PARAGUAY

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INTRODUCTION

The 1:5,000,000 map of Paraguay gives a fairly acceptable picture of the distribution of the systems of rocks in the region east and south of Asunción. It is, however, unsatisfactory in the northern half of eastern Paraguay. Figure 1 shows the correct generalized distribution of the outcrops according to our present knowledge. In addition, a tiny exposure of fossiliferous Lower Devonian rocks should be plotted in the Chaco plains near Fortín Aroma (Lat. 20°12′ S., Long. 60°28′ W.).

The following account of the geology of Paraguay is mainly a summary of the writer's paper (1950) on the eastern half of the country, with the addition of some information on the Chaco region, made available through the courtesy of the Union Oil Company of California.

The geologic literature on Paraguay is very meager. The most important papers are Milch's (1894) and Goldschlag's (1913) descriptions of some Mesozoic eruptive rocks, Beder's (1923) discovery of *Mesosaurus*-bearing beds near Villarrica, Beder and Windhausen's (1918) report on the discovery of Lower Devonian fossils, and Boettner's (1947) brief account of the Precambrian and Lower Paleozoic rocks exposed south of the Rio Apa.

STRATIGRAPHY

PRECAMBRIAN (epЄ)

Two main areas of Precambrian rocks are known in Paraguay, one in the northern and the other in the southern part of the country. The northern exposures are mainly gneiss, micaschist, and phyllite intruded by biotite granite and crossed by granite pegmatite dikes many of which bear tourmaline and beryllium. These rocks were briefly described by Boettner (1949) between Puerto Fonciere and Toldocué, south of the Rio Apa. The metasedimentites appear to be a southern extension of the Cuibá group of Mato Grosso (Brazil) and are best regarded as middle Precambrian.

Metasedimentites are scarce in the southern exposures. They crop out in small patches between Villa Florida and Paso Pindó on the Rio Tebicuary and consist of foliated gneiss, micaschist, and chlorite quartzite with occasional thin intercalations of marble. These rocks are intruded by biotite granite and granite porphyry. Extensive exposures of rhyolite and keratophyre seem related to the granite. They are little weathered and almost devoid of metamorphism and may be tentatively correlated with the late Precambrian Aiguá extrusives of Uruguay and the Castro and Maricá "porphyries" of southern Brazil.

Two small outcrops of pink biotite granite are known a little east and southeast of Asunción, one at San Bernardino on the east shore of Lake Ypacaraí (Fig. 2) and the other near Itá.

PALEOZOIC

Ordovician (?) (ЄO).—The oldest Paleozoic rocks of Paraguay are those marked ЄO in the map. They form a group of limestones with interbedded marls, exposed between Puerto Pinasco and Santa Isabel.

