Geology and Mineral Resources of Paraguay— A Reconnaissance

GEOLOGICAL SURVEY PROFESSIONAL PAPER 327

Prepared in cooperation with the Departamento de Geología, Ministério de Obras Públicas y Comunicaciones, República del Paraguay, under the auspices of the Institute of Inter-American Affairs

Geology and Mineral Resources of Paraguay— A Reconnaissance

By EDWIN B. ECKEL

With sections on

IGNEOUS AND METAMORPHIC ROCKS

By CHARLES MILTON *and* EDWIN B. ECKEL

SOILS

By PEDRO TIRADO SULSONA

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By Edwin B. Eckel

ABSTRACT

Although this report includes the results of a 6-month reconnaissance investigation of the geology and mineral resources of Paraguay, it is essentially a compilation and interpretation of existing published and unpublished information on the subject.

The rocks can be divided into five major classes, depending on age and mode of origin. The oldest are of Precambrian age, here subdivided into an older group of metamorphic rocks and a younger group of granitic rocks. They are a part of the Brazilian shield and underlie the entire country but are exposed at the surface in only a few places. The second group consists of marine sedimentary rocks and ranges in age from Cambrian or Ordovician through Early Devonian. It comprises three mappable units, here called the Itapucumí series, the Caacupé series and the Itacurubí series. The third group, which ranges from Pennsylvanian through Triassic in age, constitutes the Gondwana or Santa Catarina continental clastic sedimentary rocks known in a large part of South America. This group is divisible into three map units—the Tubarão series of glacial deposits, the Independencia series, and the Misiones sandstone, and, like the marine beds of Paleozoic age, is much thinner in eastern Paraguay than it is in parts of the Gran Chaco in the western half of the country. The fourth group is Tertiary to Recent in age and consists in large part of unconsolidated clay and sand of continental origin. These materials are very thin in most of eastern Paraguay, but they cover nearly all of the Gran Chaco to depths as great as 2,000 feet.

The fifth large group of rocks consists of igneous extrusive and intrusive rocks, mostly of basic composition. The most important single member is the Serra Geral basaltic lava, of Late Triassic or Jurassic age, which covers the eastern edge of the country and extends far into Brazil. Associated with the Serra Geral lavas are many smaller bodies of intrusive diabase, extrusive basalt, and possibly other rocks. There are also many intrusive and extrusive igneous rocks whose age is unknown. Some are strongly alkalic and of considerable interest petrographically; some may be related in age and origin to the Serra Geral lavas, but for others there is strong evidence that they are no older than late Tertiary. Chemical and spectrographic analyses of a number of samples of the igneous rocks are included in the report.

The geologic structure of Paraguay appears to be relatively simple in its grosser aspects, but little is known of even the larger features. In the eastern half of the country the beds dip gently eastward toward the great Paraná basin of southeastern Brazil. This easterly dip appears to reverse along the axis of a low anticline that trends north-south only a few kilometers east of the Río Paraguay and exposes the older sediments and the Precambrian basement rocks at the surface in many places. West of this axis the beds either dip steeply westward, or are downfaulted to the west, into the depths of the Gran Chaco basin. The rocks in this basin are, in places, at least 10,000 feet deeper than they are in eastern Paraguay; west of the basin, in eastern Bolivia, they rise to the surface in a series of anticlines and synclines that form the foothills of the Andes.

Paraguay possesses large quantities of certain nonmetallic mineral resources, notably clays for brick, tile, and pottery; limestone and other raw materials for portland cement and for lime; common and ornamental building stones; glass sand; talc; and mineral pigments. Except for iron ore, of which there are many small but rich deposits, Paraguay appears to be poorly endowed in most other mineral resources. It has a little manganese, copper, mica, and beryl and there are good geologic reasons for hoping that worthwhile deposits of salt, gypsum, and bauxite may yet be discovered.

Aside from wood, and water power that is both remote and undeveloped, the only known source of fuel or energy lies in some little-known peat deposits near Pilar. Petroleum may exist in the Gran Chaco basin, but proof of its presence must await a willingness on the part of Paraguayan or other investors to risk much more money than has already been spent in one exploratory campaign.

Besides the available facts on all of the country's known and reported mineral resources, a number of suggestions are given for establishing local industries that could provide mineral products for local use and conserve some of Paraguay's foreign exchange. By all odds the most valuable and promising of Paraguay's mineral resources are the water resources, both surface and underground, and the soils.

INTRODUCTION

PRESENT INVESTIGATION

The investigation recorded here was a part of the United States' Point Four program of giving technical aid to underdeveloped countries. The author was assigned by the U. S. Geological Survey to act as geologic technical advisor to the Government of Paraguay under the auspices of the Institute of Inter-American Affairs. He was in Paraguay from February 25 through August 6, 1952. In addition to the work whose results are recorded here, his duties included advice on the establishment and maintenance of a Department of Geology and Mines, as well as the related problems of staffing and training geologists and engineers for such a Department. These latter duties were discharged by means of official written and oral communications to the Government of Paraguay.

This report contains a base map and a geologic map that are as complete as can be expected from the facts now available. The chief contributions of this report are that it assembles in one place most of the hitherto widely scattered published information on the geology of Paraguay; it contains a considerable amount of hitherto unpublished information collected from various sources; it presents new facts, based on modern petrographic and chemical methods, on a few of the igneous rocks; and it contains an objective summary of the country's mineral resources and its potentialities as a mineral producer. This summary is not as optimistic as many would hope, but it does point out a few real possibilities and narrows the areas that most deserve further study.

The report is, then, a compilation and interpretation of existing information on the geology and mineral resources of Paraguay based on a 6-month reconnaissance study, but if it were confined to recording personal observations during that period it would be a "thin" report indeed. Travel conditions in Paraguay are difficult at best, and were made somewhat more so by greater than average rainfall during the winter of 1952. These and other tangible and intangible factors permitted field work for considerably less than half the total time available for the project. The author's personal observations were limited to a comparatively small part of central Paraguay, plus spot studies at the termini of a few airplane trips; these flights permitted excellent aerial views of representative cross sections of the country. These personal observations were greatly supplemented by the use of aerial photographs, by the study of specimens in various museums and private collections, and by data supplied by several geologists and others who had observed and recorded the geology at particular spots.

The facts gathered would, by themselves, have been been utterly insufficient as a basis for a report of the scope attempted here. Personal observations, supported by studies of the small collections of rocks and fossils have, however, given a clearer understanding of the existing literature on the subject. They have also given a modicum of confidence in this attempt to gather published information on the geology of Paraguay and to integrate it with facts observed by workers in neighboring countries, where geologic knowledge is more advanced than in Paraguay.

Throughout this report an effort has been made to distinguish between fact and fancy as well as between the author's own contributions and those of others. Since facts that are absorbed by the mind, regardless of their source, have a tendency to emerge as new discoveries, these efforts have doubtless been only partially successful. The reader would, therefore, do well to remember that the present author is a compiler of scattered information, rather than a recorder of his own observations. Naturally, he must bear responsibility for all the interpretations, good or bad, that have been drawn from the basic data.

PREVIOUS GEOLOGIC INVESTIGATIONS

A considerable body of knowledge on the geology and mineral resources of Paraguay has been accumulated through the years. Most of this information, however, is widely scattered through the world literature of geology, where it appears in several languages, or exists only in unpublished files or in the memories of individuals who have made observations of particular spots or restricted areas. It should be remembered, too, that until 1938 more than half of the Gran Chaco belonged to Bolivia, hence descriptions of this area in the older literature are referenced under the name of that country. The pertinent literature that has been found is listed in the annotated bibliography, which contains a number of items that are not referred to specifically in the text. Such items have served a purpose by providing needed background for other facts and all will be of interest to future serious students of the subject.

The most complete descriptions of the geology of Paraguay that have appeared in print are the recent papers by Harrington (1950, 1956). Unfortunately, his work is limited to the eastern part of the country and is based on only a few weeks fieldwork. Even with these limitations, he was able to present a clear and accurate picture of the stratigraphy and geologic history, one on which the present author has leaned very heavily in preparing this compilation. The only other comprehensive study of the geology known to the author is that made by the Union Oil Company during its exploration for petroleum in 1944–49. In addition to the drilling of five deep wells, this company is understood to have done reconnaissance geologic mapping of the entire country, plus a very large amount of geophysical explorations in the Gran Chaco. Of the information accumulated, only the records of the deep wells and fossil identifications made by Dr. Horacio J. Harrington are available for publication.

Among the older descriptions of the geology of eastern Paraguay, those of Carnier (1911, 1913), supplemented by Goldschlag's (1913) chemical and petrographic descriptions of Carnier's rocks, are by far the most useful; much dependence has been placed on them here and in the compilation of plate 1. Kanter (1936) gives the most complete description extant of the geology of the Gran Chaco region. DeMersay (1860) and DuGraty (1865) give far more complete accounts of the country's mineral resources than any more modern workers and both give, in addition, many notes on the geology. M. S. Bertoni (1921), A. deW. Bertoni (1939), G. T. Bertoni (1940), Conradi (1935), and Boettne

(1947, 1952) are the only Paraguayan writers who have contributed materially to the literature; each of their papers supplies data on areas or on phases of the geology that are not to be found elsewhere.

Information gleaned from the literature on Paraguay has been supplemented in part by unpublished facts generously furnished by various individuals who have visited parts of Paraguay. Another valuable source of information is, of course, the literature on the geology of the neighboring countries. The summary works of Ahlfeld (1946) on Bolivia, of Oliveira and Leonardos (1943) on Brazil, and of Stappenbeck (1926) on Argentina are particularly helpful in understanding and collating the relatively few scattered bits of knowledge on Paraguay itself.

MAPS OF PARAGUAY

Base maps on a scale sufficiently large to use for detailed geologic mapping are not available for any part of Paraguay. There are, however, several sets of maps that are adequate for reconnaissance investigations.

The Mapa Provisional de la República del Paraguay, published in 1945 by the Instituto Geográfico Militar, is the best base map produced in Paraguay. Published on a scale of 1:1,000,000 (1 cm=10 km) as well as on several smaller scales, it can be purchased from the Instituto and from several book stores in Asunción. Though very generalized in many places, it is particularly useful for its delineation of all roads and trails in the country and for location of towns and settlements and official spelling of their names. It contains no information as to altitudes, but the main topographic features are shown by shading.

Various sheets of the Carta Aeronáutica de la República Argentina, published by the Instituto Geográfico Militar of Argentina in 1945 and succeeding years, cover the entire Republic of Paraguay. On scales of both 1:500,000 and 1:1,000,000, they are not easily available in Paraguay but can be purchased "over the counter" from the Instituto Geográfico Militar offices in Buenos Aires. Like the Paraguayan map described above, their portrayal of many natural and cultural features is much generalized, but they have great usefulness because of their detailed data on aerial navigation. Perhaps even more important to the geologist, they show the elevations of many points and portray the shape of the land by means of reasonably accurate contours at intervals of 100, 200, 500, and 1,000 meters.

The Asunción, Corumbá, Río Apa, Río Pilcomayo, Sucre, and Tucumán sheets of the World Map, of the American Geographical Society published in 1940 and succeeding years on a scale of 1:1,000,000, with topography shown in colors by 100-meter intervals, were used extensively for checking place names and topographic relationships.

