Vetas are flatter along the fault plane, but the exposures here are not so good as those farther north. In the mines the fault plane shows a very steep westerly to vertical dip.

The observations prove beyond question that the fault plane has a steep westerly dip greater than the normal dip of the Vetas. With respect to the direction of movement along the fault plane the evidence is not unequivocal, some exposures indicating that the Vetas have been pushed over the Ramos, others that the Vetas have slipped down over the Ramos. Hence the structural evidence along the fault does not permit of a definite conclusion with respect to the relative stratigraphic position and age of the two series of rocks.

The fault plane is the only line of contact between the Vetas and Ramos in the area investigated. Hence there are no other structural features that might aid in solving the problem, and we are brought back to the paleontologic evidence that both series are of nearly the same age with the probability that the Ramos are the younger.

THE DESAGUADERO SERIES

Capping the Cerro Corocoro and extending to the south and southwest in the direction of Tarejra is a third series of rocks. They seem to continue far to the west, to the Desaguadero River and beyond, and for that reason we are calling them the Desaguadero Series. They differ from the Vetas series in nearly lacking the coarse clastic materials which are so prominent in the latter and in the absence of the gray sandstones and conglomerates. They differ from the Ramos in the absence of gypsum beds and stringers. They differ from both the Ramos and Vetas in the lack of the copper mineralization of those rocks. They are like the Ramos in the dominance of the red-colored beds and the fine-grained character of the sandstones and for that reason doubtless had previously been assumed to represent that series.

Except for the absence of gypsum, these rocks are strikingly similar to the Ramos. That they represent a younger series of rocks unconformably overlying the two older series, is clearly shown by the relations in the Cerro Corocoro. There are considerable variations in strike and dip from place to place, but the series has a prevailingly easterly or southerly dip on the Cerro Corocoro. The outcrop of a prominent sandstone horizon shown on the geologic map has a trend across the strike of the fault and the Vetás and Ramos. The latter geologic features have been followed in the mine workings nearly 1 km. south of the point on the north side of Cerro Corocoro where they are covered up by this overlying series. There is no mineralization at the surface above the Guallatiri Grande tunnel nor at the Challcoma shaft, yet in depth the fault, the Vetás, and the Ramos are encountered. The Desaguadero series is younger than either of the other series, it is subsequent to the Corocoro fault, and subsequent to the mineralization.

On Cerro Corocoro the Desaguadero series lies unconformably over the Vetás, but to the southwest, the two series are separated by a fault. Along the fault line the Vetás beds are distorted and often dragged to the extent of reversing their normal position to an easterly dip. As the fault reaches the flanks of Cerro Corocoro, east of the main trail at the southwest edge of the city, the outcrops become obscure and it can not be followed farther. It seems to die out before reaching the Corocoro fault for there is no evidence of it in the Remedios mine. The fault is a break along which the Desaguadero beds moved down with respect to the Vetás, and is probably a reverse fault that accompanied the folding and tilting subsequent to the deposition of the former series.

AGE OF THE DESAGUADERO SERIES

The rocks of the Desaguadero series failed to yield any organic remains, although they were carefully examined on Cerro Corocoro, along the railroad between Corocoro and

Tarejra, and at other points in the vicinity. In 1915, Mr. Fernando Dorion, general manager of the Corocoro Copper Mines, Ltd., gave Singewald and Miller a plaster cast of a fossil footprint found in a small quarry along the railroad about 3 km. southwest of Corocoro. The stratigraphic relations of the beds at this locality to the Vetas and Ramos were then unknown. The plaster cast was examined by Professor Richard S. Lull who thought it represented the foot print of a form closely related to *Cheirotherium* and hence of Triassic age. In 1919, Mr. Dorion gave the authors the original specimen. A further examination of it leads to the conclusion that it probably represents an Edentate or sloth, possibly related to some such form as *Priodontes*, but as yet of undetermined affinities. It cannot be older than Pliocene and may be Pleistocene in age. This determination is thoroughly in harmony with the stratigraphic position of the series as determined by its structural relations.

The Desaguadero series is, therefore, younger than the Vetas and Ramos and of Pliocene or Pleistocene age.

The Desaguadero series is believed to correspond in a general way with what Pompeckj (1905) called the Puna beds. The source of materials was largely from the older Ramos rocks in the immediate vicinity augmented by volcanic materials from the Western Range. It seems probable that the Desaguadero series was at least partially synchronous with much of the surficial deposits that mantle the high plateau and through which the La Paz River has cut back its valley. The mammal-bearing beds at Ulloma to the south and the plant-bearing tuffs at Jancocata to the north, we regard as of this age, although there is no direct evidence for this conclusion. What appears to be the continuation of the Desaguadero series west of Corocoro antedates the stream terraces along the Pontezuelo and Desaguadero rivers.

The borings and sun cracks in the rocks of this series would suggest a seasonal rainfall. The conclusion to be derived from the mammal fauna at Ulloma and the flora at



Edentate footprint from the Desaguadero series.

Jancocata are best reserved for separate accounts of those localities, since the above mentioned correlation of them with the Desaguadero series is only conjectural.

IGNEOUS ROCKS

No igneous rocks outcrop within the Corocoro district. The participation of fragments of igneous rocks in the composition of the Vetas is described in a preceding section and also the occurrence of coarse clastic beds at the base of the Vetas exposed at the Carmen mine north of Corocoro made up of igneous material. Hence at the time the lowest outcropping horizons of the Vetas were being laid down the region had already been the seat of igneous intrusions and volcanic outbursts.

The nearest outcrops of igneous rocks are on Cerro Chukapaca, 15 km. west of Corocoro, and on the Cerro de Comanche at Mirikiri, 20 km. to the north.

A specimen of the Chukapaca rock obtained at Corocoro is a rhyolite porphyry. It has a light gray, dense porcelain-like groundmass with phenocrysts of sanidine, orthoclase, and quartz averaging from 2 to 3 mm. in diameter and with a maximum of about 6 mm. The rock also contains minute phenocrysts of biotite. At one end of the specimen are veinlets of micaceous specular hematite.

The Mirikiri rock is much more coarsely crystalline than that of Chukapaca. It consists of over 50 per cent of feldspar phenocrysts, 10 per cent of hornblende phenocrysts, and less than 40 per cent groundmass. Its color is medium gray. The groundmass is made up chiefly of feldspar grains ranging from .03 to .1 mm. in diameter. The feldspar phenocrysts are from $\frac{1}{2}$ to 3 mm. in length and characterized by very pronounced zonal growths. Their composition is between that of oligoclase and andesine. Some of the hornblende phenocrysts are larger than $2 \times \frac{1}{2}$ mm. in cross-section, but most of them lie between $.45 \times .15$ mm. and $3 \times .1$ mm. Some facies of the rock are more porphyritic

than others. The groundmass in some facies is almost granitic, but is more generally microgranitic. The most appropriate name for the rock would seem to be hornblende diorite porphyry, although by some it has been called a diorite.

Following is Douglas' description (p. 29) of the Mirikiri or Comanche rock, which he calls a diorite:

"Macroscopic Characters: A pale-gray holocrystalline rock of even-grained medium texture, composed of white plagioclase and dark green hornblende, the latter frequently segregated into more basic patches. No quartz visible. It often contains abundant micaceous hematite, especially developed along the joint faces.

"Microscopic Characters: Holocrystalline, hypidiomorphic structure. Plagioclase, chiefly andesine and acid labradorite, showing Carlsbad and polysynthetic twining and well-marked zonary structure. The feldspar is mostly fresh, but exhibits some alteration to sericite—beginning usually at the centre of the crystals. Green hornblende occurs in small well-defined crystals, with idiomorphic contours. Ilmenite altering to sphene, and a little apatite, epidote, and chlorite also are present."

Orrego * describes the Comanche rock as intrusive in the sediments, into which it has sent numerous apophyses which have produced slight metamorphism along their contacts. He calls the rock a diorite of pale-gray color, holocrystalline, made up of andesine and probably labradorite, black hornblende and lacking in quartz, and with an abundance of micaceous hematite occurring especially along joints.

Steinmann (p. 367) says that Stelzner called the rock a fresh holocrystalline, hornblende andesite, but that a specimen which he secured is fully crystalline, though markedly miarolitic, and hence he regards it as a rock intermediate between diorite and andesite.

Forbes (p. 29) preferred the term diorite to andesite. He says there are two belts of dioritic rocks extending through the Andes in a nearly north-south line marked by discon-

* Alfredo Escuti Orrego: Observaciones Geológicas siguiendo el trazado del Ferrocarril de Arica a La Paz. Boletín de la Sociedad Geográfica de Lima, vol. 34, 1918, p. 82.

tinuous series of outcrops which extend from Peru to Puerto Montt in southern Chile. The eastern belt enters south central Bolivia from the desert of Atacama, shows itself at the Cerro de las Esmeraldas south of Corocoro, at the hill of Comanche to the north of that place, and at the south end of Lake Titicaca near Tiahuanaco. The rock at Comanche he describes as intrusive in the red sandstone.

Steinmann (pp. 362-367) considers the line of dioritic intrusions which includes Comanche genetically related to the porphyries of the eastern range of the Bolivian Andes, and places the age of all as approximately the same as that of the Potosi plant-bearing tuffs which are now definitely determined as Pliocene* though regarded by Steinmann as Miocene or early Pliocene.

The inclusion of fragments of rock identical in character with the Mirikiri rock and various varieties of fresh volcanic rocks in the Vetas series proves that igneous activity had commenced in the region prior to the deposition of the oldest exposed Corocoro sedimentaries and that in part at least the fragments were derived from rocks originating from the same magma as the Mirikiri rock. On the other hand, the Mirikiri rock is regarded as intrusive into the red rocks of the Corocoro region. Hence the general period of igneous activity is more or less coincident with that of the deposition of these rocks, although it may have had its inception prior to the beginning of the sedimentation. This conclusion is in harmony with Steinmann's correlation of the igneous activity of the Corocoro region with that of the eastern Andes, that is, in late Tertiary time.

RESUMÉ OF GEOLOGIC HISTORY

The latest general submergence of this region was in Upper Cretaceous time as is shown by the presence of

* Edward W. Berry: Fossil Plants from Bolivia and their bearing upon the age of the uplift of the Eastern Andes. Proc. U. S. Nat. Museum, Vol. 54, 1917, pp. 103-164.

marine fossiliferous rocks of this age in both the Eastern and Western ranges that bound the high plateau of Bolivia and on the latter near Lake Titicaca. Throughout the Tertiary progressive folding went on accompanied by moderate uplift. This is shown by the mature slopes of both the Eastern and Western ranges in the erosion cycle preceding the present. This elevation was not sufficient to bring any part of the region to the snow line nor to interfere with the trade wind circulation. Subsequent elevation brought about the semiaridity of the present high plateau and the desert along the Pacific coast. It is believed that at the time the flora found in the Vetás series lived the altitude of the region could not have been above 6500 feet, and it was probably not as high as this. Hence the country was over a mile nearer sea level than is the present surface of the Bolivian plateau. Toward the close of the Tertiary the region of the plateau was progressively depressed. The nature of this subsidence can only be conjectured. Whether it was of the nature of a geosyncline, or an enormous rift or graben, or was due to block faulting, or to differential warping along a region of major faulting is unknown. Bowman has advanced the theory that it was of the nature of a graben, but there is no direct proof.

During Pliocene time the Corocoro district was the scene of rapid accumulation of Continental sediments derived from the rising mountain mass to the west. Coincident with the inception of sedimentation were igneous intrusions and volcanic outbursts that contributed their quota to the clastics. The igneous activity continued throughout the period of sedimentation. The deposition of the Vetás series with its evidence of an abundant flora was followed by the Ramos series with its barren mud-cracked and ripple-marked gypsiferous red beds, which might be interpreted as indicating that the Eastern Range had at that time been elevated sufficiently to have modified the climate west of the divide and brought about the partial extinction of the flora represented in the Vetás series. Following the deposition of the

Vetas and Ramos series there was a period of tilting and faulting with copper mineralization that at least spatially is closely related to the Corocoro fault. The great thickness of the Vetas and Ramos series as determined by the usual methods of measuring thicknesses is probably to be interpreted as slope deposition or alluviation, since it is certain that the determined thicknesses do not furnish a measure of subsidence, although it is conceivable that they might represent a measure of the differential movement, assuming that there was faulting along the boundary between the high plateau and the western Andes.

Subsequent to the mineralization from the solutions rising from the underlying dioritic magma, sedimentation was resumed and the Desaguadero series was deposited. Another period of tectonic disturbances resulted in the tilting, minor folding, and faulting of these beds. Since the deposition of the Vetas series the region has undergone a considerable uplift estimated as exceeding 6500 feet. All of this was accomplished subsequent to the close of the Miocene and the later stages may have extended into what was synchronous with the Pleistocene of the Northern Hemisphere although antedating the mountain glaciation of Bolivia.

THE ORE DEPOSITS

EARLIER DESCRIPTIONS

Corocoro is the most important deposit of a series of similar copper deposits that extend across the Bolivian high plateau from Lake Titicaca to the Chilean border and beyond into the province of Antofagasta as far as San Bartolo. The principal features of this mineralization have long been understood, but no detailed critical study of the ore occurrence such as might lead to a satisfactory interpretation of its mode of genesis has ever been made.