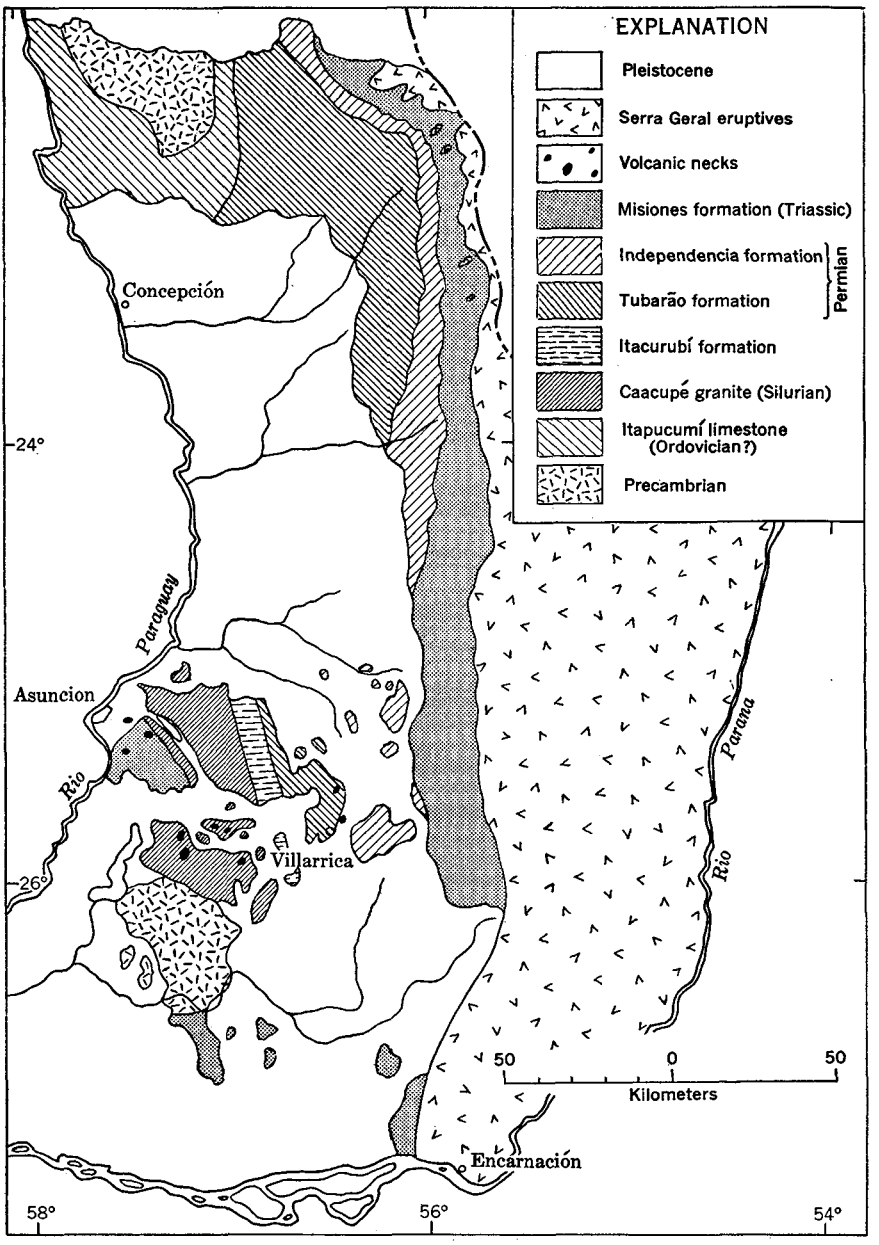

FIGURE 1.—*Geologic map of southeastern Paraguay*

The predominant rocks are thinly bedded, light-gray limestones, many semi-crystalline to coarsely crystalline. Calcareous marls and marly shales form frequent interbeds. The group is probably not less than 100 m thick, and the beds are gently undulating in open folds; dips as steep as 30° are exceptional. These rocks, which