A set of preliminary base maps published in 1949 and succeeding years by the U. S. Aeronautical Chart Service cover all of Paraguay except two small areas—one along the Cordillera de Amambay in the northeastern corner, and the other along the upper reaches of the Río Paraguay, near the common junction of Paraguay with Bolivia and Brazil. These maps, on a scale of 1:500,000 (1 cm=5 km), are not readily available to the public, but can be obtained for official use from the Headquarters, Aeronautical Chart Service, Washington 25, D. C. Prepared from trimetrogon aerial photographs with little or no ground control or field checking, they are inadequate as to identification of towns and other human features. Their portrayal of roads is even more inaccurate, particularly as to their classification and usability. On the other hand, the natural features such as streams and swamps are shown far more accurately than they are on any other maps known to the author. Land elevations are shown by 1,000-foot (300 meters) contours and by many point elevations. The detailed portrayal on most of the sheets of forested and cultivated lands as well as of swamps and other features is of incalculable value to the reconnaissance geologist, not only because they help to solve problems of location but because all these features have geologic meaning when properly interpreted.

In addition to the base maps mentioned above, there are aerial photographs for most of the country. Those known to the author are the trimetrogon photographs, taken by the U. S. Air Force in 1943 through 1945, which were used in compilation of the preliminary base maps described above. The pictures were taken at altitudes of 20,000 feet, and cover virtually all the country except the northeastern corner. The strips of vertical pictures were extremely useful in both field and office for studying and mapping geology. The oblique pictures were also useful in studying general relations, but they are not easily adapted to field mapping without special trimetrogon stereoscopic equipment that was not available in Paraguay at the time of this investigation. Complete sets of prints of the trimetrogon pictures are available for official use in Washington, D. C., in the offices of the Aeronautical Chart Service and in Asunción in the Instituto Geográfico Militar. In 1952, an exasperatingly incomplete set of prints was also available in the Asunción office of the Institute of Inter-American Affairs.

All the maps and pictures described above and much material from other sources were used in compiling the

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base for plate 1. The compilation was done under the author's direction by Mrs. Gladys Benedict of the Geological Survey. This base, originally compiled on a scale of 1:1,000,000 for reduction to the present scale of 1:1,500,000, is as accurate as the source data would permit and is far more accurate in most places than the geologic map for which it was primarily prepared. It admittedly lacks completeness in at least two important respects—its portrayal of towns and roads. To have shown all of the towns, forts (fortin), ports (puerto), and ranches (estancia) that are shown on other base maps of the country would have cluttered this map unnecessarily; instead it was decided to show only the more important places, plus smaller ones whose names or locations were needed in describing the geology. Similar decisions were made with regard to roads. A great majority of the innumerable roads shown on other base maps are only cart tracks; many of them are difficult to find on the ground, and even more difficult to travel during large parts of every year. Only the more important roads—ones that are believed to be usually the best means of access to the towns shown on the map—are shown on plate 1. The map user who is interested in other places will find their approximate locations, and possible routes of travel thereto, on some of the other base maps described above. The traveler will also do well to make inquiry of local inhabitants.

Most of the names of places or of natural features are taken from the Guaraní language or from a mixture of Guaraní and Spanish. Because many of these names are descriptive of the local scene, some knowledge of their meaning is helpful to any reconnaissance natural scientist. The dictionaries of Bottignoli (1926) and Ruiz de Montoya (1876) are helpful, as is a brief glossary given by DuGraty (1865).

ACKNOWLEDGMENTS

The author is indebted to many officials of the Ministério de Obras Públicas y Communicaciones, Republic of Paraguay, of the Institute of Inter-American Affairs, in both Asunción and Washington, and of the U. S. Geological Survey for the many facilities and the constant advice and encouragement that made his work possible. In particular, the help of Ing. Ricardo Mazó Ugarriza, Jefe, Departamento de Geologia, Ministério de Obras Públicas y Communicaciones warrants special acknowledgment for his direct and indirect contributions to the work. Except for that part of his time that had to be devoted to administrative and related duties of his own Department, he worked with the author for the entire period of the latter's visit, acting as co-observer, interpreter, and friend. In addition, he contributed the many data on the subject that had been accumulated in the past by his Department.

Messrs. Charles Milton of the Geological Survey and Pedro Tirado Sulsona of the Institute of Inter-American Affairs deserve special thanks for contributing the chapters on igneous rocks, and on soils, respectively, as does Mrs. Gladys Benedict who compiled the base map used for plate 1. Messrs. A. J. Boucot, A. R. Palmer, and R. J. Ross, all of the Geological Survey, studied the paleontologic evidence that is available for the Paleozoic rocks.

Dr. Horacio J. Harrington, then of the Universidad de Buenos Aires but later a visiting lecturer on geology at the University of Kansas, was kind enough to advise the author of many of his unpublished geologic observations and also helped immeasurably by reviewing this report in manuscript form. His critical but friendly eye, backed by vast knowledge of South American geology, caught many errors that would otherwise have found their way into print here.

Mr. Robert Miller of Asunción gave largely and generously of his time and special knowledge of many of the mineral deposits as did Mr. Albert Morris with regard to his records of water wells and his geologic observations in many parts of the country. Unpublished reports for the Institute of Inter-American Affairs by Elvin A. Duerst and Bertram H. Lindman on economic resources and on the transportation problem were of much help, as were the many additional facts supplied informally by Mr. Duerst.

Finally, a great many other people, both public officials and private citizens, gave freely of their time, knowledge, and hospitality; sincere thanks are hereby extended to all of them.

GEOGRAPHY

Much of the material in this section is derived from the report by Duerst (1952) and from other unpublished reports on file in the Asunción and Washington offices of the Institute of Inter-American Affairs.

LOCATION AND AREA

Paraguay, one of the two land-locked countries in the Americas, lies south of the center of South America, between latitudes 19° and 28° S. and longitudes 54° and 63° W. (fig. 1). The Tropic of Capricorn passes through its center at the latitude of Concepción. The total area of the country is about 407,000 square kilometers, or 40.7 million hectares (157,000 square miles), almost exactly that of California. Its extreme dimensions, both from north to south and east to west, are approximately 900 kilometers (570 miles). It is bounded by Bolivia, Brazil, and Argentina. Approxi-

FIGURE 1.—Index map showing the location of Paraguay.

mate airline distances from Asunción, the capital city, to capitals of neighboring countries are as follows:

	Miles	*Kilometers*
Buenos Aires, Argentina	650	1, 050
La Paz, Bolivia	610	980
Lima, Peru	1, 000	1, 610
Montevideo, Uruguay	650	1, 050
Rio de Janeiro, Brazil	920	1, 480
Santiago, Chile	1, 100	1, 770

TOPOGRAPHY AND DRAINAGE

The entire country is one of low relief (pl. 1), with altitudes ranging from 55 meters above sea level at the junction of the Río Paraguay and Río Alto Paraná to an extreme of 700 meters on one peak just east of Villarrica.

There is, however, a marked difference in the topography on the two sides of the Río Paraguay, which bisects the country along a north-south line. That portion east of the river, called Paraguay Oriental, is gently rolling to hilly, with nearly level valleys. Some of the relatively low hills and mountains occur in rather distinct chains. Made up in large part of soft sedimentary rocks or of deeply weathered basalt, the hills are being degraded by erosion processes and present low rounded outline in most places. Here and there, however, where there are outcrops of harder sedimentary or igneous rocks, they have more rugged shapes and present bits of spectacular scenery, albeit on a rather small scale.

The Chaco Boreal on the western side of the Río Paraguay, the Paraguayan part of the Gran Chaco, is a vast aggrading alluvial plain that rises almost imperceptibly westward from the river toward the foothills of the Andes not far within the Bolivian border. The monotony of this nearly level, poorly drained plain (see fig. 2) is broken only in its most northern part, where there are a few good-sized hills, both in Paraguay and in Bolivia, that mark places where islands of bedrock protrude above the thick alluvium.

Virtually all of Paraguay lies within the great drainage basin of the Río Paraná, which also drains appreciable parts of Bolivia, Brazil, Argentina, and Uruguay and empties into the estuarine Río de la Plata, above Buenos Aires. A few maps show a small area in the extreme northwest corner of Paraguay as drained by the Amazon, but the weight of existing evidence is that the entire country lies within the Paraná basin and it is so shown on plate 1.

The true Río Paraná heads at the southern tip of Paraguay at the junction of its two main branches, the Paraguay and the Alto Paraná. The Río Paraguay is the larger of these two and is the main avenue of drainage and of river commerce in the country. It heads in Mato Grosso, Brazil, and trends nearly due south. It

FIGURE 2.—Typical terrain and vegetation in the Gran Chaco. View about 30 kilometers west of Puerto Casado.

bisects the Republic of Paraguay in its lower reaches, and marks striking differences in topography, vegetation, and cultural development between the two parts of the country. It has a total fall of only 250 meters in its 2,500 kilometer course, and a speed through its Paraguayan portion of 5 to 7 kilometers per hour. It is several hundred meters wide in most places and is generally navigable as far as Corumbá, Brazil, by ships with 3-meter draft and even farther by smaller craft. Its course is characterized by innumerable meanders and by frequent channel shifts. From the Río Apa southward almost to Concepción the east bank is marked by discontinuous cliffs of limestone and marble, nearly vertical, and several tens of meters high in places. Elsewhere the sandy to muddy banks slope gently into the river or form steep cutbanks, carved from flood-plain alluvium and only a few meters high at most.

The Río Paraguay, with its tributaries, drains all but the southeastern portion of the country. The Río Pilcomayo, heading 2,000 kilometers westward in the Andes in Bolivia, and forming much of the international boundary with Argentina, is the largest tributary on the western or Gran Chaco side of the river. It is navigable in places by small boats. Except for its length and relative continuity, it is similar to any of the other streams that drain the Gran Chaco. Normally, they are all sluggish, intermittent, and discontinuous streams that wind their way slowly across the nearly level plains between banks that are seldom more than a couple of meters high. During rainy seasons they overflow their banks and spread over most of the land. Working together, first in one part of the Gran Chaco and then in another, they are still building up the plains. Their loads of mud, silt, and fine sand debris, carried down from the Andes, are redistributed over the plains during periods of overflow or by changes of course that take place on most streams, if not from year to year, at least from decade to decade.

Most of the eastern part of Paraguay drains into the Río Paraguay through seven main tributaries and several smaller ones. Five are 180 to 275 kilometers long and are navigable in part by small boats and barges, but all the tributaries are slow and shallow in most places and subject to frequent shifts in channel.