Baron C. A. de la Ribette said the Corocoro formation extends with indications of rich veins from Lake Titicaca to Turco, a distance of 60 leagues. The ores occur in beds

concordant with the stratification and as fine particles of metallic copper penetrating white sandstones. Neither the red sandstones nor the shales contain ore and as sandstones become red or argillaceous, they lose their richness. Twelve principal beds from $\frac{1}{3}$ to 3 m. wide, had been worked. Locally the copper ores grade over into silver ores. Where this takes place the white sandstones become red and shaly, the copper content diminishes, and the silver increases and exceeds the copper in amount. The metallic silver occurs in the same manner as the metallic copper except that salt is associated with it. There is no regularity in the position of the silver which is encountered at some places at 70 m. and at others at more shallow depths.

A fuller description of the ore deposits and of their structural relations is given by Forbes (pp. 40-47). He says the main object of exploitation is native copper which occurs as metallic grains or larger masses, disseminated irregularly in certain beds of sandstone, but west of the fault combinations of copper with oxygen, arsenic, etc., are also found. The metalliferous district is divided into two parts by the Corocoro fault. On the west side of the fault are three principal veins, called vetas. The main vein, nearest the fault, the Umacoya, was producing native copper disseminated irregularly through a coarse grit, in grains, irregular lumps, or plates, sometimes of very considerable size. Beyond it lay the Rejo vein, also called the Copacabana and Negra, which produced a very dark ore because of its richness in copper sulphides and arsenides as chalcocite and domeykite. Farthest from the fault was the Buen Pastor, an impregnation of a fine-grained sandstone not only by copper but also with native silver. This bed was being worked exclusively as an argentiferous exploration. On the east side of the fault the metalliferous beds are described as differing considerably from the vetas and as they are of much less thickness are called, in contrast, ramos. There were 5 workable ramos and 9 lesser ones. The ramos ore is in a finer state of aggegation than that from the vetas

which is explained by its occurrence in fine-grained sandstones instead of coarse and porous beds of grit and conglomerate. In both Vetas and Ramos the ore is seldom continuous for any great distance, but is scattered through the metalliferous sandstones in irregular patches of white or greenish color full of small grains of metallic copper which contrast strikingly with the red color of the rest of the bed. Forbes also mentions the occurrence of crystalline and beautiful dendritic forms of copper in sheets and plates in the planes of stratification of the sandstone, and of native copper pseudomorphs after aragonite in the Umacoya vein.

Reck says the Corocoro ore beds usually range from $\frac{1}{2}$ to 2 m. in thickness and that the copper occurrence is local and sporadic. The Umacoya was the principal vein and had a maximum thickness of 4 m. and average of 2 m. The ramos differed from the vetas in the finer grain of the impregnated sandstone and in the absence of native silver. Next in importance to the Umacoya was the Buen Pastor which near the surface carried oxidic, sulphidic and arsenical ores of copper and in depth native copper and native silver. The occurrence of the native silver was in small, rich, but irregularly distributed pockets. The silver production for some years prior to 1860 is given at 25 tons of native silver concentrate.

Forbes in 1866 gave a few additional notes in describing the occurrence of domeykite in the Buen Pastor mine. It occurred as irregular nodules imbedded in the sandstone along with metallic copper and minute grains of metallic silver. The nodules vary in size from that of a pea to 3 or 4 inches in diameter and are irregularly imbedded in a comparatively soft red sandstone which is bleached in their vicinity. The nodules are an intimate mixture of quartz grains and domeykite.

Mossbach describes 14 ramos and 4 vetas. The richest ores are found above 100 m. Above that level shoots or pockets of rich ore are more frequent; below that level they are less numerous and not as high grade. The ramos range

from 1 m. to 5 m. in width, averaging about 2-3 m. They carry native copper and its oxidation products, the oxides and carbonates of copper, near the outcrop. The first veta, the Copocabana, was the most important. It averaged 4 m. wide, but varied between 2 and 6 meters. The upper part usually consisted of dark sulphide ore, which in depth changed to native copper ore. It contained much charque associated with gypsum and in druses crystals of calcite in all stages of transformation to native copper. (This remark probably refers to the pseudomorphs of copper after aragonite.) The fourth veta, the Buen Pastor, is described more fully because of its silver content. The discovery of the silver ores of this veta caused considerable excitement, but numerous shafts and tunnels quickly proved the area of workable silver ore to be very restricted and included in the Buen Pastor mine. This was worked with reasonable success until the mine was abandoned and became flooded during the revolution of 1859. Below the narrow oxidized part of the veta, were copper sulphides, and still deeper native copper. The silver was first encountered at a depth of 20 m. and alternated with the copper in such a way that at some places the one metal predominated, at other points the other metal. For a depth of 60 m. there was eight times as much silver as copper; at still greater depths silver predominated but not in so great ratio. Rich ores contained 2400 ounces of silver per ton, and medium grade ores yielded on amalgamation 700 to 1200 ounces.

One of the interesting mineralogical phenomena at Corocoro are the hexagonal prisms of native copper pseudomorphic after aragonite which are encountered disseminated in the ramos. They are found in all stages of replacement from the pure aragonite to almost pure copper. Domeyko describes these crystals and the manner in which their transformation is affected quite fully. He says they are never completely changed to copper but that the densest do not exceed 5.8 sp. gr. and include cavities and small patches of unreplaced aragonite. In conclusion he adds a brief

description of the Corocoro ore deposits taken from Sotomayor. The vetas are mineralized sandstones which contain in addition to disseminated native copper, sub-sulphate, oxide, sulphide, and arsenide of copper. Locally native silver occurs instead of copper. The ramos are not so rich in copper and are more argillaceous. The richest vetas are those nearest the plane of contact of the Vetas and Ramos and the mines extend for 3 km. along that contact. A sketch shows the plane of contact parallel to the vetas and truncating the ramos beds, but he does not refer to it as a fault.

Denegri states that in 1888 silver ores were no longer being produced and that the principal vetas were the Umacoya, the San José, and San Marcos.

Lorenzo Sundt says the Corocoro ores are encountered on both sides of the fault plane, in the vetas and in the ramos. They are merely certain strata of these rocks impregnated with native copper, and very rarely native silver. The metals are accompanied by calcium sulphate, barium sulphate, and a little calcium carbonate, and in the vetas, but not in the ramos, by arsenides and sulpharsenides of copper. These substances constitute the cement of the sandstones and vary in size with that of the grains of sand and the interstices that separate them. The grains of copper are usually from pin-point to pin-head in size, but in coarse sandstones they are much larger. The barite sometimes forms nodules impregnated with native copper. Calcium sulphate often traverses the barite in thin fibrous veins and glistens in the sandstones. Native copper is encountered principally in the sandstone beds intercalated in the shales, but in the ramos series it is also found in the shales as slender sheets, in grains up to the size of hazel nuts, and in nodules impregnated with sulphides and carbonates. In the vetas native copper associated with barite fills fissures cutting the stratification perpendicularly and obliquely as thick sheets, called "charque," which attain to weights of 2-½ to 5 tons. The fractures, or at least the copper fillings, never extend beyond the cupriferous beds whose width varies

from a few centimeters to 3 to 4 meters. To a depth of a few meters the copper has been altered to the oxide, carbonate, and silicate. Otherwise there is no change in the ore in depth down to 380 meters, the lowest level reached in the mine.

Dereims adds little to the description of the deposits but says in a vertical interval of 350 m. in the Guallatiri mine he saw 13 workable beds of copper ore ranging from .8 to 15 m. wide.

Steinmann describes the cupriferous beds as occupying an area on both sides of the Corocoro fault with a width of 2 km. and a length of 3-4 km. Those in the vetas are chiefly thick beds of coarse sandstone and those in the ramos thinner beds of fine-grained sandstone and shales. Wherever the strata are metalliferous they are bleached, so that the irregular distribution and pockety character of the mineralization is strikingly apparent. For the most part ore deposition occurred as an impregnation of the mineralized beds with native copper but veinlets of native copper intersect the strata in all directions. In the sandstone the metal fills the interstices between the sand grains as a binder; and when they are widely spaced, the copper appears as a sponge-like mass enclosing countless sand grains. In the shales the copper is usually a fracture filling and occurs as sheets and plates in cross fractures or along bedding planes. The ores usually consist solely of native copper. In the upper levels of the vetas silver ores were also formerly worked associated with which were chalcocite, domeykite, and other sulphur and arsenic compounds. Barite is occasionally encountered and more rarely calcite intimately intergrown with native copper. Large crystals of bluish celestite Steinmann says occur as a primary mineral in druses in the red shales of the ramos, but are not related to the ore deposits. On the other hand, gypsum is a never failing companion of the copper. It especially occurs between the plates of charque and the inclosing sandstone.

The Corocoro deposits are briefly described in a paper

by Strauss that deals principally with mining conditions in the district. The vetas are said to be traceable continuously for over 5 km. but there are no ramos outcrops. Six mineralized layers of each kind have been exploited, the thicknesses of which vary from a few centimeters to 7 meters. Sheets and masses of copper, called charque, occur up to 600 pounds in weight, but the copper is found generally in minute grains, pellets, or granular masses of the native metal with which are associated other minerals as malachite, chrysocolla, azurite, domeykite, and chalcocite. Gypsum and salt are the principal gangue minerals. Silver minerals are rare. The vetas are conglomeratic and contain the copper in coarser particles; whereas the ramos are finer-grained and the copper occurs in them in smaller particles and masses.

F. A. Sundt gives the average grade of the native copper ores of the Compañía Corocoro de Bolivia at 4 per cent and of the Capilla mine, the richest in the district, at 7 per cent copper. The native copper veins he says also contain cuprite. Contrasted with these are the "yanabarras" veins, which at the surface have oxides and green sulphates of copper, but at a depth of a few meters consist of "the black sulphides without iron that correspond to chalcocite and are found in an arsenical gangue." Hand-sorted yanabarras ores carry 18 per cent or more copper and some of the veins with a width of 9 m. average 5 per cent copper. He gives no information concerning the relations of the yanabarras and the native copper ores.

With respect to their position, Singewald and Miller describe three types of ore bodies—the vetas, the ramos, and the dorado. The latter is the name applied to the mineralization in the Corocoro fault plane which is now practically worked out. Louis Gasqual, chief engineer of the Corocoro United Copper Mines Ltd., described the dorado as a shoot of rich ore that lay in the fault plane where it intersected the ramos ore beds. The vetas and ramos are mineralized beds in the shale-sandstone series;

and as the sandstone beds are more prominent and thicker in the former series, the vetas are believed to average thicker than the ramos. In both series, mineralization has occurred at a number of closely spaced horizons, but at only a few to form important orebodies. The thickness of the mineralized beds varies from a few inches up to as much as 10 or 12 feet. Active mining operations are centered about the Cerro Corocoro and the south end of the ridge on the west side of the Corocoro valley. Here the vetas outcrop, but the ramos are first encountered in depth. On account of the geologic structure along the fault plane, the zone of the ramos pitches upward toward the north and emerges to the surface in the northern part of the district in the vicinity of the Libertad mine. Wherever mineralized, the beds have lost their red color and are white or light-green. Residual patches of red rock are unmineralized and the impervious shales which enclose the cupriferous sandstones retain their red color. The bleached rock is, as a rule, soft and friable as though much of the cement that held together the sand grains had been removed. In the ramos the ore is entirely native copper, and occurs chiefly in the form of small particles disseminated through the sandstone. The ordinary rich ore is called "tacana;" if the particles of native metal are coarse, it receives the name "chafra." In very rich ore, the copper grains are knitted together and isolate the sand grains to such an extent as to make the ore soft, yet difficult to break on account of its toughness. Plates and arborescent forms of copper are abundant as fillings of joints, cracks, and openings along bedding planes. These are called charque. F. A. Sundt is cited as authority for the statement that the rock in the vicinity of charque is poorer than the average, suggesting that the copper had been deposited in that form in those places instead of having been disseminated in the bed. Gypsum, and less abundantly, barite and celestite occur as gangue minerals, but chiefly in association with charque. In the lower part of the vetas the mineral-

ization is described as identical in character with that of the ramos. But toward the surface the ore of the vetas is chiefly chalcocite with which are associated domeykite and other arsenic and sulphur compounds of copper in smaller quantity. Close to the surface these minerals have undergone oxidation and there is an abundance of green basic copper sulphate, considerable malachite and azurite, and also cuprite. The depth to which the sulphides extend varies in the different vetas, but is in the neighborhood of 100 to 150 m. Lower down only the native copper is found. The average grade of the native copper ore is $2\frac{1}{2}$ to 4 per cent and of hand-sorted sulphides 10 to 20 per cent.

All published descriptions of the Corocoro district agree in making the Corocoro fault the boundary between the Vetas and the Ramos. A different interpretation of their relations is held by Fernando Dorion, general manager, and Adrian Berton, chief engineer of the Corocoro United Copper Mines, Ltd., as set forth by Singewald and Miller. They believe that the vetas and ramos in the vicinity of Corocoro are the same beds and that both lie west of the Corocoro fault. A southward-pitching zone of disturbance has more or less dislocated the vetas and reversed their dip in depth. Because easterly-dipping beds in the vicinity of the Libertad mine on the east side of the fault were called ramos, the same name was applied to the easterly-dipping parts of the vetas. Subsequently it was erroneously concluded that both sets of easterly-dipping ore bodies are the same. The areal geology is against this view and there is no direct evidence in favor of it, so there is every reason to believe the generally accepted interpretation the correct one.