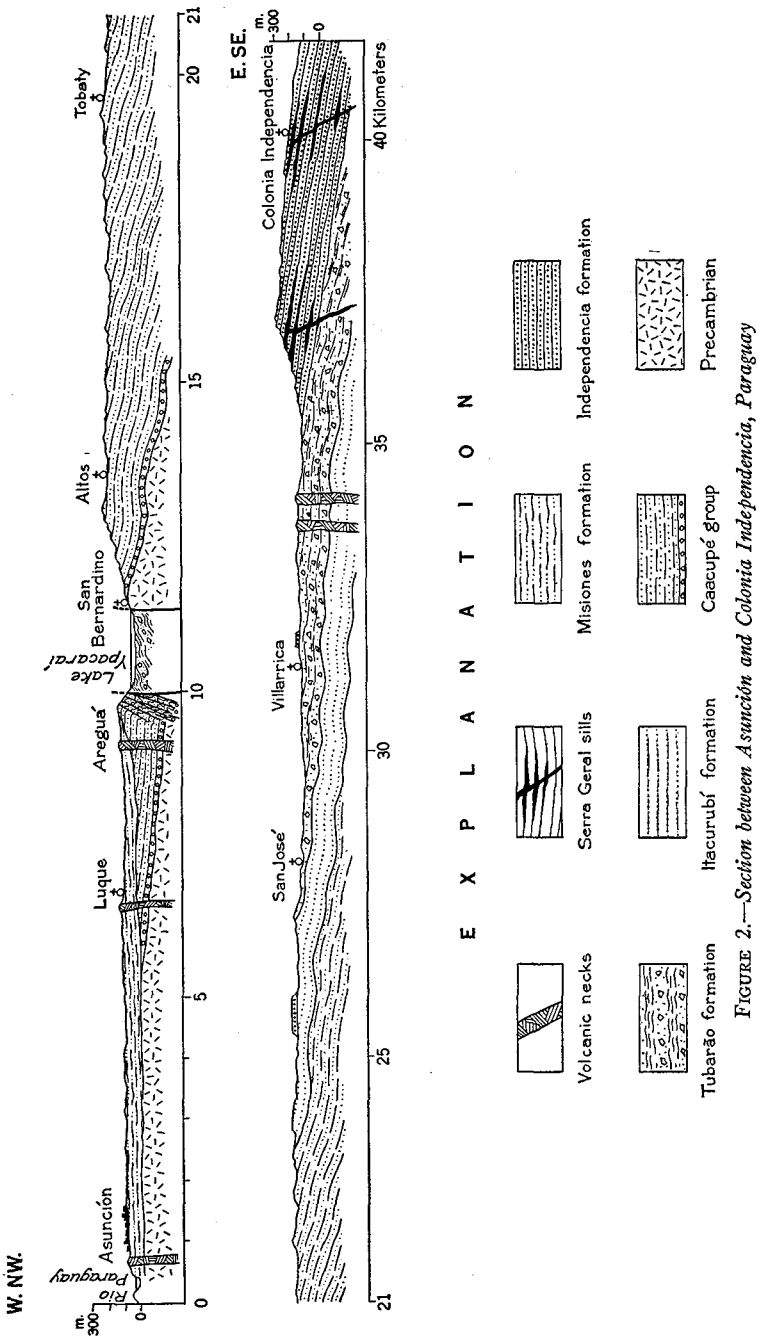

FIGURE 2.—*Section between Asunción and Colonia Independencia, Paraguay*

have been termed "Itapucumí limestones", rest on Precambrian metamorphics. They are unfossiliferous, and their age is unknown, but they seem to represent a southern extension of the Corumbá limestones of Mato Grosso of probable Ordovician age.

Silurian (S).—The Silurian rocks of Paraguay are especially well developed in the "Cordillera de Altos" east of Lake Ypacaraí but are also known west and south of this region.

The sequence, which has been called Caacupé group, is about 800 m thick and begins with 50 m of conglomerate, unconformably resting on Precambrian granite at San Bernardino. The conglomerate contains well-rounded pebbles and cobbles of quartzite and interbeds of coarse-grained, roughly cross-laminated sandstone. These rocks grade upward into a group 600–650 m thick, of fine- to medium-grained, little-cemented, cross-laminated yellowish-white, light-cream, and light-buff feldspathic sandstones, especially well exposed near Piribebuy. Thin lenticular interbeds of whitish clay-shale, often secondarily stained deep yellow, lilac, purple, or red, are occasionally found in the upper part of the sandstones. In two localities (Cerro Aparipí and Vargas Pena quarry west of Lake Ypacaraí, Fig. 2) they have furnished fossils. The most characteristic species are:

Atrypina? paraguayensis Harrington
Palaeoneilo constrictiformis Harrington
Nuculites opisthoxystomus Harrington
Calymene boettneri Harrington
Climacograptus innotatus var. *brasiliensis* Ruedemann
Diplograptus modestus Lapworth var.

The graptolites indicate a Lower Silurian (Valentian) age.

The sequence ends with about 100 m of fine- to medium-grained, slightly coherent sugary yellowish-white sandstone, stratified in beds a few decimeters to a meter thick and devoid of cross-lamination. These beds are covered by Lower Devonian sedimentites, apparently with slight regional unconformity.

The Silurian sequence of Paraguay may be correlated with the Carmen formation of the Chiquitos region, with the Trombetas formation of the Lower Amazon basin, and probably with the Curamalal group of the southern hills of Buenos Aires in eastern Argentina.

Devonian (D).—The Devonian rocks of Paraguay are exposed in a narrow band directly east of the Silurian outcrops and consist of about 250 m of sandstone and shale bearing typical "austral" Lower Devonian fossils in the upper part.

The sequence begins with fine-grained, thinly bedded, and somewhat feldspathic light-yellowish sandstone. This is succeeded by massive, hard sandstone packed with *Skolithos* tubes and bearing thin intercalations of cream-colored, yellow, and purple clay-shale. There follows about 100 m of fine-grained, thinly laminated, yellowish-brown shaly sandstone which has yielded a single specimen of an orthoceratid. Purplish intercalations appear in the upper part, and these have furnished one coiled specimen of *Homalonotus* sp. The sequence ends with about 80–100 m of thinly bedded, soft, and little-cemented yellowish-brown to yellowish-white and light-purple sandstone, with thin lenticular intercalations of yellow clay-shale and

of coarse-grained to conglomeratic yellow sandstone. Near the top of the sequence, the fine-grained sandstones have yielded:

Chonetes falklandiscus Morris et Sharpe
Schellwienella inca (d'Orbigny)
Australostrophia conradii Harrington
Tentaculites crotalinus Salter
Phacopina itacurubensis Harrington

The Devonian sequence, which has been termed Itacurubí group, may be correlated with the Paraná group of São Paulo and Paraná, but no close lithological comparison is possible. In particular, the Furnas sandstone and the Ponta Grossa shale "facies", which form such a persistent succession in Brazil and Uruguay, cannot be recognized in Paraguay.