The Río Alto Paraná, about 3,000 kilometers long, heads deep in southeastern Brazil; in its lower reaches it forms the southeastern boundary of Paraguay for a distance of 850 kilometers. On its way toward Paraguay it meanders slowly across high basalt plains, but where it first touches Paraguay it plunges abruptly over a series of jagged basalt escarpments to form the awe-inspiring cataracts of Salto del Guairá. From these falls to Encarnación it is incised in basalt and follows a relatively straight, narrow and swift course as compared with its upstream or downstream portions. From Encarnación to its junction with the Paraguay the stream is broad and shallow, characterized by shifting, braided channels. It is navigable by moderate-sized craft as far upstream as Guairá. The southeastern part of the country drains to the Alto Paraná by means of 11 major tributaries, only 2 of which are more than 150 kilometers long. These, too, are slow meandering streams and resemble the tributaries of the Río Paraguay in all but two important respects. First, though their meanders superficially resemble the aimless wanderings of the rivers farther west, on closer study they are seen to be related to fracture patterns in the basalt flows that underlie most of the area. Second, most of the tributaries make their final descent into the Alto Paraná gorge by a series of low steplike falls or rapids where they cross the edges of the basalt flows. Recognition of these two features is of great help to the reconnaissance geologist. Moreover, the falls seem to represent the only potential source of hydroelectric energy that is not subject to international complications.

There are two fairly large permanent but shallow lakes in the country—Lago Ypoá and Lago Ypacaraí—and countless intermittent ponds, lagoons, and swamps, some of them enormous.

CLIMATE

The climate, comparable in some respects to that of southern Florida or south-central Texas, ranges from subtropical to tropical. Paraguay is an interior country of hot summers and mild winters, with the dominant characteristic of the weather extreme unpredictability from month to month and from year to year. The winter months, especially July through September are generally somewhat drier and considerably colder than the summer months, December through February, with rainfall ranging between one-fifth and two-thirds the average of all months.

The summer months and shorter periods throughout the year are hot and humid, though moderated from time to time by heavy rains that may last only a few minutes or may continue almost steadily for several days. Virtually all living habits, from housing arrangements to business hours, are adjusted to the predominantly warm parts of the year. This is particularly noticeable during the comparatively few cooler days of winter, when tile floors, high ceilings and the general lack of heating arrangements tend to make temperatures of 5° to 10°C (41° to 50°F) somewhat uncomfortable.

Figure 3 shows the geographic distribution of mean average temperatures by isotherms ranging from 22° to

24° C (72° to 75° F). The average maximum summer temperature measured during the same period, 1940–50, shown on figure 3 was 36°C (97°F) in the northern Gran Chaco and the average minimum winter temperature at Encarnación was 10°C (50°F). During this period, an extreme maximum of 43°C (110°F) was recorded in the Gran Chaco in July 1942, and extreme minimums of −4° and −5°C (21° and 23°F) were measured at Encarnación in July 1945 and in the Gran Chaco in July 1942. Five of the country's eight weather stations reported freezing temperatures or below in at least 1 month during the period 1940–50, and Encarnación had freezing weather in one or more months in each of the 11 years.

Figure 3 shows also that the average annual rainfall during the period 1940–50 inclusive ranged uniformly from 600 millimeters (23 inches) in the western Gran Chaco to 1,800 millimeters (71 inches) along the eastern border of the country. This uniform, and rather abrupt, increase in rainfall from west to east bears no apparent relationship to the local topography, hence is obviously controlled by more regional factors. Of these, the high Andes on one side and the much lower highlands of southern Brazil on the other, together with the prevailing north winds, appear to be dominant in controlling rainfall.

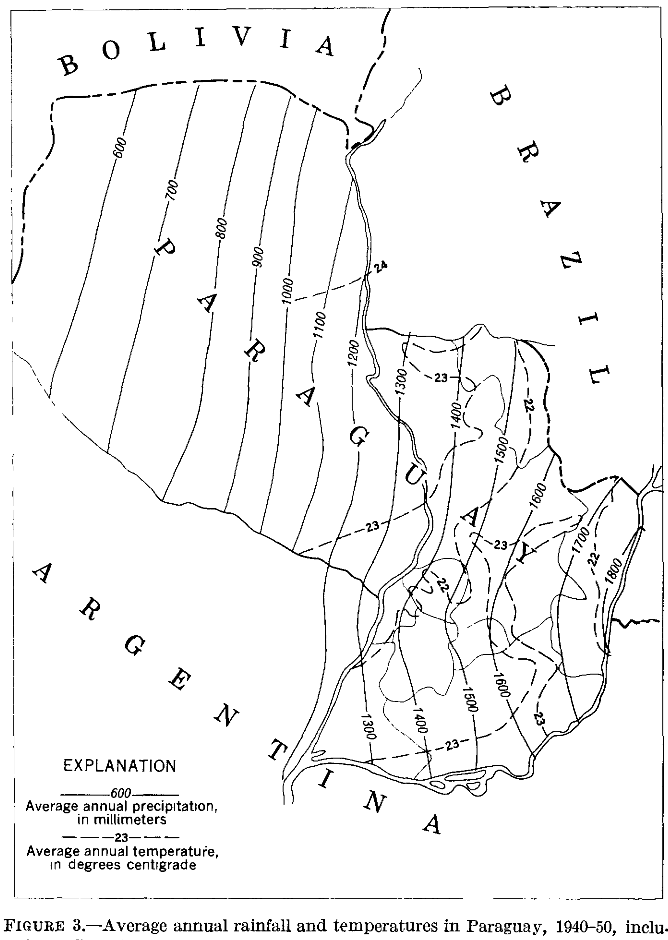

FIGURE 3.—Average annual rainfall and temperatures in Paraguay, 1940-50, inclusive. Compiled from various sources, 1953, by Dorothy A. Cassel for the Institute of Inter-American Affairs.

The periods of highest relative humidity are generally in March, June, July, and August; the lowest occur during December in eastern Paraguay and in August and September in the Gran Chaco. Evaporation generally exceeds precipitation from June through August in the east and during nearly all of the year in the Gran Chaco.

VEGETATION

More than half of Paraguay is heavily forested with virgin stands of tropical and subtropical trees and shrubs. More than 3,000 species of these have been recorded. Many of the trees are deciduous hardwoods, but new leaf growth follows so quickly on the fall of older leaves, or even accompanies it, that bare trees are rare at any season. Many species bloom profusely in the spring and a few bloom at other seasons, lending great masses of white, yellow, pink, purple, and blue colors to the landscape. The undergrowth of shrubs and vines is commonly thick, and virtually impenetrable in places, especially around the fringes of the forested areas. There is no true rain forest, but here and there many individual trees tower far above the forest blanket.

In eastern Paraguay, the forests once covered nearly all of the hills and rolling uplands. In the more heavily populated central region, the hills, called "islas" or "islands," have been partly or entirely cleared and now support the bulk of the country's farm lands. Farther from centers of population the forests are still virtually untouched, though here and there they are strikingly marked by angular farm clearings, most of them small in comparison to the forests around them. The forestry industry itself, large though it is, does not generally result in denudation of the land or in clearings that can be converted to agriculture. This is because the trees most sought by lumbermen are widely scattered and their cutting results in little or no visible thinning of the forest.

The lower and flatter portions of eastern Paraguay, called "campos" or "camplands," are grass covered in large part, with trees and brush in thick borders along the water courses. Parts of these plains, which are used principally for grazing, are swampy, but some could be easily drained by ditching.

On the Gran Chaco side of the Río Paraguay, vast areas of nearly level grasslands drain into sluggish meandering rivers that are bordered by thick stands of deciduous trees. The grasslands are interspersed with peculiar brush forests of mesquite and many other thorny semidesert plants that are adapted to alternations of severe droughts and prolonged wet seasons when almost all of the surface of the Gran Chaco is swampy or actually covered by water. Scattered through the brush forests are various hardwoods; along their edges are groves of black palm (carandaí), some many square kilometers in extent (fig. 2).

TRANSPORTATION

Paraguay is severely handicapped in its development and in international commerce by its inland location, which necessitates travel through neighboring countries for access to ocean transport. Its international commerce depends largely on facilities that are owned and controlled by foreign governments or corporations. Even so, the international transportation situation is better than the domestic one.

Within the country, all the usual forms of transportation—water, rail, air, and road—are represented but all are inadequate for the present needs of the country and will, unless improved greatly, hinder its development in future.

By far the greater part of the country's international trade, and a considerable part of its internal trade, is carried by water. Between 1941 and 1950, more than 87 percent of total exports were moved by river, nearly all of the remainder going on the one international railroad that links Paraguay with Buenos Aires. Truck shipments to and from Brazil and Argentina are negligible, but substantial contraband movements of cattle on the hoof are generally believed to take place regularly.

The Paraguay-Paraná river system, comparable in most respects to the Mississippi, is the main avenue of commerce. Its channel accommodates ships with 9-foot draft during periods of normal flow, but this is decreased to 7-foot draft during low water. The Alto Paraná, the only other stream that can be used for regular navigation, is shallower than the Paraguay and requires smaller craft. Asunción, Concepción, Villeta, Pilar, and Encarnación are the main ports. Of these, only Asunción has modern port facilities; even here logs must be floated out to waiting ships and lifted from the water by cranes or made up into rafts.

More than 200 vessels, most of them old wood-fired ships and barges originally designed for ocean travel, and of Argentine registry, serve the country's international transport needs. Most of them connect Asunción with Buenos Aires, 1,600 river kilometers to the south, but a few move 1,100 kilometers up-river to Corumbá, Brazil.

Shipping rates for the trip from Asunción to Buenos Aires range from 4 percent of the f. o. b. value of some meat products to 86 percent of that for some timber products. A surcharge of 50 percent is commonly added during periods of low water, which sometimes last more than 6 months.

In addition to the international commerce described above, there is a large internal water traffic. Most of this is limited to the many ports along the Paraguay and Alto Paraná rivers, but there is some movement of goods on the smaller tributary rivers.

A British-owned standard-gage railroad connects Asunción, Villarrica, Encarnación, and many smaller towns along its route with Buenos Aires. It provides regular freight and passenger service but outworn wood-burning equipment and poorly maintained trackage cause delays at times. A number of other railroads are shown on plate 1. All are privately owned narrow-gage lines, used principally for moving of forest products.

Several foreign airlines provide regular passenger, mail, and freight service between Asunción and Río de Janeiro, Montevideo, Buenos Aires, Santiago, La Paz, and Lima. All but Lima are only 4 to 5 hours' flight time from Asunción. One Argentine company uses hydroplanes that operate from the Asunción harbor; all the other companies use the national airport, which has a single, asphalt-paved runway on the outskirts of Asunción. Aside from a few privately owned planes, all internal air transportation is by a government-controlled company, which uses small 1 to 3 passenger aircraft and Paraguayan Air Force pilots. Most of the towns, as well as many private ranches, have earth or grass landing strips. Any of these can be reached within about 3 hours' flying time from Asunción, though there are likely to be many delays, due to weather and other factors, in obtaining passage. Moreover, many of the landing strips are likely to be unserviceable during parts of every year because of rain, mud, or overflow from nearby streams.

Within the country, most travel and transport of goods are by roads and cart tracks. At the end of 1951 there were about 5,000 automotive vehicles in the country; nearly four-fifths of them were registered in the capital city. Of the total, about half were passenger automobiles and half were trucks or buses. Horses with light wagons are used extensively in a few of the colonies settled by Europeans, but the great bulk of overland transportation throughout the country is done by oxen. In 1943 there were 27,000 carretas—two-wheeled heavy carts drawn by one to six oxen—in use by farmers alone, plus an unknown but large additional number in the forest industries.