Lincoln ascribes a length of 11 miles to the Corocoro district, including thereby the Carmen and Grau properties on the north side of the railroad near Ballivian station, and a maximum width of about half a mile. Ore has been worked to a depth of 1600 feet. Near Corocoro the vetas

come to the surface and the ramos are found in depth; but a mile and a half north of the city the ramos also outcrop. The copper-bearing sandstones are closely spaced and separated by beds of shale. They vary in thickness from one inch to 25 feet, averaging 4 feet. The ore body in the fault plane, which is now worked out, Lincoln thinks may possibly have been drag from the vetas and ramos. This would make the Corocoro fault later than the mineralization, a conclusion with which we do not agree. The intensity of the mineralization varies in different ore-bearing beds and in different parts of the same bed and nowhere does the entire bed consist of ore. The copper-bearing beds are generally white in color and are always free of copper where they contain red patches. The white sandstone is more friable than the red, as a result of having been leached of its original cementing material and of having had this replaced in part only by ore. The principal ore mineral is copper. In the ramos this has been oxidized to an average depth of 100 feet to malachite, azurite, and chrysocolla. The vetas also contain native copper in depth but a zone averaging 300 feet deep from the surface contains chalcocite, which to an average depth of 50 feet has been oxidized chiefly to bronchantite. Other ore minerals of minor importance are cuprite, domeykite, native silver, and galena. The principal gangue mineral is gypsum. Small amounts of hematite, barite, and celestite are also found. Lincoln says a polished section of ore containing both native copper and chalcocite showed these minerals as a cementing material between the grains of sand, and intergrown in such a manner as to indicate contemporaneous deposition.

SUMMARY ACCOUNT OF THE ORE DEPOSITS

The principal mines of the Corocoro district have a longitudinal extent along the Corocoro fault of a little more than 4 km. from the Challcoma mine 1 km. south of the city to the Libertad mine 3 km. north of the city. With

the exception of the Libertad mine, the shaft of which is $\frac{1}{2}$ km. east of the fault, all of the mines are located close to the Corocoro fault.

Two prominent cupriferous horizons in the vetas, called the Yanabarra and the Umacoya, parallel the Corocoro fault and can be easily traced on the surface by their outcrop and lines of old workings to where overlapped by the Desaguadero series. In the mines other workable vetas are encountered. No equally prominent ramos cupriferous beds outcrop, although some of the beds outcropping between the Libertad mine and the fault plane are beds that underground yield workable ore.

Mineralization has taken place principally in beds of the Ramos series and the Vetas series close to the fault plane, but also to a limited extent in the fault plane itself. The characteristic manner of mineralization has been the impregnation of sandy beds by native copper. As until about six years ago no facilities were available for working sulphide ores such ores were disregarded and the extent of the sulphide mineralization not realized.

No observations are available to indicate clearly the relations between the sulphide ores and the native copper ores, other than the general statement that the sulphides occur in the vetas near the surface and in depth pass over into the native copper ores and that the ramos ores are all native copper ores. In the Gullatiri Grande mine a streak of sulphide ore is encountered on the third level which is about 200 m. below the surface. In the Remedios mine, the sulphide ores extend to 200 m. below the surface and are there replaced by native copper ores. The upper levels of the Vizcachani shaft yield sulphide ores, but the lower levels are in native copper ores. The Umacoya veta in the Vizcachani shaft carries native copper ore to above the fifth level, a depth of about 150 m., whereas the veta adjoining it in the hanging wall still contains the sulphide ores at this depth. The mines in the ridge north of Corocoro, the Estrella, Copacabana, Capilla, Malcocoya, and San Augustin

are producing sulphide ores, but the depths to which they extend are not known.

Ore deposition has taken place principally in arenaceous and pebbly beds and only in the ramos occasionally in shales. Typical native copper ore consists of nearly white to light-greenish sandstone irregularly mottled with specks of copper. A thin section of this ore is made up of rounded to subangular grains of quartz, and a little plagioclase feldspar, ranging from .15 to .60 mm. in diameter and averaging .3 mm. The matrix of these grains is feldspar, chlorite, and a little calcite. The native copper occurs chiefly as a replacement of the matrix, penetrating the boundaries of the quartz grains to a very limited extent, in grains and flakes varying from .1-.3 mm. in diameter and averaging .15 mm. In some places the copper is regularly distributed through the rock; in other places it occurs in small streaks and patches between which the sandstone is nearly barren. The barren places are sometimes thoroughly bleached but often they are more or less red in color. The alteration products of the native copper ores are cuprite, malachite, and azurite. The ores show wide local variations in richness. The run of mine ores usually range from 2.5 to 3.5 per cent copper. The ore from the Capilla mine averages 6 per cent and the San Augustin is said to have produced ore with 15 per cent copper.

Typical sulphide ore is more highly mineralized than the native copper ore, and the rock is more uniformly impregnated with chalcocite. A thin section of this ore shows that the quartz grains of the original sandstone have been little affected by the mineralizing solutions and ore deposition has taken place by the replacement of the matrix, a process which has proceeded much further than is usually the case in the native copper ores, even to the point of almost complete replacement of the matrix by chalcocite. The color of the sulphide ore unaffected by oxidation is a uniform, metallic-looking gray. Its average

tenor is 7 to 8 per cent copper. In the zone of oxidation it alters chiefly to the basic sulphate bronchantite, but also to malachite and azurite; and especially in fractures and along bedding planes, cuprite forms. Hand-sorted mixed oxidized and sulphide ores carry 18 to 25 per cent copper.

The charque, or sheets and arborescent forms of native copper, occurs in fractures, along bedding planes, and in the principal fault planes. The thickness of the sheets varies with the width of the fracture and according to whether gangue minerals are associated with the copper or not. In some cases the native metal occurs as a single sheet completely filling the opening; in other cases it is enclosed in gangue, or is intergrown with gangue. The commonest gangue mineral is gypsum, but celestite occurs in considerable quantity. Celestite also occurs in tabular crystals lining druses in which there has been no copper deposition.

No additional data can be given concerning the occurrence of silver ores, as such ores are no longer produced and silver is a very subordinate constituent of the copper ores now worked. The native copper concentrates, with a tenor of 85 per cent in copper, contain only 6 oz. ag; and the sulphide concentrates, with a tenor of 45 per cent in copper, contain only 3 oz. ag.

GENESIS OF THE COROCORO COPPER DEPOSITS

An epigenetic origin of the Corocoro deposits and a deep-seated source of the mineralizers was suggested by Baron C. A. de la Ribette. He considered the ore deposition to have taken place at the time of formation of the Andes, the elevation of which was accompanied by the emission of metallic vapors from the bosom of the earth, which elsewhere produced regular veins, but in this case penetrated the softer beds which they encountered.

The genesis of the Corocoro ores was considered more fully by Forbes. He regarded the copper content syn-

genetic, but its reduction to the metallic state he ascribed to sulphurous fumes emitted at the time of intrusion of the dioritic rocks. Forbes says the problem would have been easier if the deposits could have been shown to have had their cupriferous contents injected into them at the time of the dioritic intrusions as in the case of the copper veins of Bolivia, Peru, and Chile; but he believed the facts in hand point to the copper as originally present in the sedimentary beds, probably not as metallic copper, but in a state of combination, and subsequently reduced to the metallic state. What facts he alludes to he does not specify, and his own description of the occurrence is at variance with such an interpretation. He recognizes clearly that the copper content is confined to the bleached parts of the strata, and he ascribes the bleaching to the magmatic exhalations. Hence the more natural assumption would seem to be that they also introduced the metal. The discoloration of the mineralized rock he concluded was "caused by the evolution of sulphurous fumes, disengaged, and penetrating into the pores of the strata, at the time of the eruption of the dioritic rocks of Comanche and the Cerro de las Esmeraldas, situated respectively to the north and south of the metalliferous district of Corocoro;" and the protusion of these rocks through the Corocoro strata he thought caused the fault and the accompanying dislocations of the strata. More specifically he considered the ore bodies to have been calcareous sandstones impregnated with copper oxide or carbonate. The sulphurous fumes reduced the copper to the metallic form and were themselves thereby oxidized to sulphuric acid. The latter reacting with the calcium carbonate produced the gypsum which so commonly accompanies these deposits. But it might be added in comment on this suggestion that gypsum is not confined to the mineralized parts of the Corocoro rocks but is quite widespread and abundant in its occurrence beyond the limits of copper mineralization.

Mossbach thinks that the association of native copper

and gypsum can be explained by assuming a basin in which copper sulphate waters came in contact with calcium carbonate. The sulphuric acid attacked the carbonate and formed gypsum and the copper was precipitated as the metal. After the deposition of the first veta, silt carried in by a flood of new waters covered it and protected the copper from oxidation. A repetition of this process gave rise to the various ore beds, and the pressure of the accumulating sediments consolidated more and more the underlying and earliest formed beds of the series.

Sotomayor attributed the copper of the Corocoro deposits to the reduction of sulphate of copper, which probably represented solutions originating from the decomposition of the cupriferous iron sulphides so abundant in the metalliferous deposits of both chains of the Andes, by ferrous sulphate which in turn would decompose calcium carbonate and produce the gypsum and iron hydroxide which the metalliferous sandstones enclose. Aside from the improbability of the source of the copper sulphate, this explanation has the weakness that the iron hydroxide is least prominent where the mineralization has occurred; and the fact that it explains the deposition of gypsum is no asset for its validity because gypsum, as noted in a preceding paragraph, is in no wise restricted in its occurrence to the mineralized rocks.

Domeyko makes the somewhat fantastic suggestion that the discordant juxtaposition of the two systems of beds, composed of strata permeable to liquids and united to the two chains of the Andes, would seem to have formed an enormous battery. The sources of emission of electricity would be perhaps the two ranges which enclose metallic substances undergoing decomposition, and the electrodes would be the strata themselves, at the extremities of which the immense deposit of copper has been reduced.

Lorenzo Sundt discussed the genesis of these deposits at some length. He presents four arguments in support of their epigenetic origin. First, the sheets of copper filling fractures in the beds are naturally younger than the beds

themselves. Second, the aragonite twins, replaced in part by copper, must have formed subsequent to the deposition of the beds enclosing them or they would be water worn, and their replacement by copper came still later. Third, the copper occurs not only as a cement but also penetrating the grains and pebbles of the mineralized strata of whatever type of rock they may consist. Hence it was not deposited merely as a filling between the interstices of the constituent particles, but the solutions penetrated the rocks as a whole. Though not specifically stated, the inference from this evidence seems to be that the metal-depositing solutions were more active than ordinary bodies of water in which sediments are laid down, and represent subsequent mineralizing solutions. Fourth, the copper occurs in the Ramos and the Vetas and hence in rocks of different age. It is more natural to suppose one period of mineralization occurred subsequent to the deposition of the metalliferous beds.

Four other features which he regards as significant with respect to the mode of origin of the deposits are cited by Sundt. First, the copper is generally intimately associated with calcium sulphate and barite, and often so intricately as to predicate simultaneous formation. Second, the unmineralized sandstones are usually red in color, due to the presence of ferric oxide. Where they are mineralized they are bleached through the reduction of the ferric oxide. Third, the cupriferous beds usually contain more or less water characterized by high salinity through the presence of sulphates and chlorides of the alkalis and alkaline earths. Fourth, the position of the ore bodies on each side of the Corocoro fault would indicate some relation between the fault and the infiltration of the cupriferous solutions.

Supported by the above observations Sundt concludes that at some period subsequent to the deposition of the Ramos and Vetas series, possibly when the Corocoro fault was formed or possibly when the high plateau was uplifted, solutions of copper, chlorides, and sulphates impregnated

some of those beds, preferably the more permeable sandstones, and where they found conditions favorable deposited the copper. He next raises the question: "What were these favorable conditions?" His answer is quite unsatisfactory. He again calls attention to the replacement of calcium carbonate by native copper in the aragonite twins. The action of cupriferous sulphate solutions on calcium carbonate would explain the formation of calcium sulphate but not that of copper instead of copper carbonate. The latter is explained by assuming the calcium carbonate derived from marine shells. Then the putrefying organic matter contained by the shells would be available as a reducing agent to reduce the copper to the metallic state and the ferric iron of the strata to the ferrous state. The carbonate of iron that would be formed in this way being soluble in carbonated waters would be carried away leaving the mineralized sandstones bleached and colorless. We may suppose further, he says, that the reductive power of the organic materials had not been sufficient to reduce the ferric oxide until it had been aided by the carbonic acid liberated in the reduction of the copper. In this same paper Sundt comments on the "complete lack of fossils" in the Corocoro strata; he can hardly consistently advance a theory of ore deposition based on the presence of marine shells and putrefying organic matter within those beds.

A still fuller consideration of the genesis of the Corocoro ores has been presented by Steinmann. To him the epigenetic nature of the deposits is beyond question. The ores are not restricted to one or more definite horizons, nor are they restricted to any particular facies of the sediments. They frequently show a veinlike occurrence, and though this is not pronounced, their distribution in the beds is quite irregular. Accepting then an epigenetic origin, he ascribes the peculiarities of the occurrence to peculiar conditions accompanying ore deposition. These were in part inherent in the nature of the mineralizing solutions and in part inherent in the rocks which they invaded. In support of

the first conclusion he cites certain characteristics of the copper veins that are widely distributed along the west slope of the western Andes from central Chile to Peru. Most important is the small amount of the common gangue minerals which they contain, from which fact he concludes that the metalliferous solutions to which they owed their origin were relatively deficient in silica, alkali earths, etc. Except in the abundance of gypsum, the Corocoro deposits are analagous to the other Andean copper deposits in this respect. The occurrence of chalcocite, bornite, and domeykite in the Corocoro ores is another point of similarity between them and the West Coast copper deposits. On these grounds Steinmann refers the metalliferous solutions of this district back to the same source and considers them of the same general character as the other cupriferous mineralizing solutions of the Andes.