In the Chaco area, Devonian rocks are exposed in a tiny outcrop near Fortín Aroma. The beds, discovered by J. W. Moran, are medium-grained, light brownish-pink sandstone and have yielded *Leptocoelia flabellites* (Conrad). Farther southwest, Devonian rocks are extensively developed in the subsurface. The Picuiba and Santa Rosa deep borings (Union Oil Company of California) disclosed about 2000 m of Lower Devonian sedimentites, mainly dark-gray to almost black shale and silty shale, bearing fossils in many levels. The most characteristic species, identified by the writer, are:

Leptocoelia flabellites (Conrad)
Schellwienella inca (d'Orbigny)
Australospirifer antarcticus (Morris et Sharpe)
Australostrophia sp.
Tentaculites jacculus Clarke
Nuculites sp.
Hadrorhachus australis (Clarke)

The base of the sequence was not reached, and the Devonian beds, showing a facies not unlike that of the Cordillera Real formation of Bolivia, are capped by reddish sandstones of possibly Late Paleozoic age.

Permian (Cuc and Pmc).—The Santa Catarina "system" of the Paraná basin is extensively developed in eastern Paraguay, but, although the beds can be generally correlated with the Brazilian sequence, no detailed agreement exists.

The sequence begins with the Tubarão formation (Cuc on map), which the writer prefers to regard as Lower Permian. The lower junction is nowhere displayed, and the formation is rather poorly exposed in a narrow band east of the Devonian outcrops. It consists of glacial conglomerates with lenticular intercalations of massive, yellowish-white silicified sandstone and hard, fissile olive-green shale banded like varves. In Paraguay, as in Uruguay, no distinction can be made between Itararé glacials and Bonito sandstones. A thin, reddish, shaly, medium-grained sandstone near the top of the sequence, exposed southwest of Villarrica, has yielded *Mesosaurus* remains, originally discovered by Beder in 1920. It is difficult to calculate the total thickness of the Tubarão formation in Paraguay, but apparently not more than 250 m is displayed.

The Tubarão formation is succeeded, with slight angular unconformity, by the Independencia formation, which seems equivalent to the Estrada Nova-Rio do

Rasto beds of Brazil. These are the rocks marked PMc on the map, properly regarded as Upper Permian. In Paraguay, however, no equivalent of the Palermo and Iratí shales of Brazil has been found, and the Independencia formation rests on Tubarão deposits and even transgresses on Lower Devonian beds.

The Independencia formation is excellently exposed directly east of Villarrica where it attains about 450 m. It begins with 150 m of massive, medium-grained, cross-laminated feldspathic yellowish-brown or pink sandstone. These are succeeded by 50 m of fine-grained, thinly bedded light-brown shaly sandstone alternating with thin beds of yellowish and light-gray clay-shales. The upper 250 m is formed of fine- to medium-grained, little-cemented to friable feldspathic sandstones, light pink to yellowish pink with occasionally more reddish tones. They display well-developed cross-lamination with straight foresets much like the lower beds of the formation, which they resemble in many other respects.

Fossils have been found in three levels within the Independencia formation. The first level is practically at the base of the sequence, and the fossils were discovered by Beder (1923) near Villarrica and by Windhausen almost midway between San José and Valenzuela. Only one determinable species has been found, and the Valenzuela material was identified by Cowper Reed in 1935 as *Pinzonella* cfr. *illusa* Reed.

A second fossiliferous level near the base of the upper sandstones at the locality known as Melgarejo, west of Colonia Independencia, has yielded fragments of wood, probably *Araucarioxylon.*

The third level is in the lower third of the upper sandstones. The fossiliferous locality lies 800 m south of Hotel Tilinsky in Colonia Independencia and was discovered by Boettner. The fossils are in a single silicified layer about 25 cm thick, and only two species of pelecypods have been discovered, identified by the writer as *Pinzonellopsis occidentalis* (Reed) and "*Pseudocorbula*" *anceps* Reed.

The Independencia formation displays a typical continental facies, and the pelecypods in it are evidently lacustrine.