The principal road net is shown on plate 1. Aside from some of the streets in Asunción and a few blocks in Encarnación and Villarrica, the only paved, all-weather highway in the country extends eastward from

Asunción to Eusebio Ayala, a distance of 73 kilometers (45 miles). In addition to this two-lane, asphalt-surfaced highway there are nearly 965 kilometers (600 miles) of graded and maintained highways, about two-thirds of them gravel surfaced. Except for the lack of bridges in places, most of these roads are excellent during fine weather; it is both illegal and virtually impossible to traverse any of them for a period of 24 hours after each rain.

There are also many thousand miles of unimproved roads and cart tracks throughout the country. Only a few are shown on plate 1, and fewer yet can be easily traveled by other than oxen or specially sturdy automotive vehicles, even in dry weather.

POPULATION

According to the 1950 census, the total population of Paraguay was 1,405,627, or an average of 3.5 persons per square kilometer (0.7 per square mile). This is the lowest population density in South America and among the lowest in the world. As indicated by figure 4, the population is very unevenly distributed. In fact, 96 percent of the people live east of the Río Paraguay and more than half occupy only 4 percent of the land in Asunción and nearby departments.

The Paraguayan people are predominantly a homogeneous mixture of Spanish and Guaraní Indian. Spanish is the official language but outside Asunción and even within it to considerable extent, Guaraní is far more widely used than Spanish.

There are a total of about 40,000 indigenous Indians belonging to about 30 different family and linguistic groups. Nearly all of them lead nomadic lives in the Gran Chaco; a few work for timber companies or for farmers.

The 1950 census showed that there were 38,000 foreign nationals in Paraguay, representing a score of countries, but largely from central Europe. Nearly all are religious, political, or economic refugees who have come to Paraguay since 1900. Offered asylum, as well as lands, by Paraguay, they are largely settled in isolated colonies, particularly in the central Gran Chaco, in the area southeast of Concepción, and in the Misiones region along the Río de Alto Paraná near Encarnación. To date there has been little tendency toward social or economic mixing between the immigrant and Paraguayan populations.

INDUSTRIES

Paraguay depends almost entirely on agriculture, livestock, and forest products for its economic existence. Local industries are largely limited to partial processing of these products for export; nearly all manufactured goods are imported. One indirect result of the heavy dependence on food growing is that the people are well fed, with a calorie intake per capita of 2,813 per day as compared with 3,098 calories in the United States. On the other hand, the money income per capita is one of the lowest in the world, amounting to less than $40 in United States money per year in 1950.

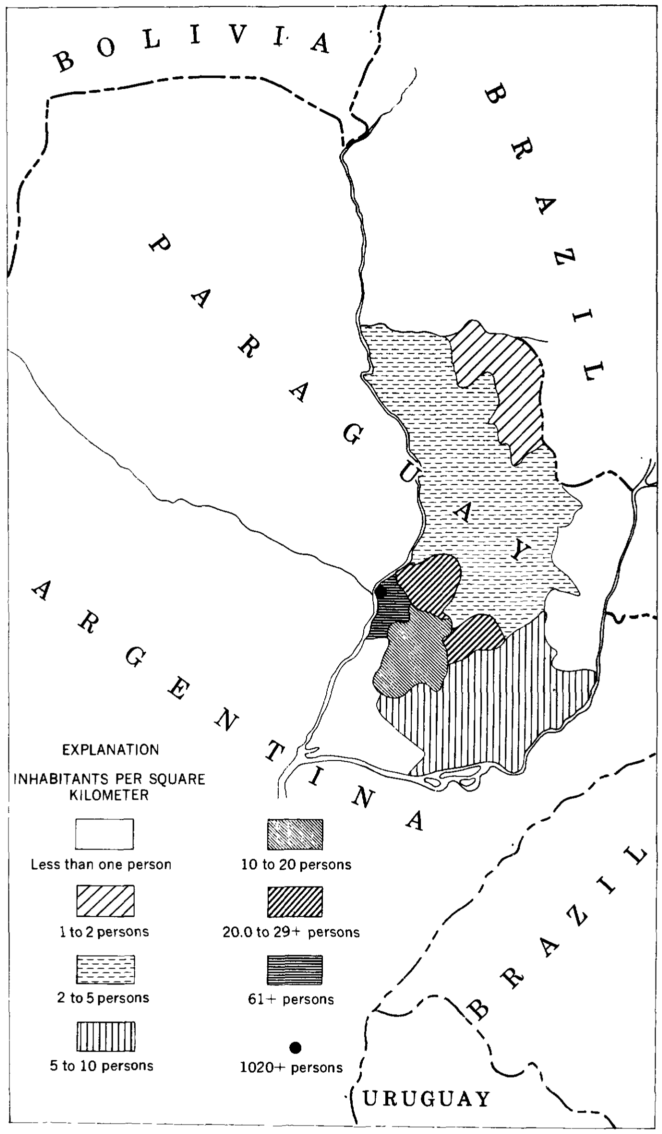

FIGURE 4.—Density of population, Paraguay, 1950, compiled from data in the files of the Institute of Inter-American Affairs, Asunción.

Four percent of the total land is in farms, but less than one percent is actually under cultivation. All but about 10 percent of the farmers have less than 20 hectares (50 acres) per farm. Of the remaining land, 40 percent is devoted to grazing, 54 percent is forested, and 2 percent is classed as wasteland.

Exports in 1950, which were approximately balanced by imports, were valued at 167.4 million guaranies, or 18.6 million United States dollars at the then average official rate of exchange for exports. Forest products, chiefly logs, rough lumber, quebracho extract for tanning, and oil of petit grain for perfume, made up 43.3 percent of the total value. Agricultural products, chiefly cotton, vegetable oils, tobacco, and mate accounted for 28.4 percent; animal products, largely beef, meat extract, and hides yielded 22.2 percent. No packing plants were in operation in 1952. Large quantities of meat, grain, fruit, root crops, and cane sugar are, of course, produced for local consumption.

The mineral industries are limited to production of materials for local use. Clay products, chiefly brick and tile but including some pottery, lead the list. Stone, sand, and lime are produced in quantities sufficient to meet local needs but the several small bottle factories fall far short of meeting the local demand for glass. A portland cement plant, with an ultimate rated capacity considerably larger than Paraguay's probable consumption, went into operation in a small way early in 1952.

FUEL AND POWER

Except for wood, charcoal, and alcohol, Paraguay has no fuels whatever and no other developed sources of electric or other power. This is one of the chief factors that has retarded the development of manufacturing industries. Electricity is available in only nine towns; in all of them the generating equipment is wood fired, as are all locomotives, and virtually all ships and barges. All gasoline and other petroleum products are imported, but some alcohol for domestic heating is produced as a byproduct of the sugar industry.

The demand for wood fuel is so great that the supplies near the heavily populated centers, particularly near Asunción, are being rapidly depleted with consequent increases in cost due to longer hauls. The high cost of wood and charcoal is in part also due to the expense of chopping by hand the extremely hard woods that make up so much of the forest growth and to the primitive and wasteful methods used in making charcoal.

It is not known whether wind-operated electric generators, which are used in many parts of the western United States, would be successful in Paraguay, nor whether they have been tried there. They might well be adapted for domestic use, however, particularly at the ranches and colonies in the Gran Chaco, where the winds are stronger and more constant than in eastern Paraguay.

The only promising sources of hydroelectric power known are along some of the tributaries to the Río Alto Paraná and at the falls of Guairá on the Río Paraná itself. The latter falls could be used to develop very large amounts of power, but very valuable power sites could be developed at the places where low falls and rapids form on the Monday, the Acaray, and several other tributaries of the Alto Paraná in their final descent to the level of the Paraná. Unfortunately, all these potential sources of power are remote from the center of population; moreover, the most promising one, Guairá, is partly owned by Brazil, so that any power development would require international efforts.

GEOLOGY

GENERAL FEATURES

The rocks of Paraguay can be divided into five major classes, depending on age and mode of origin as shown in the table below and on the geologic map (pl. 1). The oldest ones are the granitic and metamorphic rocks of the Precambrian complex; they underlie the entire country at varying depths but are exposed at the surface in only relatively small areas near the Río Apa and in the south-central part of eastern Paraguay. The second group consists of marine sedimentary rocks, mostly shale and sandstone, and ranges in age from Cambrian or Ordovician through Early Devonian. This group is relatively thin in eastern Paraguay but much thicker in the Gran Chaco basin west of the Río Paraguay. The third group of rocks, which range from Pennsylvanian or Permian through Triassic in age, constitute the Gondwana or Santa Catarina continental clastic sediments known in a large part of South America. Like the older marine beds of Paleozoic age of the second group, they are thicker in at least part of the Gran Chaco basin than they are in eastern Paraguay. The fourth group is Tertiary to Recent in age. It consists, at least in large part, of unconsolidated clay and sand of continental origin but may contain some marine beds in places. It covers all but a tiny fraction of the western half of the country, where it appears to be as much as 2,000 feet thick in places. In eastern Paraguay these younger unconsolidated materials are very thin in most places and consist of swampy alluvium.

The fifth large group of rocks consist of igneous extrusive and intrusive rocks, mostly of basic composition, and some of uncertain age. The most important single member of the group is a thick series of basaltic lava flows that cover the eastern edge of the country and extend far eastward into Brazil where they reach their maximum thickness in the Paraná basin. Associated genetically with these lavas, which are of Triassic or possibly Jurassic age, are a number of smaller bodies of intrusive diabase, extrusive basalt, and possibly other rocks. Besides the igneous rocks whose age is fairly certain, there are many bodies of igneous rock whose age is unknown. Some are intrusive and others are extrusive; all are small as compared with the extensive basalt flows. Some are strongly alkalic and of considerable interest to the petrographer. Some of the bodies group here may be related to the basaltic lava flows, hence of Triassic or Jurassic age; for some, however, there is strong geomorphic and other evidence that they are no older than late Tertiary.

The geologic structure of Paraguay appears to be relatively simple in its grosser aspects, but there is much to learn of even the larger features. In the eastern half of the country the beds dip gently eastward toward the great Paraná basin of southeastern Brazil. This easterly dip appears to reverse along the axis of a low anticline that trends north-south only a few kilometers east of the Río Paraguay and exposes the older sediments and the Precambrian basement rocks at the surface in many places. West of this axis the beds either dip steeply westward, or are downfaulted to the west, into the depths of the Gran Chaco basin. The rocks in this basin are, in places, at least 10,000 feet deeper than they are in eastern Paraguay; west of the basin, in eastern Bolivia they rise to the surface in a series of anticlines and synclines that form the foothills of the Andes.

IGNEOUS AND METAMORPHIC ROCKS

By Charles Milton and Edwin B. Eckel

In the course of a 6-month field study of the geology of Paraguay, Eckel collected about a hundred specimens of rocks in 1952. Earlier, geologists had made such collections, notably Pöhlmann (1886), Lindner (Milch, 1895), and Carnier (1911c, 1913); these collections have been described respectively by Pöhlmann (1886), Milch (1895 and 1905), and Goldschlag (1913a). Harrington made extensive collections in 1946 which, unfortunately, were lost, so that his otherwise excellent memoir on the geology of Paraguay (1950) contains only field notes on the petrology. Milton has studied the collection made by Eckel and to a considerable extent compiled the notes here presented.