Why then, he asks, is the copper not united with sulphur and with arsenic as in the West Coast copper veins and why is it in the native state? That the copper was introduced as some salt or sulposalt will be conceded. Previous explanations have assumed that it entered as a carbonate or chloride, and hence a reducing agent had to be postulated to explain the deposition of native copper. Herein Steinmann believes a fundamental error was made, and thinks the mineralizing solutions were characterized by a scarcity of oxygen, that is, of sulphates, as compared with sulphur and arsenic. In that event, in order to explain the precipitation of native copper, one must seek oxidizing agencies rather than reducing. These, he said, were at hand in the form of ferric oxide of the Corocoro strata. On entering these beds the sulphides of the metalliferous solutions would be oxidized at the expense of the iron oxide and the beds thereby bleached. The resulting sulphuric acid having greater affinity for lime, magnesia, and iron, which it encountered in the beds, than for copper would form sulphates of those elements and the copper would be precipitated in the native state. Iron and magnesium sulphates

would be sufficiently soluble to be carried away, the less soluble calcium sulphate would remain. In this way would be explained the bleaching of the sandstone, the formation of gypsum, and the deposition of metallic copper; and the result would be accomplished by solutions of such a chemical character as Steinmann believed formed the other Andean copper deposits. He adds that with an excess of sulphur in the solutions over the available ferric oxide, the copper might be precipitated in part or entirely as the sulphide.

The final genetic query raised by Steinmann is concerning the source of the metalliferous solutions. He points out that the copper deposits of the western Andes are associated with dioritic rocks, usually with granular texture, but in part porphyritic, and are genetically connected with the magmas from which they were derived. Forbes recognized two zones of dioritic rocks, a westerly zone running along the Pacific slope of the Andes and an easterly which extends from the Atacama region through Esmeraldas and Comanchi to Lake Titicaca. Corocoro and the other similar copper districts of the Bolivian high plateau lie in this second zone. Hence Steinmann concludes that the rocks of the dioritic zone exist in depth beneath the Corocoro district and that the mineralizing solutions originated from the same magma. Further it might be mentioned that Steinmann correlates these intrusions in age with the porphyries of the eastern Andes of Bolivia and concludes that the period of intrusion was late Miocene or early Pliocene. If Steinmann was correct in his determinations of the age of the Comanche rocks, then he himself presents evidence against his opinion of the Cretaceous age of the Vetas for they contain fragments of that igneous rock.

Straus (p. 208) says only that: "the mineralization appears to be due to the reduction effected by organic matter, as well as the replacement of the cementing lime that filled the interstitial spaces in the sandstone."

Douglas (p. 28) does not enter into the question of the

origin of the Corocoro deposits but remarks: "it can hardly be doubted that the presence of copper in the metallic state is due to the intrusion of the dioritic rocks."

Singewald and Miller consider the close association of the mineralization with the Corocoro fault as indicative of some relation between the two, and think that the parent magma of the diorities was the source of the mineralizers which deposited the ores.

GENETIC COMPARISON WITH LAKE SUPERIOR DEPOSITS

The Corocoro copper deposits are often spoken of as analagous to the Lake Superior copper deposits. These have been more closely studied than the Bolivian occurrence and it would seem that an explanation of their genesis might be applicable to or at least suggest the explanation of the origin of the Corocoro deposits.

A comparison of the geologic features and the ore deposits of the two districts discloses, despite certain features of similarity, features of considerable difference, and renders it rather doubtful whether reasoning concerning the genesis of one has any direct applicability to that of the other. A close relationship is implied in an article by Alfred C. Lane* on native copper deposits. After mentioning a number of occurrences of native copper ores, of which only the Lake Superior and Corocoro districts are of economic importance, he summarizes the following characteristics as common to them:

1. All occur in connection with red sedimentaries.
2. The deposition of the copper is attended by a blanching of the sandstones.
3. The formation of the red sediments is associated with basaltic dark-colored lavas containing a large amount of ferrous iron and a small percentage of copper.

* Alfred C. Lane: Native Copper Deposits. Types of Ore Deposits, 1911.

4. The native copper is associated with waters containing a high percentage of earthy chlorides.
5. The native copper is characteristically irregular and in the nature of a replacement or infiltration of the country rock.
6. Not absolutely universal is the occurrence of zeolites.

It is obvious that these characteristics are more applicable to the North American native copper occurrences than to the Corocoro. Thoroughly applicable to the latter are points 1, 2, 4, and 5. Too little is known concerning the Corocoro mine waters to rule out the probability that their chemical character is merely a reflection of the aridity of the climate and the character of the rocks through which they have flowed and that it has no genetic significance with regard to the ore deposition. The other three common characteristics, 1, 2, and 5, though probably significant are not of fundamental genetic import. Much of the Lake Superior ore is not in red sandstones, hence they were not essential agents in the precipitation of the native copper and they were not the source of the copper-bearing solutions. The Corocoro copper beds extend through a great thickness of strata and the mineralization is so closely related to the Corocoro fault that the ore deposition hardly took place *pari passu* with the deposition of the sediments. Consequently the conditions under which the red beds were formed were not essential to the precipitation of the ores. In other words, one is almost forced to the conclusion that the association with red beds is a fortuitous coincidence rather than a significant genetic factor. The blanching of the sandstones indicates that the mineralizing solutions were capable either of reducing the ferric oxide to which they owe their red color to the ferrous state or of dissolving and removing it. No studies of the chemical composition of the bleached and unbleached rock have been carried on to determine which has happened. *A priori*, one might expect most primary ascending mineralizing waters to be

capable of blanching red rock by one or the other process, so that the mere fact of blanching tells little concerning the origin or the character of the mineralizers. The occurrence of the ore as impregnations of the country rock is an element of form rather than of genesis and may mean only that the mineralizing solution encountered porous strata rather than open fissures as channels of circulation.

Wholly lacking in the Corocoro deposits are Lane's features 3 and 6. Yet the theory that he advanced to explain the native copper deposits is based more essentially on feature 3 than on all the other of the six characteristics he enumerates, and feature 6 is consequent on 3. His corroborative geologic evidence is all based on the facts of Lake Superior geology and not on those of Corocoro. Hence irrespective of the validity of his conclusions, they apply specifically to the Lake Superior deposits; and because of the departure of the Corocoro deposits from them in the essential features 3 and 6, those conclusions are not applicable to the Bolivian district.

The explanation of the Lake Superior copper deposits offered by Van Hise, Leith, and Steidtmann* is also based on a direct relationship between the mineralization and the basic igneous rocks that constitute a large part of the copper-bearing series of rocks. Hence, their arguments apply only remotely, if at all, to the Corocoro region. The same is true of other theories that have been advanced to explain the Lake Superior copper deposits, their fundamental bases are geological conditions that do not obtain at Corocoro. It would not aid our present problem to present these various theories for critical examination; because, whether acceptable for the American deposits or not, a theory acceptable for the Corocoro deposits must conform to and be based on different geologic relations.

* Van Hise and Leith: The Geology of the Lake Superior Region, Mon. LII, 1911, U. S. Geol. Survey.

CONCLUSIONS CONCERNING GENESIS OF COROCORO DEPOSITS

The Corocoro deposits are unusual or anomalous primarily in the occurrence of native copper. But mining developments of recent years have called attention to the large quantities of sulphidic ores and the gradation of the one type of ore into the other, that is, have made less marked the line of separation between the native metal ores and the more common type of copper ores. Experimental chemical work has also demonstrated the ease with which copper may be precipitated from its solutions in the metallic state. Stokes* showed that ferrous sulphate will precipitate copper from a solution of copper sulphate and Fernekes† that ferrous chloride acts in the same way on copper chloride solutions provided the hydrochloric acid is constantly neutralized. These particular reactions hardly apply to the genesis of the Corocoro native copper, because ore deposition seems to have taken place under conditions that produced a concomitant reduction of ferric oxide in the rocks, but they do show the readiness with which native copper can be precipitated.

Despite many uncertain features and the lack of detailed and exact data, the geologic relations and the mode of occurrence of the Corocoro deposits are now sufficiently well established to rule out all syngenetic theories of their origin. They are due to the impregnation of porous strata along and adjacent to the Corocoro fault by ascending cupriferous solutions. If one could postulate reducing conditions within those strata, the chemistry of the native copper precipitation would be relatively easy to write. It

* N. H. Stokes: Experiments on the Solution, Transportation and Deposition of Copper, Silver, and Gold. *Econ. Geo.*, Vol. I, 1906, pp. 646-647.

† Gustave Fernekes: Precipitation of Copper from Chloride Solutions by Means of Ferrous Chloride. *Econ. Geol.*, Vol. 2, 1907, pp. 580-581.

is true that many of the beds in the vetas contain carbonized plant remains, but they are not coextensive with the cupriferous beds of the Vetas and this material is lacking in the Ramos. Hence it can not be called upon as the precipitating agent. On the other hand, the solutions reduced ferric oxide or dissolved it wherever they deposited copper. Consequently ore deposition took place in the presence of ferric oxide and probably the mineralizing solutions were being oxidized by it. The balance between the deposition of native copper and copper sulphide seems to have been delicate as both were deposited in large quantity. Just what was the chemical character of the mineralizing solutions and just what were the reactions that caused the precipitation of the native copper throughout most of the cupriferous beds are questions that, in the light of present knowledge, can only be speculated on but not convincingly or unequivocally answered. Steinmann's theory of the oxidation of sulphides in those solutions by the ferric oxide and the reaction of the resulting sulphuric acid with the alkaline earths of the impregnated beds, leaves the copper in a state and under conditions favorable to the deposition of native copper. It is the most plausible of the theories that have been reviewed.

The source of the mineralizing solutions may be ascribed with reasonable certainty to an underlying dioritic magma of which the Comanche rock is an offshoot. Evidence of igneous activity during the period of the geologic history of the Corocoro district with which we have had to deal was presented in the account of the geology of the district. The period of mineralization coincided with the period of consolidation of that magma and the mineralizing solutions doubtless bore the usual relations to it which are so generally recognized in the case of epigenetic deposits associated with igneous rocks.

MINING OPERATIONS

The mines of the Corocoro district were formerly in the hands of numerous operators, but the ownerships were gradually consolidated so that for a number of years all the active mines have been under the control of the two companies, the Corocoro United Copper Mines, Ltd., and the Compañía Corocoro de Bolivia.

The active mines of the Compañía Corocoro de Bolivia are the Remedios on the north slope of Cerro Corocoro, and the Capilla, San Augustin, and Malcocoya on the ridge and in the valley northwest of the city. Prior to the installation of the flotation plant, they were all producing native copper ores and some high grade sulphide and brochantite shipping ore; but since 1918 only sulphide ores have been produced. The Remedios mine is developed by a tunnel which enters the Cerro Corocoro at the San Francisco mill and by the Remedios shaft which cuts the tunnel at a depth of 60 m. The lowest level is 570 m. below the surface, but only the levels within 210 m. of the surface are now being worked, this being the lower limit of the sulphide ores. The Malcocoya is the newest of the four mines and was opened in 1915.

The production of the Corocoro United Copper Mines, Ltd. has been derived chiefly from four mines on the Cerro Corocoro, the Challcoma, Gullatiri Grande, Santa Rosa, and Vizcachani. All of these mines produced native copper ores until the completion of this company's flotation mill in 1919, when the Vizcachani operations were divided between the sulphide ores of the upper levels and the native copper ores of the lower levels, and due to the slump in the copper market the other mines were temporarily shut down. In the ridge north of the city, the old Estrella mine and the Copacabana, 100 m. to the north of the former, have been cleaned out and wide bodies of sulphide ore are being developed in them.

The Challcoma mine is worked through a shaft 360 m.

deep, the collar of which is located high up on the south slope of Cerro Corocoro. There are 12 levels extending from a depth of 80 m. to the bottom. The workings are in the vetas Blanca and Azul and in the Dorado. The levels above level 6 are inaccessible and the ores in the deeper levels are exclusively native copper ores. The levels of the Challcoma mine are connected with the corresponding levels of the Guallatiri Grande mine. It is developed by a tunnel 762 m. long from the Guallatiri Grande mill beside the railroad on the level of which two interior shafts have been sunk. Level 8, 240 m. below the tunnel, is the lowest accessible one. The important ore bodies are the Dorado, and the Umacoya and Azul vetas. The Vizcachani shaft has a depth of 390 m. divided into 12 levels. The native copper ores are derived from the Blanco and San Jorge ramos, and the sulphide ores from the upper levels in the vetas.

The Libertad mine is the only important independent mine in the district and it has been idle for a number of years. It is situated well out in the Ramos and has developed only ramos ore bodies.

TREATMENT OF ORE

Until 1912, only the native copper ores were worked and until 1918 only the native copper ores were milled. There were five mills in the district for the concentration of the native copper ores: the Libertad mill at the mine of that name, the San Francisco mill of the Compañía Corocoro de Bolivia, and the Guaychuni, Guallatiri Grande, and Guallatiri Chico mills of the Corocoro United Copper Mines, Ltd. The Libertad mill has not been operated for some years.

The treatment of the native copper ores at the San Francisco mill was the following:

The ore was brought to the mill by aerial trams from the mines and dumped on a platform above a Blake crusher.