MESOZOIC

Triassic (Ṝc and Mzb).—East of Villarrica the Independencia beds are succeeded by a group of red sandstones which has been named Misiones formation. These beds are also extensively exposed in the Misiones region south of the Rio Tebicuary, between Asunción and the Ypacaraí depression (Fig. 2), in the northern part of the country between Bella Vista and Capitán Bado, and in the Bogado-Encarnación district near the Upper Paraná River.

East of Villarrica the basal junction of the Misiones beds is not displayed, but here they evidently overlie the Independencia formation. In the Asunción-Ypacaraí area they rest on Lower Silurian sedimentites and in the Misiones district they overlie Precambrian rocks. The unconformable and transgressive relation of the Misiones formation to the underlying rocks is, therefore, evident.

The Misiones formation consists of dark-red sandstones, occasionally somewhat brownish and weathering reddish brown. The dominant rock is medium- to coarse-grained, characterized by highly rounded, smooth quartz grains which, however, are far from spherical. The grains are loosely cemented by a shaly-hematitic mix-

ture. The sandstones are generally massive and stratified in thick layers, but occasionally they are thinly bedded and display cross-lamination with straight, steeply inclined foresets and subparallel topsets and bottomsets. The laminae are characterized by slight textural changes and are not sharply defined by bedding planes.

Many of the more massive varieties contain small scattered pebbles of quartz and quartzite. These are smooth, well rounded, and subellipsoidal and may be quite abundant in certain thin levels. Occasionally even true conglomerates are observed, as in the neighborhood of San Juan Bautista, where a layer about 1 m thick appears between the sandstones. Here the roundstones attain up to 15 cm in diameter, and more than 15 per cent is formed of banded agate.

A few kilometers east of Santa Rosa the sandstones are strongly silicified and contain abundant agate nodules, identical to the agate amygdules of the Serra Geral basalts. The nodules are up to 20 cm in diameter, and their surfaces are irregular, full of salient points insinuated between the sandstone grains. They are best explained as epigenetic concretions originated by hydrothermal action related to the Serra Geral volcanic activity.

Though difficult to estimate, the total thickness of the Misiones formation is probably not less than 200 m. In the Asunción and Misiones areas the beds are not capped by younger formations, but east of Villarrica and Villa Encarnación they are succeeded by the Serra Geral basalts and, apparently, interbedded with the first flows.

The Misiones formation seems to be the equivalent of the upper Triassic eolian Botucatú sandstones of Brazil. The Misiones beds, however, are only partly eolian. Massive, rather shaly and structureless sandstones quite similar to the typical "Upper Botucatú" are magnificently exposed at Itapitapunta, along the Paraguay River banks near Asunción, but even here small pebbles scattered in certain levels indicate that at least part of the sequence is definitely not eolian. The noneolian character of the beds is even more apparent in the Misiones region where conglomerates are interbedded with the sandstones. These beds, which represent the lower part of the sequence, are best compared with the Aquidauana sandstones of Mato Grosso.

The eastern part of the country, including the Amambahy-Mbaracajú hills, is covered by the extensive lava flows of latest Triassic (and early Liassic?) age which, in Brazil, have been termed Serra Geral eruptives (Mzb).

Most of the Serra Geral eruptives are plateau basalts, although more mesosilicic types are frequently observed. The predominant variety is a dark brownish-purple to brownish-violet basalt, with aphanitic groundmass and a few small mafic phenocrysts; it is highly amygdaloidal, and the cavities are filled by agate.

The basalts have been extruded by linear eruptions, and the series is formed by the superposition of many individual flows which aggregate about 700 m thick.

It seems that the first flows were coeval with the accumulation of the last Misiones sandstones. In addition, thin sills intrude the Misiones formation as well as the Independencia beds. One vertical dike cuts the Lower Silurian rocks near Piribebuy.

Volcanic necks of uncertain age (not shown on the map) are rather frequent in

certain areas of eastern Paraguay. Owing to erosion they form conspicuous conical hills, either isolated or in clusters. Most of them are basic rocks, and they are particularly numerous in three distinct regions: (1) the area between Asunción and the Ypacaraí depression, where they pierce the flat-lying Misiones sandstones; (2) the Quiindy-Sapucay district, where they protrude from the Lower Silurian Caacupé group; and (3) the vicinity of Villarrica, where they cross the Permian Tubarão formation.

One of these necks forms the Tacumbú Hill at Asunción, a small conical peak about 500 m across and less than 50 m high. According to Milch (1905) the rock is a limburgite with the chemical composition of a nepheline basalt. Two small necks near Areguá are reputed to be trachyandesite, while a fairly large one near Sapucay is said by Milch to be a phonolitic rock with haüyne. In the Quiindy region some of the larger igneous masses merit the name of plutons as they are more than 4 km across. Many are formed of syenitic rocks. Similar rocks are also known near Villarrica.