The igneous and metamorphic rocks may be classified in three main groups—metamorphic and granitic, basaltic and diabasic, and alkalic. Geographically, there are a southern and a central area, both examined by Eckel, and a northern area, examined by Carnier and others. The sedimentary rocks collected by Eckel are briefly described in connection with the stratigraphy; one peculiar sedimentary rock that has columnar jointing is described here in the section on diabase as "pseudotrachyte."

PRECAMBRIAN METAMORPHIC AND GRANITIC ROCKS

In eastern Paraguay there are two extensive areas, and several smaller ones, of Precambrian granitic and metamorphic rocks. One of the larger areas is the region around Centurión near the Río Apa; it extends northward into Brazil. The other is in southern Paraguay. This report discusses only briefly rocks of the Río Apa region, which have been investigated by Carnier (1911c), Goldschlag (1913a), and Boettner (1947); it deals more especially with the rocks from the southern and central region.

The basal complex, a southern extension of the Brazilian shield, is overlain unconformably by Paleozoic and Mesozoic sedimentary rocks as in many other parts of the world. It underlies, at no great depth, all eastern Paraguay and the northern part of the Gran Chaco west of the Río Paraguay, where there are a few small outcrops of these rocks. In the southern and western parts of the Gran Chaco, however, the basement rocks are deeply buried beneath sedimentary rocks.

The surface of the exposed Precambrian rocks in the Río Apa region is comparatively rugged, with relief of more than 200 meters, whereas in the southern region the surface is smoother, with relief of less than 100 meters. Reasons for this difference in topographic expression are not apparent.

The metamorphic rocks, which are undoubtedly older than the igneous rocks, are made up largely of schist and gneiss. A great variety of other rocks, whose distribution is not known precisely, is associated with these rocks. They include ultrabasic igneous rocks as well as argillite, quartzite, marble, and other kinds.

Most of the igneous rocks are of intrusive origin, but some are probably extrusive. Medium- to coarse-grained granite and quartz porphyry predominate, but there are many bodies of aplite and pegmatite associated with them. In at least one place, near Caapucú, fragmental pyrophyllitized volcanic rocks are associated with porphyritic rocks that show flow structure, indicating that they probably originated as surface flows.

Probably the earliest rocks were gneisses and schists that were overlain by shale and sandstone beds, and this whole sequence was then intruded by the granitic rocks, accompanied by extensive metamorphism and a considerable amount of folding and faulting. The Precambrian rocks were later eroded to a relatively smooth surface before the deposition of the limestone and argillite of the Itapucumí series, of possible Cambrian and Ordovician age. This interpretation agrees with that of Carnier (1913) and of Harrington (1950).

Without more knowledge than is available at present it is impossible to assign definite ages to any of these rocks. Harrington (1950) suggests correlation of the metamorphic rocks with the Cuibá series of Mato Grosso which has been assigned to the Algonkian by Oliveira and Leonardos (1943, p. 217), Evans (1894), and others. Possibly both Archean and Algonkian eras are represented, just as they are believed to be in northeastern Bolivia (Ahlfeld, 1946, p. 19–25). For convenience, the metamorphic rocks are grouped here and shown on plate 1 as "older Precambrian metamorphic rocks" whereas the granitic and porphyritic rocks are grouped as "younger Precambrian igneous rocks."

SOUTHERN AREA

One of the two large bodies of Precambrian rocks is in the southern part of the country between the latitudes of Carapeguá and San Juan Bautista. The mapping of this area (pl. 1) is based in large part on Eckel's field observations, supplemented by Harrington's map (1950) and by interpretation of aerial photographs.

OLDER METAMORPHIC ROCKS

The eastward-trending belt of older Precambrian rocks between San Juan Bautista (pl. 1) and Villa Florida is very poorly exposed in most places, and its character is known only in a general way. The northern contact of this belt with the younger granitic rocks is covered in all places examined, but is thought to be somewhere near the Río Tebicuary at Villa Florida, as shown on the map. Along the ridge west of San Juan Bautista the Triassic sedimentary rocks south of the belt rest unconformably on the metamorphic rocks, with a thick basal conglomerate. This same relationship possibly exists along the entire contact, but the apparent absence of basal conglomerate just north of San Juan Bautista and strong shearing within the metamorphic rocks near San Miguel indicate that part of the contact between Triassic and Precambrian rocks may be a fault.

The best exposures are along the highway from San Miguel to a point about 6 kilometers north of that town. At and near San Miguel most of the rocks consist of white to gray glassy quartzite with a little feldspar, most of which has been intensely crushed and contains much bright-green muscovite along fracture surfaces. The lineation of this crushed material strikes N. 80° E. and dips 45° N. There are also two sets of prominent joints that strike due north and N. 45° E. and dip 30° E. and 60° NW., respectively. The quartzite is conspicuous because of its bright-green mica. Small flakes of graphite are fairly abundant in the specimens at hand, and numerous grains of rutile are seen under the microscope.

From San Miguel northward toward Villa Florida the rocks are fairly well exposed in roadside ditches (fig. 5). They consist of a wide variety of rocks in parallel bands that trend N. 40° E. and dip northwest at angles of 30° to 60°. Nearly all the rocks are crushed and their constituent minerals are strung out along the direction of the bands so that they resemble flow banding in glassy volcanic rocks. The rocks range from granite, aplite, and pegmatitic quartz

FIGURE 5.—Precambrian rocks exposed in a gully along the highway just north of San Miguel. The weathering profile is distinct. The rocks are mostly granite and aplite, but also contain some gneiss, schist, and talc, the latter probably derived from basic rocks.

through mica schist, gneiss, and ultrabasic rocks. Harrington (1950) says that in the Sierra de Itayurú, a little north of San Juan Bautista, this same series of gneiss and schist contains intercalations of marble.

At kilometer 176,[1] about 3 kilometers north of San Miguel, there are several bands, 30 to 50 meters apart and each 2 to 3 meters wide, that are largely altered to talc. The original rock, as exposed in the road ditches and in a shallow prospect pit (see fig. 58), was apparently an ultrabasic rock. The talc, which contains a few specks of chromite locally, ranges from white through dull green to gray and from very smooth to gritty texture. It contains a few narrow and irregular veinlets of white quartz and a cross-fiber mineral that has the appearance of asbestos but which is shown by X-ray-diffraction methods to be fibrous talc.

In addition to the talc, the belt of metamorphic rocks is known to contain deposits of magnetite and hematite (p. 85), some of them rich near San Miguel.

On a hill 1 kilometer east of the main road, and about 5 kilometers north of San Miguel there is a comparatively large body of white quartz in country rock that has a rhyolitic appearance. The quartz outcrops over a roughly circular area about 50 meters in diameter. It is milk white and glassy, with a few faceted crystals, 2 to 3 centimeters in diameter, in vugs. One small bleb of coarse-grained galena was found on the dump of a shallow prospect pit; a few specks of free gold are reported by former prospectors. This deposit of quartz, obviously of hydrothermal origin, containing a little galena and possibly some gold, lends some basis to reports that the early Jesuits found gold and mercury ore near San Miguel.

In a strong shear zone near Villa Florida is what appears to be a sheared granite (specimen P–70). (Throughout this chapter, field numbers assigned to specimens collected by Eckel are retained so as to avoid confusion and repetition.) It is a thinly banded rock, with layers of dark-gray glassy quartz and greenish-brown epidote with feldspar. Microscopically, it shows sheared aggregates of highly altered microcline, diopsidic pyroxene, and zoisite (garnet?) interlayered with quartz. The photomicrograph (fig. 6) shows the elongate lenses of feldspar in the coarsely crystallized quartz. The diopsidic pyroxene is associated with these feldspar pods. A more siliceous phase

[1] As used in this chapter, kilometer numbers refer to markers along the main highways (Rutas). They measure distances from Asunción.

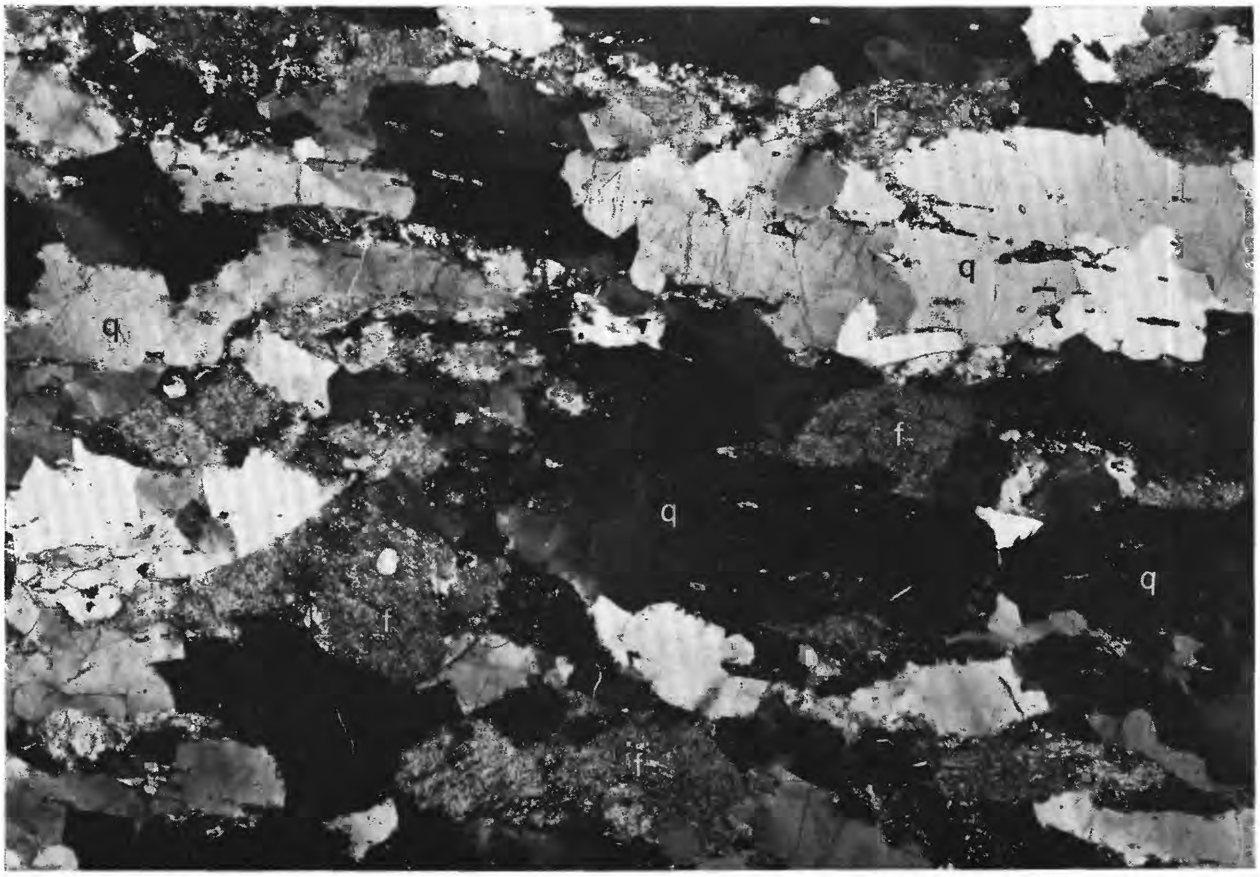

FIGURE 6.—Sheared Precambrian granite (specimen P–70), from shear zone near Villa Florida. *q*, quartz; *f*, feldspar (microcline) with mafic minerals. × 15. Crossed nicols.