Lumps too large for the crusher were broken with sledges and the ore fed to the crusher by hand. The crushed ore was ground in four Chilean mills. The pulp from each mill was passed over a screen with $\frac{1}{8}$ " x $\frac{1}{2}$ " openings and the oversize shoveled back into the mill from which it came. The pulp was elevated to a $\frac{1}{16}$ " impact screen and the oversize sent back to the mills. The undersize was classified in a 6-spigot hydraulic classifier, making 3 sizes, 2 spigots to a size, each of which fed one of three jigs. The jigs were 3-compartment Harz jigs with $\frac{1}{16}$ " screens. The three hutch products of the three jigs were mixed to form a first concentrate averaging 50 to 60 per cent copper. This was retreated on a fourth jig to make a final product with a tenor of 85 to 90 per cent copper in the first compartment, the products of the second and third compartments being retreated on the same jig. The tailings of the four jigs were reground in the Chilean mills. The overflow of the classifier was settled in a spitzkasten and distributed to 3 Overstrom tables which made a concentrate that was retreated on a fourth table and tailings averaging .3 to .5 per cent copper which were discarded. The tailings of the fourth table were also discarded, the middlings were retreated on it; and the concentrates were a final "barilla" running as high as 95 per cent copper. The capacity of the mill was 300 tons per day and its recovery was given at 85 to 90 per cent. The barilla was sun-dried on an open stone floor and packed for shipment. Ninety per cent of the barilla was produced by the jigs and 10 per cent by the tables.

From 1912 to 1918 the Compañía Corocoro de Bolivia supplemented its output of native copper ores by shipping considerable quantities of hand-sorted copper sulphide and sulphate ores which carried 18 per cent or more copper. In 1918 the San Francisco mill was converted into a flotation plant, the mining of native copper ores suspended, and the mill utilized for the treatment of low grade sulphide ores. The ore is now crushed in a 11 x 18" jaw crusher

and ground in two Allis Chalmers ball mills. The mill pulp is elevated to a Dorr classifier, the oversize of which goes back to the mills. The undersize goes to a battery of 20 flotation cells which are of a modified Callow type. The concentrates are run into 150-ton settling tanks and the tailings through another series of 10 cells, the concentrates of which go to the settling tanks. The tailings of the second battery of cells are distributed to three Butchart tables which yield a native copper concentrate and tailings carrying 1-½ per cent copper which are discarded. The settlings of the tanks are filtered on Oliver and Portland filters. In the flotation cells 1 kg. of oil is used per ton of ore. In 1919 the daily output was 200 to 250 tons of 7 to 8 per cent ore, 180 to 200 tons of which came from the Remedios mine, which yielded 20 to 25 tons of 45 per cent flotation concentrates and 1-½ tons of native copper concentrates.

Formerly both the large Corocoro companies generated steam power with taquia, or llama dung, fuel. This sold at about \$7.00 per ton and nearly \$125,000 of it was purchased annually by them. Diesel engines have been substituted for steam power and with the falling off in demand for taquia, the local price has dropped to less than half the above price. The Compañía Corocoro de Bolivia has two batteries of 4 Diesel engines, each battery capable of furnishing 125 H. P. to generate power for the mines and two batteries of 6 Diesel engines, each capable of 275 H. P. for the mill. One battery in each case is held in reserve for emergency use. The Corocoro United Copper Mines, Ltd. has also replaced nearly all its steam engines with Diesel and Peters engines. Fuel costs in the district are said to be very high and to amount to 2-½ to 3 cents per pound of copper produced.

The Corocoro United Copper Mines, Ltd., operates the three mills for the treatment of native copper ores because the water available is not sufficient for one larger mill and the same water is used successively by the three mills.

The flow sheet of the three mills is essentially the same and only that of the Guallatiri Chico will be described. The ore comes to the mill crushed to 4" size and is dumped from the aerial tram into a bin that feeds 3 Chilean mills. The pulp passes over a 1-1/2 mm. screen, the oversize of which is shoveled back into the mills. The undersize is elevated to a classifier, the settlings of which feed two 2-compartment Harz jigs with 2-mm. screens. The two compartments of the jig produce a 60 per cent copper concentrate that is retreated on a third jig to produce an 85 per cent concentrate. The tails of all the jigs are returned to the Chilean mills. Four Wilfley tables receive the overflow of the classifier from a distributing spitzkasten. They make an 85 per cent concentrate, middlings that are reground in the Chilean mills, and tails that carry .5 per cent copper, which are run in a sluice to settle. The settlings are also returned to the Chilean mills. In 1919 the Guallatiri Grande mill was shut down and the Guallatiri Chico and Guaychuni were treating 180 tons of ore daily. The recovery of these mills is given as 70 per cent and equivalent to an ore tenor of 2.3 per cent copper.

In 1919 the Corocoro United Copper Mines completed its flotation plant on the east side of the Guallatiri River, 1/4 km. below the Guallatiri Grande mill. Since 1912 this company had also been shipping high-grade copper sulphide and sulphate ores running 20 to 25 per cent copper, and on the completion of the flotation plant began the utilization of its lower-grade sulphide ores in the Vizcachani mine. The ore comes to the Guallatiri Chico mill by the aerial tram and is thence transported on a horse-drawn tram to the flotation plant. On arriving there, the cars are raised on an incline and dumped into a bin at the top of the mill. The ore is discharged from the bin over a grizzly and the oversize fed to a 9 x 15" jaw crusher. The crushed ore

is elevated to a second bin with an automatic feed to a Hardinge conical mill. The total quantity of oil used for flotation is 1 kg. per ton of ore, and $\frac{2}{3}$ of this is added in the Hardinge mill. The mill pulp is run into a Dorr classifier, the oversize of which goes to a second Hardinge mill and the pulp returned to the classifier. The under-size of the classifier is dewatered in three Callow tanks. The waters are returned to the mills and the settlings pass to a battery of 6 mineral separation cells at which point the other $\frac{1}{3}$ of the oil is added. The tailings of the flotation cells, carrying 2- $\frac{1}{2}$ per cent copper, are discarded. The concentrates are treated in a second battery of 2 cells, the tailings of which are sent back to the first battery and the concentrates to a settling tank in which lime and oil are added to hasten settling. These settlings are dewatered in an Oliver filter and the pulp dried on a conveyor over an oil-fired furnace. Two sacking machines bag the dried concentrates in 50 kg. sacks. The mill treats 120 to 150 tons of 7 to 8 per cent copper ore and yields 350 to 400 sacks, or 17 $\frac{1}{2}$ to 20 tons of 55 per cent copper concentrates.

A lixiviation plant with a capacity of 12 tons daily was under construction in 1919 to treat the lower grade oxidized ores that had to be rejected in the hand-sorting of the high-grade shipping ore. The plan was to leach with sulphuric acid and precipitate the copper with scrap iron.

The production of sulphide ores has temporarily displaced that of native copper ores, because the tenor of the former is two to three times that of the latter and they are consequently much more profitable to handle. So far as the distribution and occurrence of the two classes of ores is now known, the greater tonnage of reserves lies in the native copper ores and they will again at some future time be the more important type.

SYSTEMATIC ACCOUNT OF THE FOSSIL PLANTS

P T E R I D O P H Y T A

Order FILICALES

Family POLYPODIACEÆ

Genus *Polystichum* ROTH*Polystichum bolivianum* BERRY

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 117, pl. 15, fig. 1, 1917.

PLATE VII—Fig. 1.

Description.—Frond character unknown. Pinnules small, inequilaterally trilobate, short stalked. Length 9 mm.; maximum width, 5.5 mm. Two pinnules in 1919 collection have a length of 19 mm. and a maximum width of 14 mm. One small pinnule also shows an entire stout stalk 1.5 mm. long. Margin entire or with an occasional mucronate tooth, distinctly not spinulose. Texture coriaceous. The pinnule on one side above the middle shows an outwardly directed, conical, acuminate pointed lobe subtending an open rectangular sinus. On the other side one-third of the distance from the base is a similar conical acuminate lobe slightly larger than that of the opposite side, subtending a similar sinus. About halfway to the tip of the pinnule on this side there is a second vestigial lobe or mucronate tooth above which the margin curves inward to the conical acuminate tip of the pinnule. The venation is largely immersed in the thick lamina. At the base three veins diverge at acute angles of about 20° on one side and 30° on the other, the lateral ones ending in the tips of the lateral lobes and the median one in the tip of the pinnule. A few subordinate dichotomously forking and broadly looped veinlets are faintly seen. On subordinate branches from these three primary veins on each side are impressions of round sori with a slightly raised center, about 0.25 mm. in diameter.

This fern is very obviously a species of *Polystichum*, the characters of which as a whole are very well known. When it comes to making comparisons with existing species of

Polystichum difficulties are almost unsurmountable for several reasons—namely, the inadequate amount of fossil material, the variability of the recent species, the lack of sufficient comparative material, and the difficulty of connecting mere names of recent species with actual specimens.

Polystichum is a large genus in the existing flora found on all the continents, and hence with a cosmopolitan distribution. It contains many vague or but little understood species and many extremely variable and polymorphous forms. It is found in both the tropical and boreal regions (Greenland, Antarctica) and on many high mountains, and its present distribution is clearly indicative of a long geological history which is almost entirely unknown.

Maxon, in a recent revision¹ of the West Indian species, recognizes 19 species in that region. He has been good enough to examine the fossil for me and considers it an ally of the historic and extremely variable *Polystichum triangulum* (Linnæus) Fée. The latter, as far as known, is now strictly West Indian in its distribution. In Jamaica it is common in rocky situations up to 1,800 meters. Other West Indian species whose pinnules are more or less closely similar to the fossil are the Cuban species *Polystichum decoratum* Maxon, *Polystichum heterolepis* Fée, and the Jamaican *Polystichum rhicaphorum* (Jenman) Maxon.

There are a number of existing species in South America, some ranging from the Antilles into Brazil and others ranging from Central America into the Andean region, while still others are confined to South America. I have examined specimens of *Polystichum flexum* (Kuntz) Phillippi, from Juan Fernandez, *Polystichum capense* (Willdenow) J. Smith, from Chile and *Polystichum mohrioides* (Bory) Presl from the Falkland Islands. These, while they show the generic likeness of the fossil, are not specifically close to it. Of the three the last is most like the fossil, but it is

¹Maxon, W. R., Contr. U. S. Natl. Herb., Vol. 13, pt. 1, 1909, pp. 25-39, pls. 2-9.

more dissimilar than the West Indian species previously enumerated. Other existing South American species which I have not seen include *Polystichum dubium* (Hoker) Diels of the Andes of Ecuador and Peru, which is markedly different from the fossil in its pinnate and anastomosing veinlets. Another variable form *Polystichum denticulatum* (Swartz) J. Smith of neotropical South America has reduced forms in the higher Andes, as, for example, the var *rigidissimum* described by Hooker from Colombia; but this type also seems to be remote from the fossil.

The resemblances between the fossil form and still existing West Indian species I regard as valid evidence of relationship, and while it is probable that the types mentioned from the latter region are represented in the rain-forest along the eastern foothills of the present Andes, this resemblance is sufficient, it seems to me, to stamp the fossil as a form that dwelt as either an epiphyte or a rock-dwelling form in a region less desiccated and warmer than that inhabited by such modern forms as *Polystichum mohrioides* (Bory) Presl of southern Chile and Patagonia, or *Polystichum denticulatum*, var *rigidissimum* Hooker of the high Andes of Colombia.

This species is rather common at Potosi but apparently rare in the Corocoro deposits.

CONIFEROPHYTA

Order TAXALES

Family TAXACEÆ

Subfamily PODOCARPEÆ

Genus Podocarpus L'HERITIER

Podocarpus fossilis ENGELHARDT

Podocarpus fossilis Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 5, pl. 1, fig. 12.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 120, pl. 15, fig. 2, 1917.

Description.—Leaves sessile, linear-lanceolate and falcate in outline, acutely pointed at both ends. Margins entire.

Texture very coriaceous. Length, about 4 cm.; maximum width, in the middle part of the leaf, about 3 mm. Midrib stout, impressed on the upper surface. Secondaries longitudinally parallel, 5 or 6 equally spaced in each half of the lamina.

This characteristic species is represented, usually by fragments, which occur at both Potosi and Corocoro. It is clearly referable to *Podocarpus*, belonging to the section *Eupodocarpus* of Endlicher, and is comparable with the existing *Podocarpus lamberti* Klotzsch of middle and southern Brazil and also *Podocarpus oleifolius* Decaisne which is not uncommon in the montaña of Peru and Bolivia and which I found growing freely at Ayapampa in the mountains south of Cochabamba at altitudes of 9000 feet.

The existing forms of *Podocarpus* number over 40 species and they are as dominant representatives of the Coniferales in the Southern Hemisphere as are the pines in the Northern. They extend northward to China and Japan through the East Indian region and to Jamaica and Central America in the Western Hemisphere, and have representatives in all three of the great southern land masses, as well as in Madagascar and New Zealand. This distribution is suggestive of a long geological history in keeping with which certain forms from the British Jurassic and Lower Cretaceous and the American Lower Cretaceous, are referred to the genus *Nageiopsis* and considered as the prototypes of the *Nageia* section of *Podocarpus*, which should probably be raised to its former position of generic rank. Some 15 or more fossil species of *Podocarpus* have been described, chiefly from the European Tertiary, and no conclusively identified fossil forms, other than the present species, have been discovered on the American continents. The section *Eupodocarpus* (Endlicher) to which the present fossil species belongs comprises over 30 existing species, almost as widely distributed as the genus, with several West Indian and South American

species, but found also in Africa, Asia, Australia, and New Zealand. All of these are much alike and the fossil might be successfully compared with almost any one of them. *Podocarpus* is not found at the present time west of the divide of the Eastern Andes, but is represented by two or more species in the forests of the eastern slopes, the so-called Ceja region of Herzog. In northern Peru it is also found in the lateral valleys inside the front range, the most widespread form being *Podocarpus oleifolius*, a shrubby or arborescent form, which in latitude 6° reaches altitudes up to 3,300 meters on the eastern slopes of the central Cordillera and occurs in the broken ranges of Bolivia between Sucre and Cochabamba.

Order POLYGONALES

Family POLYGONACEÆ

Genus *Ruprechtia* C. A. MEYER

Ruprechtia braunii ENGELHARDT

Ruprechtia braunii Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 6, pl. 1, fig. 19.