Some of the necks, however, are formed of normal calc-alkali rocks, such as olivine gabbro, dolerite, and basalt. The Lambaré Hill south of Asunción belongs to this class. Sometimes phanerocrystalline and porphyritic facies are found side by side in the same outcrop, as in a very small neck at the edge of Mbocayaty village north of Villarrica.

Lastly, a small conical hill rising almost along the midline of the Ypacaraí depression 2 km south of Ypacaraí village is formed of a dark-gray, almost black rhyolite with small quartz phenocrysts and microfelsitic groundmass. This rock is quite different from the Precambrian rhyolites exposed farther south.

The basic and mesosilicic rocks forming most of the necks are almost impossible to date. They may be anything from latest Triassic to Tertiary; the lower limit is fixed by the fact that the necks pierce the Misiones sandstones in the Asunción district. They may be tentatively regarded as Jurassic. The small isolated rhyolitic neck near Ypacaraí, on the other hand, is probably Tertiary, a possibility rendered likely by its location near the central line of the Ypacaraí graben.

CENOZOIC

Quaternary (Qc).—Pleistocene deposits cover the Chaco plains and very extensive areas of eastern Paraguay, especially the southern region between the Rio Tebicuary and the Paraná and the district between Concepción, Curuguaty, and Asunción.

No detailed study of these deposits has been made. Most of them are very fine silty sands, silts, and clays, partly of eolian and partly of fluviatile and lacustrine origin. Though sometimes these sediments are deep red, no true laterites are found in Paraguay, and almost invariably the color is due to the fact that they are derived from the erosion of the red Misiones sandstones. Very few fossils have been recovered from these deposits. In the neighborhood of Asunción they have yielded a few gliptodontid and gravigrad remains which have not been studied in detail.

STRUCTURAL GEOLOGY

The geologic structure of Paraguay is quite simple. The region east of the Paraguay River forms the western border of the huge Paraná basin, and, accordingly,

the sedimentary beds resting on the Precambrian basement are gently tilted toward the east and east-northeast, with a mean angle of about 2°–3° (Fig. 2).

In the northern and southern extremities of the country, the Precambrian exposures form the cores of two large and gentle swells along the western border of the Paraná basin, and the area between Concepción and Asunción seems to be formed by an even gentler depression or secondary basin.

In the Cordilleran region between Ypacaraí and Barrero Grande, the Silurian beds have a general north-northwest strike and dip 1°–3° east-northeast. The beds, however, are gently undulating and occasionally almost horizontal. The succeeding Lower Devonian strata show an almost imperceptibly stronger undulation. Between Barrero Grande and Itacurubi the strike is usually around N. 50° W., and the dip ranges between 0° and 5° NE. Small but fairly strong flexures and even tiny folds passing into small faults of slight displacement are observed. The intensity of the folding seems to increase eastward in the Permian belt of outcrops. The few and small exposures along the San José-Oviedo road show that the beds locally dip as much as 2° SW. Almost midway between Oviedo and Villarrica the tillites and interbedded sandstones dip 2°–3° NE., and south of Villarrica the *Mesosaurus*-bearing sandstone, striking N. 40° W., dips 5°–8° SW. At the same time it is obvious that the large open folds do not descend toward the east, or, if so, the angle of descent is very small.

Farther east the Independencia beds seem to be less disturbed and more uniformly dipping east-northeast with a mean angle of about 2°–3°. No western dips are observed, but in certain places the beds are practically horizontal.

Although the Tubarão-Independencia junction is nowhere displayed, the Independencia formation shows transgressive relations to the underlying strata. This is clearly indicated by the fact that, almost midway between San José and Valenzuela, a small isolated exposure of fossiliferous Independencia beds is surrounded by Lower Devonian sandstones.

The regional structure is even simpler south of the Cordilleran area. In the Carapeguá-Quiindy district the Silurian beds rest almost horizontally on Precambrian granite, while in the San Juan Bautista area the ancient rocks are covered by the Misiones sandstones, gently dipping southward. It is obvious that the Misiones sandstones are transgressive over the underlying formations and that this relation is not a simple stratigraphic overlap but is due to a primary unconformity and denudation prior to the accumulation of the Triassic beds. The actual unconformity is observable west of the Ypacaraí lake, where the red Misiones sandstones, strongly, but uniformly dipping west, directly overlie the much-contorted, folded, twisted, and brecciated fossiliferous Silurian beds.