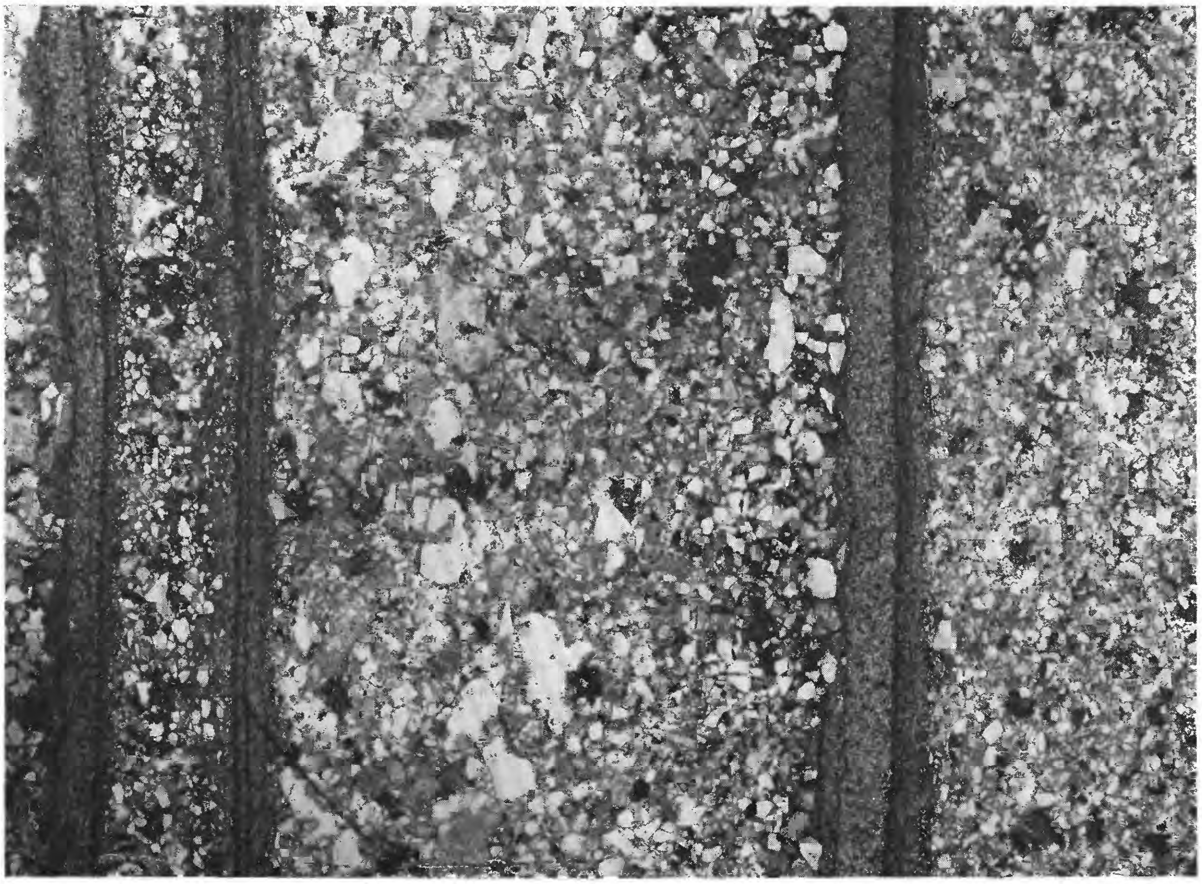

FIGURE 7.—Arkosic sandstone (specimen P–6) from near Villa Florida. × 15.

of this granitic rock (specimen P–71), from a shear zone near the talc deposit just north of San Miguel, consists largely of massive bluish-gray quartz, with minor feldspathic lenses.

On a cart track between the main highway and the Paso Pindó copper deposit, about 6 kilometers north-northeast of Villa Florida there is a body of arkosic sandstone with intercalated shale 50 to 100 meters in diameter, that appears to be enclosed by granite and aplite. The shale is hard and fissile and apparently metamorphosed by baking, with a little fine epidote along seams. It is interlayered with the arkose, and shows very thinly layered even bedding, with layers ranging from a centimeter to a hairline in thickness. The arkose is made up of moderately calcic plagioclase with some quartz. Some of the arkose forms cross-cutting clastic veinlets in the shale and closely resembles intrusive aplite. Figure 7 (specimen P–6) shows the microstructure of the arkosic sandstone. The relations of this sequence of shale and arkose to other rocks in the area are not known, but it probably represents an inclusion of older rocks in the granite mass.

YOUNGER IGNEOUS ROCKS

The younger igneous rocks comprise granite and a variety of porphyries, most of them quartz-bearing, with many smaller bodies of aplite and pegmatite. They do not show the intense shearing of the presumably older granitic rocks mentioned above as part of the older series of metamorphic rocks. Only about one-third of the comparatively large area of Precambrian rocks in southern Paraguay is exposed; the remainder, largely in the lowlands that border the Río Paraguay, is obscured in most places by swamps with only a few "islas" or hills, that stand above the plain. How much of this area is underlain by granitic and porphyritic rocks and how much by metamorphic rocks is open to question, but the distribution shown on plate 1 is partly substantiated by Hibsch (1891), who describes quartz porphyry collected by Jordan (1893) from near Lago Ypoá that appears to be identical with the quartz porphyry exposed farther east in the vicinity of Caapucú.

Even in the area where the rocks are comparatively well exposed, the granite and porphyries are not mapped separately because of lack of information. It is known that the northern part of the mapped area, in the vicinity of Quiindy, is made up mostly of granite and also that granite makes up most of the area between Caapucú and Quyquyó. Most of the remainder appears to be porphyry. The contacts between the two kinds of rock are very irregular but are comparatively easy to trace on the ground and even on aerial photographs, because the porphyries almost invariably have a streaky appearance in photographs that the granites do not. The age relations of granite and porphyry are not known.

The surface of the granite ranges from nearly level to gently rolling, with even less relief, in general, than the surface of the porphyry, which here and there forms small steep-sided hills, that rise 50 to 100 or more meters above the surrounding plains. The extensive areas of swamp that characterize these rocks, particularly the granite, suggest that they are relatively unfractured and unjointed, and therefore, unusually impermeable.

Similar lateritic soil profiles are formed on the granite and porphyry; both are very different from profiles formed on the sedimentary rocks. There is no evidence as to the age of the laterization but by analogy with similar laterites in other parts of the world, it may well be an ancient laterite and represent a quite different climatic environment than the present one. The surface material consists of a few centimeters of loesslike fine sandy loam that supports lush grasses, but very few trees. This material changes abruptly to 1 to 2 meters of white to buff sandy clay that grades downward to fresh granitic rock. The clay contains rounded grains and small euhedral crystals of fresh quartz. Most of the quartz grains and crystals are coated with 1 to 3 millimeters of limonite; nodules of limonite ½ to 2 centimeters in diameter are scattered throughout the clay. The limonite and quartz materials tend to concentrate at the top of the clay, beneath the loam, and are cemented in places to a hardpan that forms an excellent and widely used material for road surfacing. In places there are large residual boulders of fresh granitic or porphyritic rocks in the soil; locally the lateritic soil is missing and there are fairly large smooth outcrops of unaltered rock.

So far as known, the granite itself contains no mineral deposits, though it offers distinct promise as an attractive building stone. The porphyries, on the other hand, not only have potential use as building stone but contain nearly all the iron and copper deposits, as well as the one known deposit of pyrophyllite, in southern Paraguay (p. 90).

Granite and related rocks.—In general, the granite is made up of interlocking grains of pink and white feldspars in approximately equal amounts, 1 to 2 centimeters in diameter, with smaller, nearly spherical grains and euhedral crystals of clear-gray quartz. The only dark mineral is biotite, largely altered in most places to a soft brown or green material, which forms very small clusters interstitial to the quartz and feldspars. In most exposures the near-surface rock is partly weathered and crumbly, but in a few places, as on the road 8 kilometers southwest of Quyquyó, the granite is brilliantly fresh and would form an attractive polished building stone.

A typical specimen of the granite (P–62), collected a short distance east of Barrerito consists of glassy quartz, pink alkalic feldspar, and dark biotite, with porphyritic crystals of white feldspar a centimeter long. The rock is apparently much the same as a biotite-gneiss studied by Goldschlag (1913a, p. 54) from Estancia Machuca-cué near the Rio Apa; and is also similar to granite from many other parts of the world. Figure 8 shows partly chloritized biotite and a few opaque (black) ore grains. The feldspars are sodic plagioclase and orthoclase, both somewhat sericitized. There are a few euhedral deep-brown grains of allanite(?) and also some sphene. A chemical analysis of this rock is given in table 1.

Comparatively small dikes and irregular masses of aplite and, to lesser extent, pegmatite are widely distributed in both the granitic and porphyritic rocks and in some of the older metamorphic ones. Some are strongly sheared and fractured and contain considerable amounts of epidote on fracture faces. At kilometer 156 on the Caapucú-Villa Florida highway, streaks of comparatively coarse-grained dull-green hornblendite were noted in the aplite. Similar small hornblendic bodies are found in many localities.

Good examples of typical aplites (specimen P–74, 75) are shown in figures 9 and 10; chemical analyses of these two rocks are reported in table 1. The rock shown in figure 9, taken from along the road between Barrerito and Quyquyó, is particularly interesting because it is porphyritic and closely resembles some of the quartz porphyries (see fig. 14) in external appearance. It is a red felsic rock, with large glassy quartz phenocrysts. Unlike the porphyries, however, it has a distinctly granular texture throughout.