Berry, Pro. U. S. Natl. Mus., vol. 54, p. 125, pl. 15, fig. 8, 1917.

Description.—Leaves linear lanceolate in outline. Apex gradually narrowed, acuminate. Base acuminate, inequilateral. Margins entire, more or less undulate. Texture coriaceous. Length, about 6.25 cm. Maximum width, at or below the middle, about 9 mm. Petiole not preserved. Midrib thin but prominent on the lower surface of the leaf, inclined to be flexuous. Secondaries numerous, thin but prominent, ascending, somewhat irregularly spaced; they diverge from the midrib at angles of about 40° and are camprodrome.

The present species may be compared with the leaves of the existing *Triplaris salicifolia* of southern Brazil which C. A. Meyer refers to *Ruprechtia*, and with *Ruprechtia laurifolia* Martius of eastern Brazil. *Ruprechtia* is a genus,

not otherwise known in the fossil state, with about 20 existing species of shrubs and trees of tropical and subtropical regions of South America. The present species occurs at both Corocoro and Potosi.

Order ROSALES

Family ROSACEÆ

Genus *Osteomeles* LINDLEY

Osteomeles pliocenica sp. nov.

PLATE VII—Fig. 3.

Description.—Leaves spatulate or obovate in general outline, widest above the middle, with a rounded or bluntly pointed apex and a narrow, long cuneate, acute base. Margins entire except distad, irregularly and sparingly crenulate near the apex. Texture coriaceous. Length ranging from 12 mm. to 15 mm. Maximum width ranging from 4.5 mm. 7.5 mm. Petiole stout, 6 mm. in length in the largest specimen. Secondaries stout, largely immersed, diverging at acute angles of 15° to 20° , anastomosing to form distally elongated reticulations.

This species is abundant at both Potosi and Corocoro, and a second species occurs in what I regard as somewhat younger deposits at Jancocata, Bolivia. There are about a score of existing species, often referred to the genus *Hesperomeles*, the majority of which are unarmed or spinescent shrubs of the Cordillera region ranging from Central America to Bolivia. Among these the fossil is most similar to *Osteomeles cuneata* (Lindley) Decaisne (1) of the Peruvian Andes, in fact there are no obvious differences between the fossil and living leaves except the longer petioles of the former. Less closely related are the leaves of the existing *Osteomeles pernettyoides* (Wedd.)

¹Decaisne, Nouv. Arch. Mus. Hist. Nat. Paris, tome 10, p. 184, 1874.

Decaisne which is rather more common than the preceding and recorded from Colombia to Bolivia at altitudes reaching upward to between 11,000 and 12,000 feet. Specimens of the latter were collected in the Cordillera Real east of the divide east of La Paz near Unduavi at an altitude of 10,725 feet, and Weberbauer records one Peruvian occurrence at 12,350 feet.

There can be no question regarding the identification of this interesting fossil species and it has hence an important bearing on the interpretation of the physical conditions under which these late Tertiary Bolivian floras flourished. The single specimen from Potosi is more elliptical in form, lacking the narrowly cuneate base, there are no indications of teeth and the petiole is more slender. The venation is identical, however, and it may represent an individual variation or possibly a second species. In view of the already too finely differentiated flora recorded from these localities it seems wiser to regard this single specimen as simply a variant of the described species.

The lower altitudinal limit of the genus is not known. I notice records in Weberbauer's account of the Peruvian flora as low as 6,500 feet, for example he records it in the Urubamba valley associated with *Myrteola*, *Escallonia*, *Rubus*, *Fuchsia*, *Oreopanax*, etc., and it is not uncommon in the montaña region associated with *Fuchsia*, *Gunnera*, *Cinchona*, *Triumfetta*, *Weinmannia*, *Escallonia*, *Melastomataceæ*, etc.

The only previously described fossil plant that at all closely resembles the present species is a form from the Mio-Pliocene of Central France which Marty (1) identifies species of southern Asia.

¹ Marty, P., *Revue Général Botanique*, tome 32, p. 24, pl. 12, fig. 5, 1920.

Family MIMOSACEÆ
Genus *Acacia* WILLDENOW
Acacia uninervifolia ENGELHARDT

PLATE VII—Figs. 4, 5.

Acacia uninervifolia Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 11, pl. 1, figs. 10, 11, 20.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 129, pl. 15, figs. 14, 15, 1917.

Description.—Leaflets or phyllodes sessile, somewhat variable in size, slightly or not at all inequilateral, lanceolate to linear lanceolate in outline, with an equally acuminate apex and base. Margins entire. Texture coriaceous. Length, ranging from 1 to 2.25 cm. Maximum width, in the middle of the leaflet, ranging from 1 to 3.5 mm. Midrib relatively stout and prominent on the lower surface of the leaflets. Secondaries thin, numerous, regularly spaced and subparallel; about 15 pairs diverge from the midrib at angles of about 45°, curving regularly upward and ultimately camptodrome. Tertiary venation obsolete by immersion.

This species is common at Potosi and also at Corocoro. It was described by Engelhardt in 1894, who compared it with the phyllodes of the existing *Acacia paradoxa* De Candolle. Engelhardt's figure 20 shows a relatively shorter and wider form and may represent a leaflet of *Machærium eriocarpoides* Engelhardt.

The present species is similar to *Mimosites Engelhardti* Berry and *Machærium eriocarpoides* Engelhardt which occur at both Potosi and Corocoro. It is relatively longer and narrower than any of these but all may really represent the variable leaflets of a single botanical species of leguminous tree. Since they are named it has seemed best to let them stand, although it appears obvious that the species of *Leguminosæ* represented in these Pliocene floras of Bolivia have been excessively multiplied and several are connected by intergrading forms.

Genus *Mimosa* LINNÉ*Mimosa arcuatifolia* ENGELHARDT

Mimosa arcuatifolia Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 10, pl. 1, figs. 52-54.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 132, pl. 15, fig. 21, 1917.

Description.— Leaflets small, sessile, linear-lanceolate arcuate, inequilateral, with a bluntly pointed apex and base, the latter slightly wider than the apex. Margins entire. Texture subcoriaceous. Length 3 to 4 mm. Maximum width, in the middle part of the leaflet, about 1 mm. Venation obsolete except for the thin arcuate midrib.

This species is fairly abundant at Potosi and occurs also in considerable abundance at Corccoro. It is distinguished with difficulty from the smaller leaflets of the more abundant *Calliandra obliqua*, with which Engelhardt in all probability confused it. The present species is, however, less linear, somewhat more slender and arcuate, with a less oblique base, and lacks the three primaries of *Calliandra obliqua*. According to Engelhardt it is very similar to the existing *Mimosa invisá* Martius, which ranges from southern Mexico and the West Indies to Brazil, or *Mimosa lupulina* Benthám of the last region. It may also be compared with *Mimosa microcephala* Bonpland and with *Mimosa pectinata* Kunth. It has also less aptly been compared with the existing *Parkinsonia aculeata* Linnæus. It may be exactly matched by an undescribed recent species of *Mimosa* collected by the writer at elevations of about 9,000 feet in the Quimsa Cruz range in Bolivia.

Genus *Mimosites* BOWERBANK
Mimosites engelhardti BERRY

PLATE VII—Figs. 9, 10.

Mimosites linearis Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 13, pl. 1, figs. 21, 35 (not *M. linearifolius* Lesquereux, 1878. *M. linearis* Knowlton, 1898).

Mimosites engelhardti Berry, Proc. U. S. Natl. Mus., vol. 54, p. 133, pl. 15, fig. 22, 1917.

Description.—Leaflets sessile, linear-lanceolate, slightly inequilateral, with an acuminate-cuspidate tip and an acuminate base. Margins entire. Texture coriaceous. Length, 12 to 15 mm. Maximum width, 2 to 3 mm. Midrib relatively stout. Secondaries obsolete by immersion.

The name of this species appears to be preoccupied by the *Mimosites linearifolius* of Lesquereux (1) from the Green River Eocene of Wyoming, which Knowlton (2) amended to *Mimosites linearis* in 1898. While Engelhardt named his form in 1894, it seemed desirable to rename it in order to avoid confusion.

This species is abundant at Potosi, always in the form of detached leaflets, and it occurs sparingly at Corocoro. It is very similar and liable to be confused with other leguminous leaflets found at Corocoro namely, *Acacia uninervifolia* Engelhardt and *Machærium criocarpoides* Engelhardt, and as previously remarked, may represent a variant not entitled to specific rank. The first is more narrowly elongate and lanceolate, with more prominent camptodrome secondaries. The second is relatively shorter and wider, petiolulate, more lanceolate, and with more prominent secondaries.

¹Lesquereux, L., Tertiary Flora, 1878, p. 300, pl. 59, fig. 7.

²Knowlton, F. H., Bull. 152, U. S. Geol. Survey, 1898, p. 144.

Genus *Calliandra* BENTHAM
Calliandra obliqua ENGELHARDT

PLATE IV.

Calliandra obliqua Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 15, pl. 1, fig. 55.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 134, pl. 15, figs. 23-29, 1917.

Description.—Leaflets small, variable in size, oblong in outline, sessile or subsessile, acutely pointed, with a very inequilateral, obliquely truncate, or subcordate base. Margins entire. Texture coriaceous. Length ranging from 7 to 28 mm.; width ranging from 2 to 8 mm. Venation consisting of usually three primaries diverging from the base, sometimes with subordinate veins from the base, forming loops distad and connected by cross veinlets. A fragment of a leaf shows three pairs of opposite leaflets.

The leaflets of this species are the most abundant forms found at both Corocoro and Potosi, and each parting of the tufts is strewn with them. They are variable in size, and unless the venation can be seen are indistinguishable from the leaflets of *Mimosa arcuatifolia* Engelhardt; in fact, Engelhardt figured but a single leaflet of *Calliandra obliqua*, which is near its maximum size, and he probably confused the smaller leaflets with *Mimosa arcuatifolia*.

The venation is typical of *Calliandra*, but is also shared by some species of *Acacia*. The present species is said by Engelhardt to be practically identical with the existing *Calliandra macrocephala* Benthams, of Brazil. It is also identical with an unnamed *Calliandra* figured by Schenk. It may also be compared with the existing *Calliandra parviflora* Benthams.

The modern species of *Calliandra* comprise over a hundred shrubs and small trees of tropical and subtropical America, with a few outlying species in farther India, Ceylon, and Madagascar. The genus is well represented in eastern Bolivia, and some species extend westward to

the subandean zone of the eastern slopes, but so far as I know none occur in or west of the *Cordillera Real* or eastern Andes.

Genus *Enterolobium* MARTIUS

Enterolobium grandifolium ENGELHARDT

PLATE VII—Fig. 16.

Enterolobium grandifolium Engelhardt; Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 12, pl. 1, fig. 60.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 135, pl. 15, fig. 30, 1917.

Description.— Leaflets sessile, falcate-lanceolate in outline, with a shortly acuminate, cuspidate, inequilateral tip and a bluntly pointed very inequilateral base. Margins entire. Texture subcoriaceous. Length about 1.6 cm. Maximum width, midway between the apex and the base, about 4 mm., one-fourth on one side of the midrib and three-fourths on the opposite side. Midrib mediumly stout, curved. Secondaries mostly obsolete by immersion, a few subparallel with the lower lateral margins and camptodrome are made out with difficulty throughout most of the leaflet; the basal and second secondary on the enlarged side of the leaflet are more prominent and the latter curves upward to above the middle of the leaflet and when visible serves readily to distinguish this form from the associated leaflets of similar shape but belonging to other species.

The present species is not common in the collections but is represented at Corocoro by several well preserved specimens which are slightly larger than the type and show more of the details of venation. It is very similar to the existing *Enterolobium timbouva* Martius, a Brazilian species ranging northward to the West Indies, and recorded by Herzog from the hill country of Velasco, in eastern Bolivia. The genus is a small one closely related to *Inga* and *Pithecolobium*, with about half a dozen existing species of trees with even pinnate small leaves, confined to tropical

America and found from the West Indies and Central America to Brazil. Except for the two species recorded from Corocoro and Potosi it is unknown in the fossil state.

Enterolobium grandifolium is readily distinguished from the associated small, falcate, slightly petiolulate, *Enterolobium parvifolium*. It is somewhat like the broader forms referred by Engelhardt to *Acacia uninervis* as well as similar to *Mimosites engelhardti* Berry and *Machærium eriocaroides* Engelhardt. It is, however, somewhat larger than these, falcate and much more inequilateral, and usually readily discriminated.

Family CÆSALPINIACEÆ

Genus Cassia LINNÉ

Cassia singewaldi BERRY

Cassia chrysocaroides Britton (not Engelhardt), Trans. Amer. Inst. Mining Eng., vol. 21, 1893, p. 252 (part), figs. 30-33 (not figs. 29, 34, 35).

Cassia Singewaldi Berry, Proc. U. S. Natl. Mus., vol. 54, p. 136, pl. 15, figs. 32-34, 1917.

Description.—Leaflets obovate to elliptical in outline with a broadly rounded equilateral or nearly equilateral tip and a markedly inequilateral base, which is somewhat variable in outline. In some leaflets one margin narrows almost straightly, while the other is broadly rounded; in others both margins are full and that on one side resembles half of the base of a cordate leaflet; and every gradation between these two extremes are present. Margins entire, generally slightly undulate. The leaf substance is not thick, but the leaflets appear stiff and subcoriaceous in texture. A short expanded petiolule is present in some of the leaflets that it has not been found possible to differentiate from this species by means of any other characters, but the majority are sessile with an expanded base of the midrib.