The simple tectonic structure of eastern Paraguay shows a single complication. This is due to a fault zone of general north-northwest strike along the western foothills of the Cordillera, which is responsible for the Ypacaraí depression. This is a long, almost rectilinear valley, 6–8 km wide and 65 km long, extending from the Paraguay River to the town of Paraguarí; its northern part is occupied by the shallow (3 m) Ypacaraí lake. The valley is flanked by fairly high and abrupt hills, which immediately suggest fault scarps.

The eastern border of the depression is formed by the lower part of the Silurian group. The basal conglomerates, which at least in San Bernardino directly overlie Precambrian granite, crop out along the lower part of the western slope of the Cordillera and are immediately succeeded by the lower section of the Caacupé sandstones. These beds are gently tilted eastward and do not show signs of local tectonic disturbances.

The western flank of the depression is also formed by Silurian beds. In sharp contrast with the undisturbed attitude of those exposed along the eastern border, however, they are here strongly twisted, contorted, and brecciated. On the western side of the Ypacaraí lake, directly in front of San Bernardino, a large quarry discloses reddish sandstones and fossiliferous clay-shales which contain the same species found at Cerro Aparipí almost at the top of the cross-laminated Caacupé sandstones. The clay-shales are highly contorted and locally thickened, in places displaying a vertical attitude, and elsewhere dipping steeply westward. Huge blocks of reddish sandstone are mixed with the semiplastic clay-shale forming a typical tectonic breccia. As the quarry is practically on a level with the granite outcrops of San Bernardino and as the fossiliferous clay-shales are identical to those of Cerro Aparipí, the western border of the Ypacaraí Valley has been relatively downthrown several hundreds of meters (Fig. 2).

The breccia is not restricted to the quarry but may be followed all along the western border of the depression to the town of Paraguarí. It is about 300 m thick in the Pirayú district where it is formed of sandstone with occasional blocks of conglomerates. No clay-shales are found here nor farther south, near Paraguarí, where conglomerate fragments are more abundant. It is evident, therefore, that in this region the total downthrow was considerably less than in the northern area.

Although the Caacupé formation is not disturbed on the eastern side of the Ypacaraí depression, clear evidence of strong faulting is observed in the western flank of Cerro Jhú, about 2 km northeast of Paraguarí. Cerro Jhú itself is formed of Silurian conglomerate succeeded by cross-laminated sandstone, gently dipping 2° E.-NE. A small hillock, rising along the western foot of Cerro Jhú, is formed of shaly sandstone grading upward into hard, green, banded shale quite similar to varved clay. A large cobble of pink granite was found embedded in this shale. The banded sedimentite is so similar to varved clay that it is impossible to doubt its glacio-lacustrine origin. In eastern Paraguay this is equal to admitting a Permian age, as no glacial deposits of other periods are known in the Paraná basin.

The rocks just mentioned can be studied in a road cut about 300 m long where they are strongly folded; the strike ranges between N. 30° E. and N. 20° W. and the dip between 45° E.-SE. and 45° W.-SW. The strong disturbance of the beds is a direct consequence of faulting; the gap between Cerro Jhú and the western hillock is located over a main fault of general northwest strike.

The Ypacaraí depression, therefore, should be considered a true graben. This seems clearly indicated by the transverse section between Cerro Jhú and Paraguarí, where both eastern and western borders of the valley are formed of Lower Silurian strata, while Permian beds seem to be buried beneath the alluvial floor of the depression. Moreover, it seems that the western border was downthrown in relation

to the eastern, the downthrow being slight in the southern extremity but considerable near the northern end.

The Ypacaraí depression ends suddenly at Paraguarí, where the Cordillera abruptly turns to the east. This suggests that the graben ends against a transverse fault of general east-west strike which runs along the southern foothills of the Cordillera parallel to the railway line between Paraguarí and Caballero.

The age of the faulting which originated the depression is difficult to determine as the evidence is somewhat contradictory. It seems likely, however, that the graben was first delineated by Triassic faulting which took place after the accumulation of the Permian beds and prior to the deposition of the Misiones sandstone, and that a renewal of the movements along the same main lines occurred during late Tertiary time and continues even at present. On the evening of December 24, 1944, a quite noticeable earthquake was felt all along the Ypacaraí depression from Paraguarí to San Bernardino. The shock was rather strong and was attended by loud brontides.