Porphyry.—The predominant porphyritic rock is a quartz porphyry, close to rhyolite in composition; most of it is reddish brown but some is dark gray. It is characterized by the presence of irregular grains and euhedral crystals of clear glassy quartz 3 millimeters to 1 centimeter in diameter, together with irregular grains of dull-pink feldspar that are usually smaller in any given specimen than the quartz grains. These are set in a dense dull-brown to gray stony groundmass. The rock varies widely in the relative proportions of

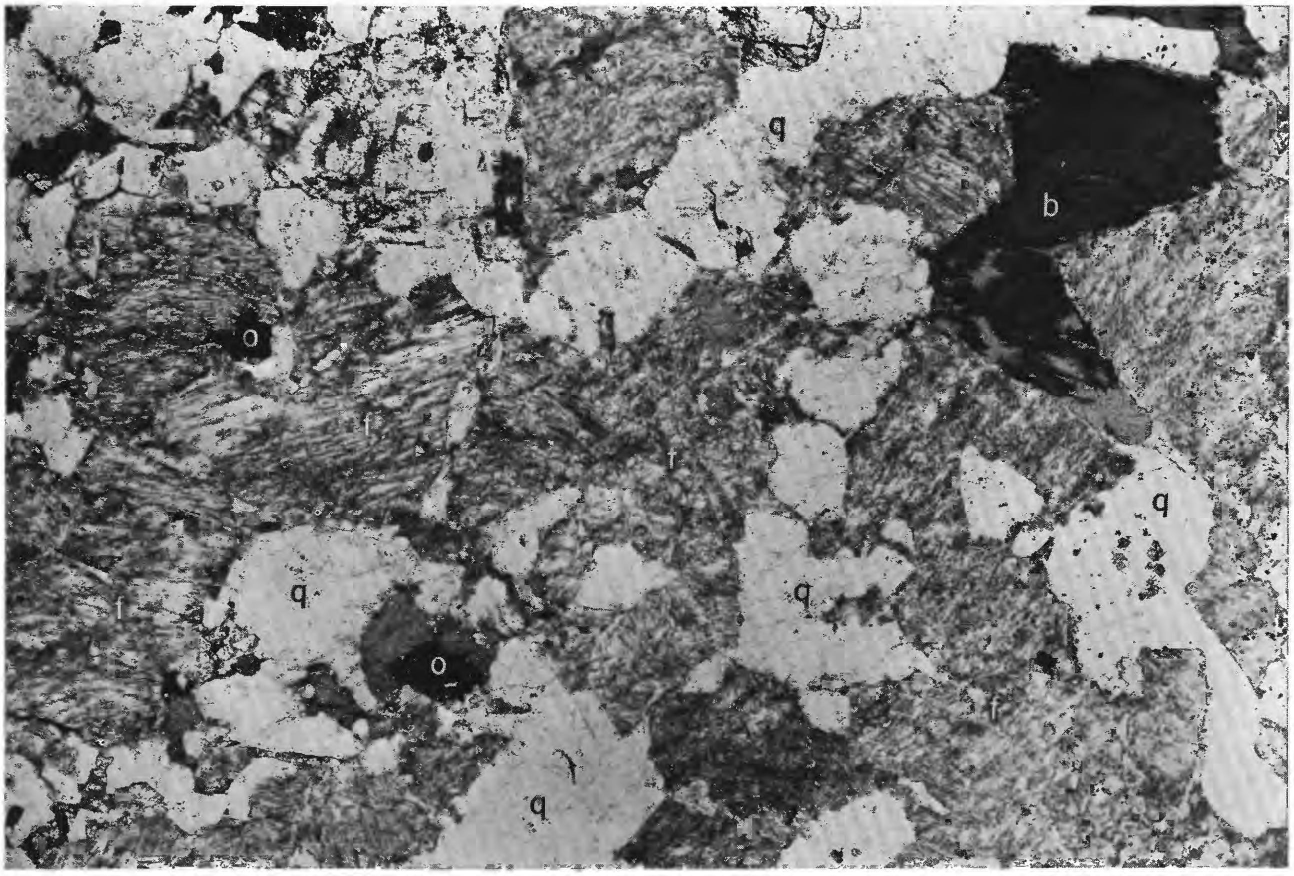

FIGURE 8.—Coarse-grained granite (specimen P–62) from east of Barrerito on the road to Quyquyó; partly chloritized biotite, *b*, with feldspar, *f* (orthoclase and oligoclase), partly sericitized, and quartz, *q*, and a few ore grains, *o*. × 20.

groundmass and phenocrysts, so that some exposures tend to resemble granite or aplite.

Good examples of the freshest rock, that would serve as beautiful polished building stone, can be seen on the Caapucú road at kilometer 134.

On the road from Quiindy, north of Caapucú, porphyritic rocks are well exposed (figs. 11, 12). In places where the clay formed by weathering processes has been removed, the rock surfaces are studded with resistant quartz phenocrysts, as shown in figures 12 and 13. The microstructure of this rock (specimen P–67) is shown in figure 14. The rock is reddish brown, because of the abundance of reddish plagioclase phenocrysts. Where the reddish phenocrysts are not abundant, the porphyry is gray; quartz phenocrysts are few and white feldspars are present.

The gray phase of the porphyry appears to be less abundant than the reddish brown. Figure 15 shows a typical specimen of the gray phase taken from an exposure close to the rock shown in figure 14. The thin section shows no quartz phenocrysts at all, but other specimens of outwardly similar rock contain a few euhedral crystals of quartz. The texture of the felsic groundmass is obviously quite different from that of the rock shown in figure 14. A chemical analysis of this rock (specimen P–60) is given in table 1.

About 12 kilometers northwest of Caapucú, and some distance west of the main highway, there is a large deposit of pyrophyllite. The country rocks in this vicinity are normal brown quartz porphyry, but the pyrophyllite (see p. 90) appears to be an alteration product of a volcanic tuff that is probably interlayered with the porphyry.

Associated with the quartz porphyries just described, notably just north of Caapucú, are many other varieties of porphyry that, in the field, appear to range from glassy rhyolite to dense gray quartz-free monzonite. Microscopic examination shows, however, that they are probably textural variants of the quartz porphyries already described.

One of these rocks (specimen P–31) forms the wall rock of the Del Puerto pyritic hematite deposit north of Caapucú. It is a brick-red fine-grained rock, with glassy quartz, red feldspar, and dark mafic phenocrysts. Pyrite is also disseminated through the rock, visible with a hand lens. Its microscopic character is shown in figure 16. At the lower left is a large quartz crystal, embayed by potassic feldspar, which, with quartz,

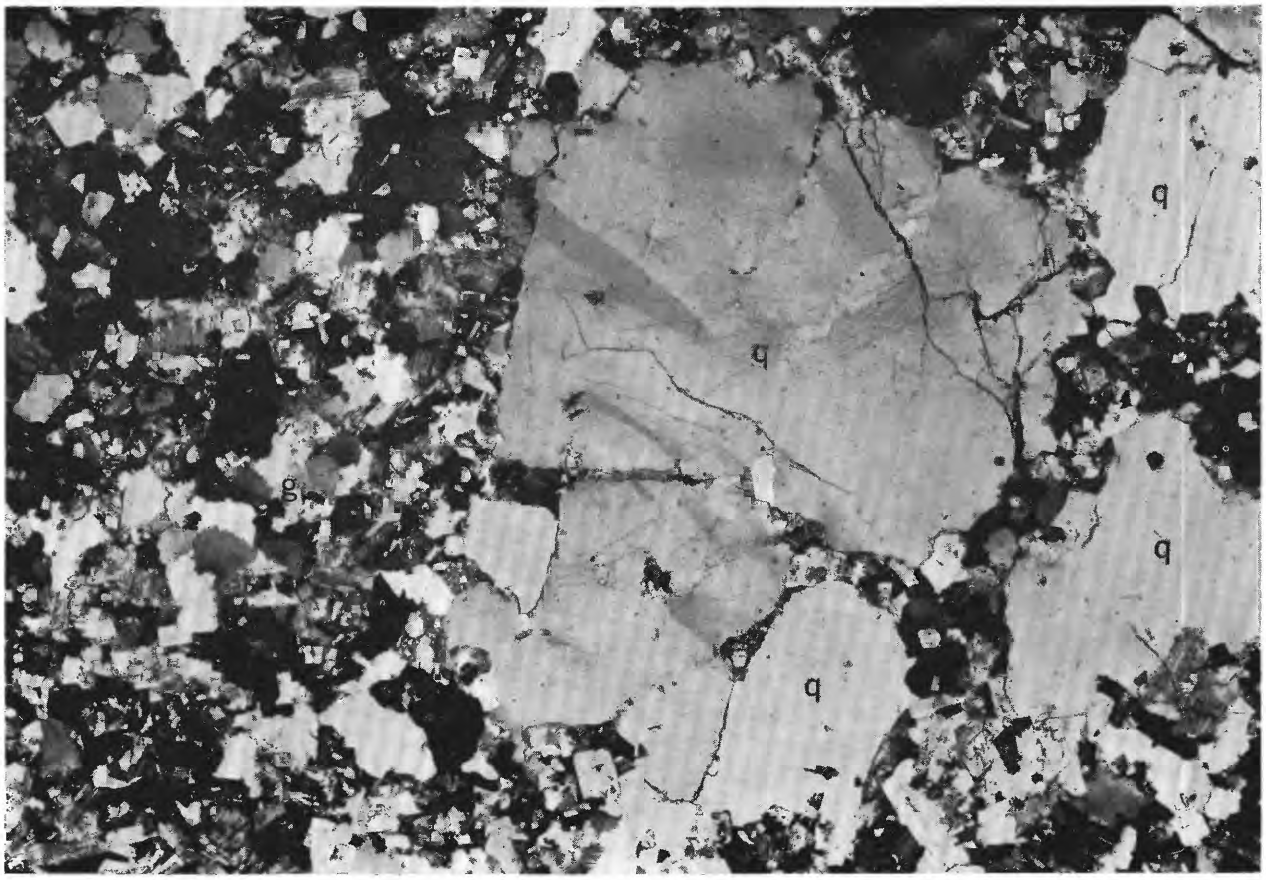

FIGURE 9.—Coarse-grained porphyritic aplite (specimen P–75) from the road between Barrerito and Quyquyó, cuts granite shown in figure 8. Aplite is made up of sodic plagioclase in a groundmass (*g*) of quartz (*q*) and turbid orthoclase with a little altered brown biotite. This rock resembles, externally, the porphyry in figure 14. Crossed nicols.

comprises the groundmass. In the upper middle, is a large feldspar phenocryst in the center of which is an aggregate of green chlorite, zoisite, and apatite. There is more chlorite along the edges, apparently after biotite. One such mass of chlorite is seen in the lower left corner. Several other large feldspar crystals are seen in the illustration. An analysis of this rock is given in table 1; the pyrite content is about 0.5 percent.

The quartz porphyry from Cerro Yahapé, southeast of Lago Ypoá, as described by Hibsch (1891) appears to be similar in most respects to the rocks described above. He describes the Yahapé rock as reddish light brown, with dihexahedral crystals of quartz and crystals of red feldspar interspersed through a microcrystalline groundmass that is rich in quartz.

A few meters east of the Del Puerto pyritic-hematite vein, and parallel with it, is a black porphyry dike (specimen P–32). It is very similar to the dark rock described above (specimen P–60, fig. 15) from the Quiindy road north of Caapucú and to the dark porphyritic rock (specimen P–34) quarried for highway use near Ypacaraí in the central region (see p. 40). All are fine-grained, almost aphanitic dark-gray rocks, with conspicuous dull-white feldspar phenocrysts, a millimeter or two in diameter. Microscopically the three rocks are very similar. The photomicrograph of the black porphyry at the Del Puerto locality (fig. 17) shows the sodic plagioclase phenocrysts in a felsic matrix, strewn with black iron oxide, some epidotic-chloritic debris, and very minor amounts of quartz (a few small grains can be seen in thin section).

Another of these porphyritic rocks from near the talc deposit just north of San Miguel is brick-red, finely granular, with conspicuous anhedral whitish feldspar phenocrysts, and numerous rounded dark glassy quartz grains, both as much as a centimeter in diameter.

Microscopically, this rock shows a feldspathic matrix in which isolated quartz grains are abundant. Some of the larger quartz grains enclose feldspar. The feldspar is turbid, strongly alkalic, and is mostly orthoclase with less sodic feldspar that shows albite twinning and is also slightly clearer. Myrmekite is abundant, in places showing an "hour-glass" structure. Strongly pleochroic brown biotite, apparently disintegrating, and a little black opaque iron oxide are the accessory minerals. This rock is almost identical with a rock (specimen P–30, fig. 18) 9 kilometers south of Caapucú and also resembles superficially but not microscopically that shown in figure 16 (specimen P–31), north of Caapucú.