Length ranging from 3.3 to 3.5 cm. Maximum width,

at or above the middle, ranging from 1.4 to 1.75 cm. Midrib stout, prominent on the underside of the leaflet. Secondaries relatively stout; about 12 pairs ascending in the narrower more obovate leaflets, and less ascending in the elliptical leaflets or in the fuller side of the leaflets. The secondaries are approximately evenly spaced and sub-parallel: they are for the most part rather straight in their courses and are camptodrome in the marginal region. The tertiaries are thin, but well marked, forming an open polygonal or often nearly rectangular areolation. The leaflets have the appearance of having had a glaucous surface, but this may be due to their preservation.

This species was based upon material collected by Singewald and Miller and on certain of the leaflets figured by Britton and referred to *Cassia chryso carpoides* Engelhardt. Of the latter the form with a petiolule may be of another species, but is otherwise indistinguishable. *Cassia chryso carpoides* Engelhardt is relatively much shorter and broader with a more pointed tip and with thinner and more curved secondaries. Not uncommon at both Corocoro and Potosi.

Cassia ligustrinaformis BERRY

PLATE VII—Fig. 11.

Cassia ligustrinoides Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1887, Abh. 5, p. 37, pl. 1, fig. 16; 1894, Abh. 1, p. 10, pl. 1, fig. 27.—Britton, Trans. Amer. Inst. Min. Eng., vol. 21, 1893, p. 252, figs. 21, 22, 24, 25, 46-48, 63 (?), not figs. 23, 26, 27, 1893; (not Schrank, Denks. Akad. Muench., vol. 6, 1816, p. 179).

Cassia ligustrinaformis Berry, Proc. U. S. Natl. Mus., vol. 54, p. 139, pl. 16, figs. 7, 8, 1917.

Description.—Leaflets sessile, inequilateral lanceolate in outline, with a pointed nearly equilateral tip and a slightly blunter pointed, inequilateral base. Margins entire, evenly rounded. Texture subcoriaceous. Length ranging from 3.5 to 5.5 cm. Maximum width, midway between the apex and the base, ranging from 9 mm. to 1.5 cm. Midrib

mediumly stout, generally curved, not especially prominent. Secondaries thin but prominent, numerous; about 10 opposite to alternate pairs diverge from the midrib at angles averaging about 45° and are camptodrome. Tertiaries thin but well marked.

This is a common and characteristic form in the Corocoro and Potosi collections, much like numerous previously described fossil species and many still existing species of this large genus, especially the existing *Cassia ligustrina* Linnæus after which it was named. Britton has referred several forms to this species which fall beyond its limits of variation, and this is especially true of the small petiolate leaves shown in his figures 26 and 27. Engelhardt's name is preoccupied by Schrank, 1816. *Cassia chrysocarpoides* Engelhardt is much shorter and wider, *Cassia cristoides* Engelhardt is a much smaller spatulate form, *Cassia wendtii* Britton is very much smaller and oblong elliptical in form, *Cassia singewaldi* Berry is a broadly elliptical form. *Cassia rigidulifolia* Engelhardt is a large retuse form, *Cassia obscura* Engelhardt is a very small obscure form, and *Cassia membranacea* is very similar to the present species, but with slightly wider thinner leaflets with more numerous secondaries.

Genus *Copaifera* LINNÉ

Copaifera corocoriana BERRY

PLATE VII—Fig. 8.

Copaifera corocoriana Berry, Proc. U. S. Natl. Mus., vol. 54, p. 144, pl. 16, fig. 18, 1917.

Description.—Pod of small size, nearly orbicular in outline, greatly compressed, pedunculate, obliquely cuspidate tipped, single seeded. Length, about 1 cm. from the top of the recurved cuspidate tip to the top of the peduncle. Horizontal diameter, about 8 mm. Peduncle stout, about 4 mm. long. Seed lenticular, nearly orbicular, compressed,

about 4 mm. in diameter. Pod tardily, if at all, dehiscent; its surface minutely wrinkled.

The present species is somewhat smaller than the normal size of the pods in the existing species which I have seen, and it is also smaller than those of the described fossil species. It may represent the fruit of the same tree as the leaflets from Potosi described as *Copaifera potosiana* since it occurs also at Potosi in association with the latter.

The genus is present in the recent flora of South America from the Caribbean region throughout the Amazon Basin and several species are known from the Yungas region of Bolivia.

Genus *Peltophorum* VOGEL

Peltophorum membranaceum ENGELHARDT

Peltophorum membranaceum Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. I, p. 9, pl. I, fig. 47.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 145, pl. 17, fig. 3, 1917.

Description.—Leaflets small, sessile, inequilateral, ovate in general outline, with a bluntly pointed apex and an obliquely cuneate base. Margins entire. Length, about 8 mm. Maximum width, in the middle part, about 3.5 mm., one side one-third wider than the other. Midrib mediumly stout, curved proximad. Secondaries thin, about three ascending camptodrome pairs.

This species was described from Potosi by Engelhardt, and was collected in 1919 from both Corocoro and Potosi. The peculiar outline serves to readily distinguish it from the other members of the flora. It has been compared with the existing *Peltophorum vogelianum* Bentham of the Brazilian region.

The genus *Peltophorum*, not otherwise known in the fossil state, comprises about eight species of trees common to the tropics of both hemispheres. Its distribution in the existing flora of eastern Bolivia is unknown.

Family PAPILIONACEÆ

Genus *Amicia* H. B. K.*Amicia antiqua* BRITTON

Amicia antiqua Britton, Trans. Amer. Inst. Min. Eng., vol. 21, 1893, p. 252, figs. 11, 45.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 146, pl. 17, figs. 4, 5, 1917.

Description.—Leaflets sessile, narrowly or broadly cuneate in general outline, with an emarginate apex. Length ranging from 2 to 3 cm. Maximum width in the apical part of the leaflet ranging from 0.75 to 1.4 cm. Margins entire, slightly undulate. Texture coriaceous. Midrib mediumly stout, slightly flexuous, prominent on the lower surface of the leaflets. Secondaries thin, numerous, ascending, camptodrome. Tertiaries obsolete.

This species was described by Britton from a limited amount of material collected by Wendt at Potosi and collected by the authors in 1919 at both Corocoro and Potosi. It may be compared with the existing *Amicia lobbiana* Bentham found at considerable altitudes in the Peruvian and Bolivian Andes (1,800-3,000 meters).

The genus *Amicia*, not otherwise known fossil, comprises five or six species of shrubs or undershrubs of the Andean region, ranging from Mexico to Bolivia.

The identification of the present species is somewhat questionable upon general grounds, for while the fossil agrees with the existing leaflets of *Amicia*, and it is quite natural to identify the fossil leaflets with a recent genus of the same general region; the fact that the vast majority of the fossil forms found at Corocoro are related to existing forms of the more humid regions of eastern Bolivia and the Amazon Basin, raises the question whether the present leaflets may not be more properly referable to some other leguminous genus with similar leaflets, such as would more naturally be expected to occur under such conditions and in such an association, as, for example, the genus *Dalbergia*, which is represented by pods at

Corocoro. With the desire not to weight the evidence by giving such considerations too great value, I prefer to let Britton's identification stand.

Genus *Machærium* PERSOON

Machærium eriocarpoides ENGELHARDT

Machaerium eriocarpoides Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 8, pl. 1, fig. 28.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 146, pl. 17, fig. 6, 1917

Description.—Leaflets petiolulate, lanceolate in outline, nearly equilateral, with an equally pointed apex and base. Margins entire. Texture subcoriaceous. Length, 1.2 to 1.4 cm. Maximum width, midway between the apex and the base, 2.5 to 3.25 mm. Petiolule stout, 0.5 to 1 mm. long. Midrib stout. Secondaries thin, regularly spaced, subparallel; six or seven pairs diverge from the midrib at angles of about 45° and are camptodrome. Tertiaries obsolete by immersion.

This species is not uncommon at both Corocoro and Potosi. While similar to several other fossil species found at Corocoro and Potosi, it may be distinguished from *Acacia uninervifolia* Engelhardt by its petiolule, greater width and fewer secondaries; from *Enterolobium grandifolium* Engelhardt by its petiolule, its smaller size, more prominent secondaries and more equilateral form; from *Mimosites engelhardti* Berry by its wider, less elongated, and more lanceolate form, by its petiolule and more prominent secondaries. According to Engelhardt it is very similar to the existing Brazilian species *Machærium eriocarpum* Bentham. The last is recorded by Herzog from the hill country of Velasco and from the broken woods along the Rio Pirai and Rio Yapacani, in eastern Bolivia.

The existing species of *Machærium* comprise over 60 trees or high climbing shrubs, with small pinnate leaves, confined to the American Tropics, where they range from the West Indies and Central America to southern Brazil.

Their maximum display is in the Amazon region, and they do not appear to be represented in the present mountain region of Bolivia.

The known fossil species are few in number and comprise, in addition to the present form, three Oligocene and a Miocene species in central and southern Europe.

Genus *Dalbergia* LINNÉ *fil*s
Dalbergia antiqua ENGELHARDT

PLATE VII—Fig. 12.

Dalbergia antiqua Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 8, pl. 1, fig. 23.

Description.— Small, coriaceous, indehiscent, stipitate single seeded flat pods, obovate in outline, widest distad, narrowed proximad to a short or slightly extended base, vexillar margin straightest. Length ranging from 1.25 cm. to 2.5 cm. Maximum width ranging from 7 mm to 10 mm. Seed single, lenticular, about 4 mm. in diameter, located near vexillar margin. The surface of the pod is ligneous and marked with anastomosing diagonally transverse relatively stout and largely immersed veins.

This species which was described by Engelhardt from a single specimen collected at Potosi, Bolivia, was compared with the existing *Dalbergia riparia* Benthams of the Amazon Basin. It is not contained in my collections from Potosi but three specimens were found at Corocoro, two of which are complete to where the persistent calyx separates the pod from its stipe.

Comparisons with recent forms appear limited to the Cynometreæ of the Cæsalpinaceæ and the Dalbergiæ of the Papilionaceæ. The latter seems the most similar and the two genera that invite the closest comparisons are *Dalbergia* and *Lonchocarpus*. These comprise tropical trees and shrubs, the latter often climbing, confined to relatively low elevations, that is, usually found below 5000 feet. It is probably impossible to reach a decision in regard to the proper genus in the case of isolated fossil

Pods. *Lonchocarpus* with many small shrubby species inhabiting xerophytic regions invites comparison as a type likely to occur in such an association as that represented by the Corocoro flora. On the other hand its existing distribution is on the whole nearer the equator than *Dalbergia* in South America. Both genera have been described from Potosi on the basis of leaflets, but unfortunately little reliance can be placed upon these determinations, since the most that can be expected is the recording of resemblances to recent forms and these can be considered conclusive only when they present distinctive features not shared by numerous other genera of the Leguminosæ.

In referring to Engelhardt's species in 1918 I questioned (1) the generic reference commenting that this pod was more likely to be a *Cassia*, since no traces of seeds were seen. In the light of the material which I collected at Corocoro it is seen that there is no close similarity to *Cassia*. The single specimen upon which this species rested was contained in the collection of the Royal Silver Mine of Potosi Co., in London and the tip was broken away and restored in Engelhardt's figure. The present material shows that it was obtusely rounded and not acute as restored. The type specimen does, however, show the stipitate nature of these pods—all of the Corocoro material being broken from the calyx. I have no doubt, however, of the identity of the two occurrences, thus adding to the Corocoro flora another element found at Potosi.

Although positive generic determination is not possible I am sure that the fossil belongs to the tribe of *Dalbergiæ* and therefore the genus *Dalbergia* may stand in a broad sense as indicative of the true botanical affinity of the fossil and in this connection it is pertinent to call attention to the stereotyped paleobotanical practice of referring fossils to the genus *Dalbergia* in many cases where it is the tribe rather than the genus that is determinable.

¹Berry, E. W., Proc. U. S. Natl. Mus., vol. 54, p. 149, 1918.

Genus *Drepanocarpus* MEYER
Drepanocarpus franckei ENGELHARDT

Drepanocarpus franckei Engelhardt, Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 7, pl. 1, figs. 36-38.

Berry, Proc. U. S. Natl. Mus., vol. 54, p. 149, pl. 17, figs. 19, 11, 1917.

Description.—Leaflets sessile, elliptical in outline, nearly equilateral, with a broadly rounded apex and a similarly rounded, sometimes obliquely, inequilateral base. Margins entire. Texture coriaceous. Length ranging from 10 to 13 mm. Maximum width, midway between the apex and the base, 4 to 5 mm. Midrib stout, prominent below, channeled above, relatively straight. Secondaries prominent, numerous, subparallel, camptodrome.

This species is well marked and readily distinguished from other members of the flora. It is comparable with the existing *Drepanocarpus lunatus* Meyer, a widespread form ranging from the West Indies and southern Mexico to Brazil, and recorded also from tropical West Africa. Species referred to *Drepanocarpus* have been described from the Eocene of Monte Bolca, Italy and from the upper Oligocene or lower Miocene of southeastern France. The existing species comprise 8 to 10 trees or high climbing shrubs, all of which are confined to tropical America with the single exception noted above.

Order S A P I N D A L E S

Family DODONÆACEÆ.

Genus *Dodonæa* LINNÉ

Dodonæa viscosaformis sp. nov.

PLATE VII—Fig. 17.

Description.—Leaves of variable size, lanceolate in outline, with acute apex and equally acute or somewhat more produced decurrent base. Margins entire. Texture coriaceous. Length ranging from 3 cm. to 4.5 cm.