GEOLOGIC HISTORY

Little can be said regarding the Itapucumí limestones except that they probably represent marine deposits laid down by an Ordovician transgression. During Late Ordovician time a general uplift occurred, and the eastern Paraguayan region was extensively eroded and peneplained. The Precambrian rocks were laid bare at many localities.

At the beginning of Silurian time a general depression was in progress, and the sea invaded, probably for the first time, the area which was to be known as Paraná basin. The Early Silurian (Valentian) transgression was responsible for the accumulation of the Caacupé group characterized by a shallow-water unda facies.

During Late Silurian time the area was gently uplifted once again, and after slight erosion of the Caacupé beds a general depression of the basin took place at the beginning of the Early Devonian. The sea once again invaded the Paraná basin, and the shallow-water epicontinental Itacurubí sandstones and shales were deposited, also mainly under unda conditions.

During Middle Devonian time there was a new regression. A general uplift was in progress, but probably the Itacurubí beds were raised little above sea level. A long erosion period ensued, which lasted from Middle Devonian to latest Pennsylvanian, and the country was once again extensively peneplained.

In early Permian time a general lowering of the temperature brought about a glacial period, responsible for the accumulation of the continental tillites, sandstones, and varved clay of the Tubarão formation. These beds are of continental accumulation, and in eastern Paraguay there is no indication of marine deposition during this epoch; the *Mesosaurus*-bearing sandstones are probably marginal lagoon deposits. The Paraguayan sector of the Paraná basin has remained a region of intermittent continental erosion and accumulation; it has not been invaded by the sea since early Permian time.

Probably during the latter half of Permian time, a gentle uplift of the basin caused renewed erosion. This movement, which was responsible for the tilting and folding of the Lower Paleozoic and Tubarão formations, was probably accompanied by

faulting along the western border of the Paraná basin originating the main features of the Ypacaraí graben. The period of erosion which followed was comparatively short, but the Permian beds were partly and even wholly destroyed in some places, the denudation even reaching the Lower Devonian rocks. During Late Permian time the Independencia formation, with beds of exclusively continental facies was deposited over a peneplained or at the most a gently undulating surface, cutting both the Lower Permian and the Lower Devonian formations. They show, therefore, unconformable and transgressive relations to the underlying formations.

During late Triassic time a new and very important period of erosion removed extensive areas of Independencia beds and underlying formations down to the Precambrian, which was once again laid bare in southern Paraguay. The strongest erosion was along the western border of the Paraná basin, owing to differential uplift. While the central part of the basin, east of Paraguay in the Brazilian states of Mato Grosso and Paraná, remained almost stationary, its western border was strongly uplifted and subsequently eroded.

At the close of the Triassic the Misiones sandstone was deposited over the new erosion surface. These beds are of typical continental origin and mainly fluviatile, but eolian intercalations are frequent in the upper part.

During latest Triassic time (or possibly in earliest Liassic?) a vast amount of basaltic lava flows was extruded in the central part of the Paraná basin, forming the so-called Serra Geral eruptives. During an unknown period, but probably still in the middle Mesozoic, volcanic activity of central-vent type formed the basic alkali rocks now exposed in scattered necks between Asunción and Villarrica.

Much later, probably during the Late Tertiary, radial movements were felt once again along the western border of the basin. These movements are responsible for the present structure of the Ypacaraí graben and the Asunción-Itaguá horst bordering the wide Chaco plains.

SELECTED REFERENCES

BEDER, R., (1923) *Sobre un hallazgo de fosiles pérmicos en Villarrica, (República del Paraguay)*: Bol. Acad. Nac. Cien. Córdoba, vol. 27.

BEDER, R., AND WINDHAUSEN, A., (1918) *Sobre la presencia del Devónico en la parte media de la República del Paraguay:* Bol. Acad. Nac. Cien. Córdoba, vol. 33.

BOETTNER, R., (1947) *Estudio geológico desde Puerto Fonciere hasta Toldo-Cué:* Rev. Fac. Quim. Farm., Univ. Asunción, no. 6–7.

GOLDSCHLAG, M., (1913) *Beiträge zur Kenntnis der Petrographie Paraguays:* Berlin.

HARRINGTON, H. J., (1950) *Geología del Paraguay Oriental:* Fac. Cienc. Exactas, Univ. Buenos Aires, Contrib. Cient., Ser. E.: Geol., vol. 1.

MILCH, L., (1894) *Über Gesteine aus Paraguay:* Tscherm. Min. u. Petr. Mitt., vol. 14, p. 383.

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PARAGUAY

Horacio J. Harrington

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