Maximum width, at or above the middle, 4 mm. to 7 mm. Petiole stout, often curved, 3 mm. to 6 mm. in length. Midrib stout, prominent on the under side of the leaf, usually curved. Secondaries thin, numerous, diverging from the midrib at wide angles, rather straight, ultimately camptodrome. The secondaries are immersed in the thick substance of the leaf and are entirely obsolete in the leaves preserved in the relatively coarse matrix at Corocoro, but better displayed in the material preserved in the fine textured Potosi tuff. The tertiaries are largely obsolete by immersion, although the characteristic *Dodonæa* areolation can be made out in the material of this species collected at Potosi.

This species is exceedingly abundant in the lower plant-bearing stratum at Corocoro but is less common at Potosi. It is on the whole well marked and is strikingly similar to the existing *Dodonæa viscosa* Linné, especially the smaller leaves of that species. The latter is found in both the oriental and occidental tropics and is a characteristic insolation resisting form of the strand and coastal lagoons. It ranges northward to peninsular Florida and Bermuda (32° North) in this habitat and is also found in the interior of South America. According to Weberbauer it occurs in the Andean valleys of Peru at altitudes up to 9750 feet. Farther south I found it east of the divide of the Cordillera Oriental north of Misque at an altitude of 8450 feet, where it was exceedingly common in bush form and abundantly fruiting at the end of the dry season. (Sept. 1, 1919)

The genus *Dodonæa* has perhaps 50 existing species, the majority of which are Australian, but it is represented in all tropics and is a member of the Hawaiian flora. Its cosmopolitan distribution denotes an extended geological history, in confirmation of which it has been discovered in the lower, middle, and upper Eocene of the Mississippi embayment region, where it is represented by both leaves and the characteristics alate fruits. There are over a

dozen European Tertiary species in the Oligocene and Miocene.

The presence of a species of *Dodonæa* at Corocoro would indicate much sunshine and probably a dry season similar to that of southeastern Bolivia. The modern species cannot exist on the Altiplanic under present climatic and topographic conditions and so far as I know it is only found in Bolivia east of the Cordillera Oriental, although nearer the Equator in Peru it is found in the interandean valleys.

Order MYRTALES

Family COMBRETACEÆ

Genus *Terminalia* LINNÉ

Terminalia singewaldi BERRY

PLATE VII—Fig. 13.

Terminalia singewaldi Berry, Proc. U. S. Natl. Mus., vol. 54, p. 157, pl. 18, fig. 7, 1918.

Description.—Samaras bialate, reniform in outline, wider than high, deeply emarginate or cordate at both the apex and the base. Peduncle stout, about as long as the vertical axis of the fruit. Length of the latter, 1.25 cm. Wings thin with entire margins. Veins thin, numerous, somewhat flexuous, frequently forking, and less frequently anastomosing. Height of wings, between 2.25 and 2.5 cm. Width, about 1.25 cm. Width from margin to margin of the opposite wings, about 3.15 cm. Essential part of fruit turbinate, rounded distad, and tapering downward proximad to join the peduncle; turgid, the veins of the wings crossing its surface diagonally.

This species apparently belongs to the section *Diptera* of the genus. It is somewhat similar to *Terminalia antiqua* Britton, which is so common at Potosi, but differs from the latter in its larger size, in its turgid and turbinate, distally rounded seed cavity, and in its more equilateral

wings with less frequently anastomosing veins. It is comparable to various two-winged modern species of Asia, Africa, and the South American Tropics east of the Andes.

GAMOPETALÆ

Order ERICALES

Family ERICACEÆ

Genus *Vaccinium* LINNÉ

Vaccinium pontzuelum sp. nov.

PLATE VII—Fig. 6.

Description.—Leaves of small size, spatulate or obovate in general outline, with a broadly rounded tip and narrowly cuneate base. Margins entire, slightly revolute. Texture coriaceous. Length about 1.25 cm. Maximum width, above the middle, about 4 mm. Petiole missing, appears to have been short and stout. Midrib extremely stout and prominent on the under side of the leaf. Secondaries are obsolete, but whether by immersion in the leaf substance or because of the pilose under surface of the leaf cannot be determined with certainty.

The Ericaceæ have a considerable representation in the existing flora of South America and there are at least ten different genera and a large number of species in the Andean region some of which range throughout the whole length of the continent, and one, *Pernettya*, reaching altitudes of 14625 feet in the equatorial portion of the range.

The genus *Vaccinium* with a number of little understood species reaches altitudes of 10725 feet in central Peru almost under the equator but presumably is confined to lower levels in the latitude of Corocoro. In general the present Andean Ericaceæ are Eastern Cordillera or Montaña species rather than interandean.

Engelhardt has described (1) a form from Potosi which he refers to the allied genus *Gaylussacia* but which may represent an allied species of *Vaccinium*. It shows considerable minor contrast to the present species although of the same general type. The present is one of the few species found at Corocoro that have not been recognized in the large collections made at Potosi.

Order RUBIALES
Family RUBIACEÆ
Genus *Rubiacites* WEBER
Rubiacites nummularioides BERRY

PLATE VII—Fig. 7.

Rubiacites nummularioides Berry, Proc. U. S. Natl. Mus., vol. 54, p. 161, pl. 18, fig. 15, 1917.

Description.— Leaves small, ovate, or broadly elliptical in outline, relative long petiolate, widest in the middle, with a somewhat narrowed rounded tip and a broadly cuneate base. Margins entire. Texture coriaceous. Length, about 4 mm. Maximum width, about 3 mm. Petiole stout, curved, about 1.5 mm. in length. Midrib stout. Secondaries thin, subparallel, openly camptodrome. Tertiaries obsolete. The Corocoro material, identical in form with the type material from Potosi, shows slightly larger leaves 1 cm. in length by 6 mm. in maximum width and a relatively stout petiole 4 mm. in length.

These small leaves are somewhat suggestive of some species of *Celestraceæ*, but upon the whole their closest affinities appear to be with several existing genera of *Rubiaceæ*, and they are consequently referred to the form genus *Rubiacites* proposed by Weber for *Rubiaceous* leaves of uncertain generic affinity. Ignoring the exclusively herbaceous genera comparisons may be made with various

¹Engelhardt, H., Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 6, pl. 1, figs. 8, 9.

existing species of *Anisomeris* Presl, *Palicourea* Aublet, and *Coprosma* Forster. None of these genera are recorded as fossils. *Anisomeris* comprises about 25 species of shrubs ranging from Venezuela to Paraguay, but chiefly Brazilian. *Coprosma* comprises about 40 species of shrubs and small trees mostly oriental and extending from Java to New Zealand and in Oceanica to Hawaii but found also on Juan Fernandez and in Chile. *Palicourea* comprises over 100 species of shrubs confined to tropical America and ranging from Mexico and the Antilles to southern Brazil.

INCERTÆ SEDIS

Carpolithus baulti sp. nov.

P.ATE VII—Figs. 14, 15.

Description.—A large drupaceous fruit with a fibrous or woody outer flesh and a large oval nearly smooth stone. One specimen shows the stone lying within the fruit, the outer covering having been carbonized. A second specimen in the same piece of matrix shows an isolated stone. The fruit appears to have been slightly wider distad. As preserved it is 2.8 cm. in length and 2.1 cm. in diameter. The stone is slightly compressed 1.9 cm. in length, 1.4 cm. in width and 1.1 cm. in thickness. There is a well marked scar on what I interpret as the proximal end of the stone which if correct shows that the habit was orthotopous. Whether one or several seeded cannot be determined.

I am not prepared to suggest its botanical affinity since the characters preserved scarcely warrant such an attempt.

There are a variety of families with drupaceous fruits and these often have the outer flesh fibrous to woody as in the genus *Mimusops* or in the familiar case of the cultivated almond.

Named in honor of the collector, M. Charles Bault, Ingénieur of the Corocoro United Copper Mines Ltd.

An object slightly smaller but otherwise similar to the

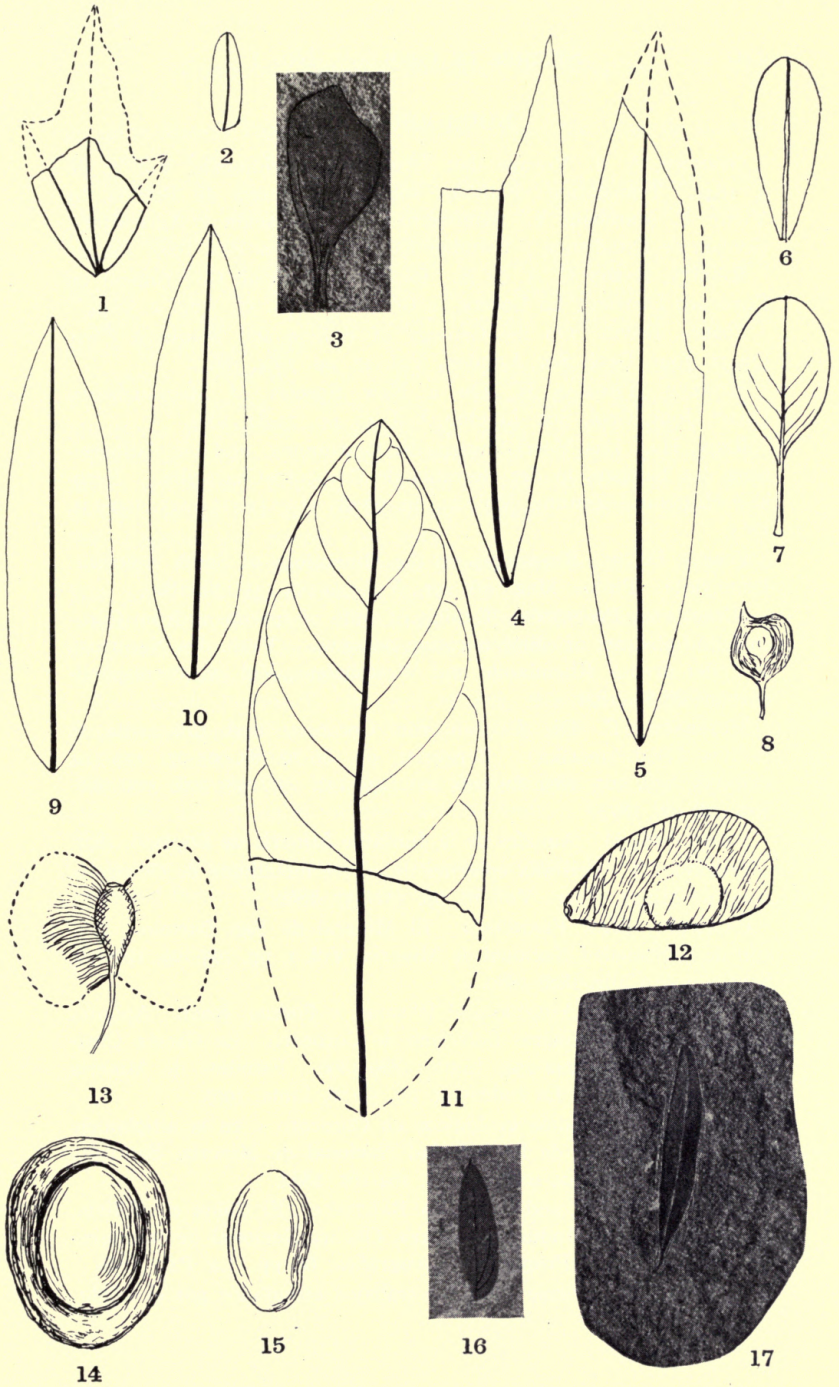
stone of *Carpolithus baulti* was described by Engelhardt from the tuffs at Potosi, Bolivia, as *Carpolites ovoideus* (1). It is possible that the two represent the same species which would add another to the considerable number of identical species at these remote localities (2) thus indicating that the environmental conditions indicated by these fossil plants were uniform over much of Bolivia during this stage of the Pliocene. There are numerous palm fruits similar to the fossil and similar forms are often referred to the palmaceous form genus Palmocarpon. Were there any collateral evidence of palms in the Pliocene flora of Corocoro I would be inclined to have called the present fossil Palmocarpon. As the matter stands the two most probable alternatives seem to be a relationship to either the Palms, the Sapotaceæ or the Myrsinaceæ.

¹Engelhardt, H., Sitz. Naturw. Gesell. Isis in Dresden, 1894, Abh. 1, p. 13, pl. 1, fig. 58.

²See Berry, E. W., Proc. U. S. Natl. Mus., vol. 54, p. 162, pl. 18, fig. 7, 1918, where Engelhardt's preoccupied name is changed to *Carpolithus Engelhardti*, and where it is suggested that the species represents some leguminous seed. This certainly seems to be true of the specimens that I described from Potosi, but these were determined on the basis of Engelhardt's figure of the single type specimen and a very inadequate description, so that all chances of error are not obviated.

EXPLANATION OF PLATE 7.

- Fig. 1. *Polystichum bolivianum* Berry, x4
2. *Mimosa arcuatifolia* Engelhardt, x4
3. *Osteomeles pliocenica* Berry, x2
4, 5 *Acacia uninervifolia* Engelhardt, x4
6. *Vaccinium ponzuelum* Berry, x2
7. *Rubiacites nummularioides* Berry, x2
8. *Copaifera corocoriana* Berry, x1
9,10 *Mimosites* Engelhardti Berry, x4
11. *Cassia ligustrinaformis* Berry, x4
12. *Dalbergia antiqua* Berry, x2
13. *Terminalia Singewaldi* Berry, x1
14,15. *Carpolithus Baulti* Berry, x1
 Fig. 15. Side view of stone
16. *Enterolobium grandifolium* Engelhardt, x1
17. *Dodonaea viscosaformis* Berry, x1



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