CENTRAL AREA

An exposure of granite at San Bernardino is small but nevertheless significant. The northern part of the town is underlain by this rock; the freshest material is along the eastern shore of Lago Ypacaraí, where there are nearly continuous exposures for a distance of about 1 kilometer.

The exposure, whose size is somewhat exaggerated on the map, (pl. 1) is scarcely more than 1 square kilometer in extent, as the rock is covered in most places by sediments in the lake or by the basal beds of the Caacupé group. Harrington (1950, p. 16) mentions having seen specimens of similar but coarser-grained granite said to have come from a small hill a few kilometers west of Yaguarón and a little south of Itá. This indicates that the granitic basement may be relatively close to the surface along both sides of the Ypacaraí depression.

At San Bernardino the granite is pinkish brown and coarse to medium grained in texture, with some suggestion of schlieren. It contains pink and white feldspar, a little interstitial biotite, and numerous glassy quartz "phenocrysts" that are subspherical and uniformly about twice the size of the feldspar grains that form the matrix.

On the upper slopes of the hill at the north edge of town the granite is very weathered and crumbly. It is capped unconformably by the basal beds of the Caacupé series.

NORTHERN AREA

RÍO APA REGION

A complex of Precambrian rocks occupies most of the area from the Río Apa southward to the Río Aquibadán, and between the latitudes of Centurión and Santa Luisa. Other outcrops of some of these same rocks, though not described in the literature, must exist near Bella Vista and just north of Concepción, for there are authenticated reports of mica-bearing pegmatites near both places. Their probable positions are sketched in plate 1. This area was not visited by Eckel, but it was possible to draw a rough approxima-

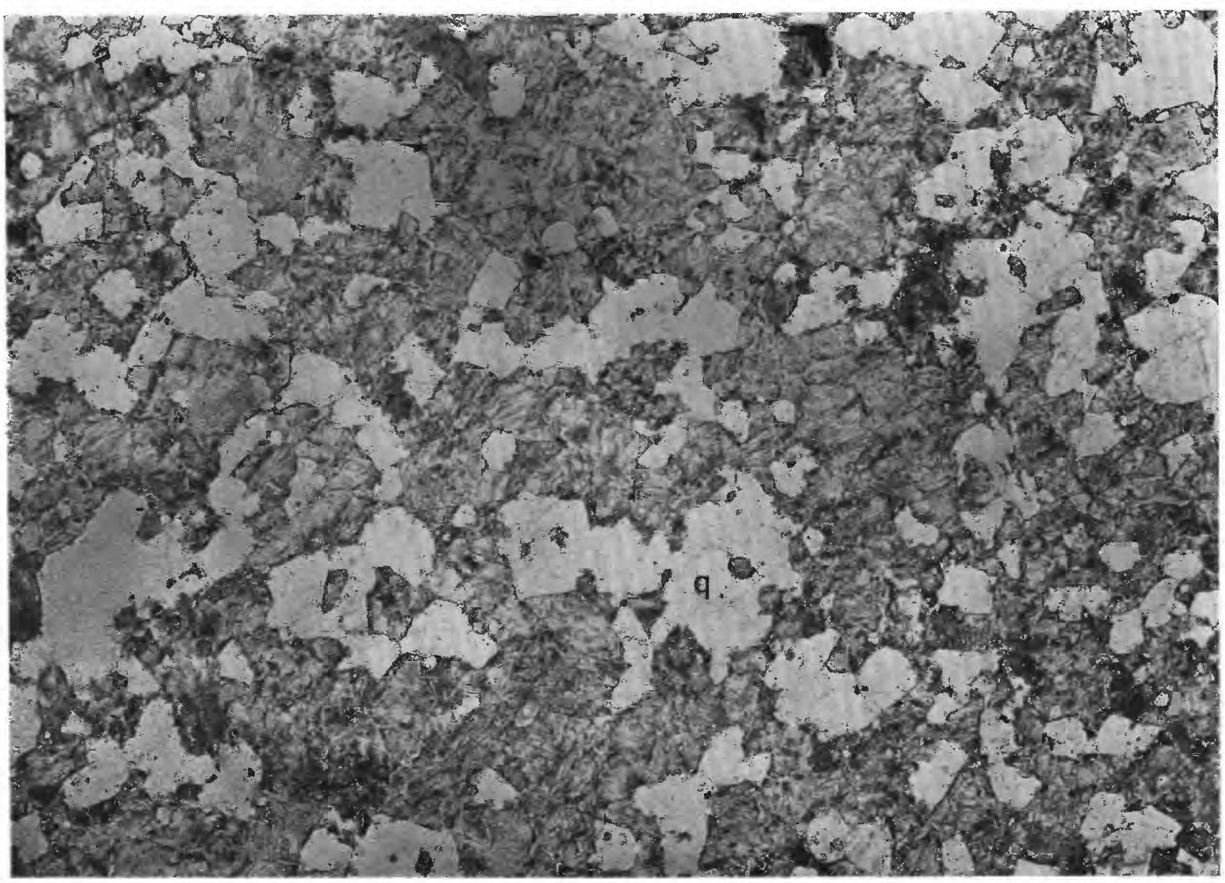

FIGURE 10.—Fine, even-grained aplite (specimen P–74), a brick-red aggregate of flesh-colored orthoclase (*f*), somewhat perthitic, and glassy quartz (*q*), from the road between Villa Florida and Caapucú. × 20.

FIGURE 11.—Typical weathering profile on Precambrian quartz porphyry on the highway between Caapucú and Quyquyó.

FIGURE 12.—Partly weathered Precambrian quartz porphyry at same location as figure 11, showing characteristic weathering out of quartz phenocrysts.

FIGURE 13.—Brown variety of quartz porphyry (specimen P–67) from Quiindy roadside north of Caapucú. Shows weathered aspect of hand specimen. The projections are quartz grains.

tion of the distribution of rocks by interpretation of aerial photographs, by use of sketch cross sections published by Carnier (1913c), and by Boettner (1947), and by piecing together scattered observations recorded in the literature.

The western part of the main area of Precambrian rocks is a relatively high and rugged chain of hills that trends northward to and beyond the Río Apa. It is called the "Apa Bergland" by Carnier (1913c) and other authors. The Paraguayan part, marked by the eminences of Cerro Paiba and Loma Porá, is also known as the Cordillera de las Quince Puntas. East of this chain is a rolling upland, known as the Saty plateau or Potrero Saty.

Biotite and hornblende gneiss, mica schist, and granite make up most of the area. Associated with these rocks are aplite, pegmatite, argillite, quartzite, hematitic schist, and other rocks. Lineations in the metamorphic rocks trend northeastward in general and dip steeply either northwest or southeast. Many of the rocks are much fractured, principally along N. 30°–50° W. trending zones. The northward-trending fault shown on plate 1 is based on interpretation of photographs and may well be in error.

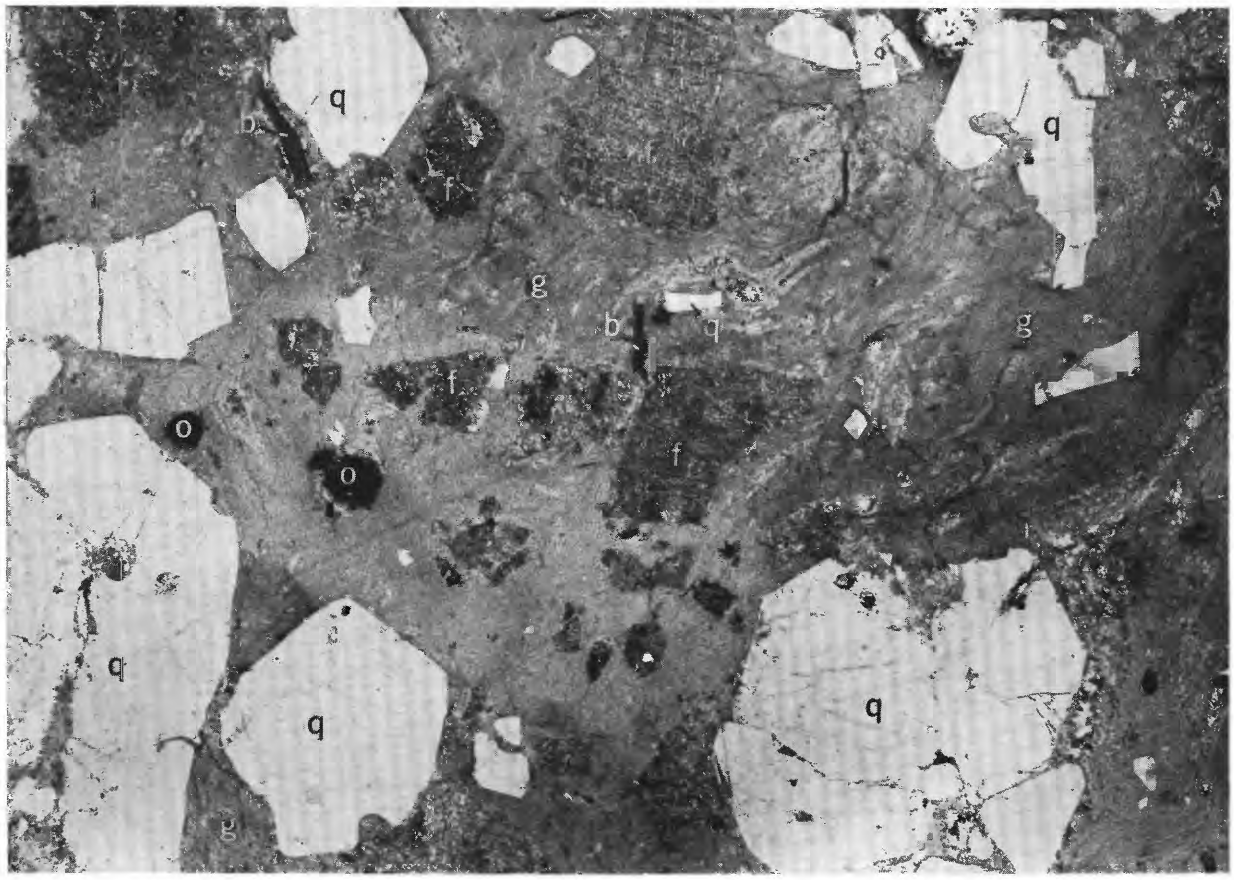

FIGURE 14.—Typical Precambrian quartz-porphyry (specimen P–67) reddish-brown phase, from the road between Quiindy and Caapucú. Phenocrysts are euhedral quartz, *q*, and reddish sericitized sodic plagioclase, *f*, each as much as 2 millimeters in diameter, with a little chloritized biotite, *b*. The fine-grained groundmass, *g*, contains some ore grains, *o*, and shows striking flow structure. × 15.

Petrographic descriptions of the granites, aplites, and granite porphyries that are available indicate that these rocks are similar to those in southern Paraguay.

The "biotite-gneiss" studied by Goldschlag (1913a, p. 54) from Estancia Machuca-cué is similar in mineralogy and chemical composition to the granite from southern Paraguay, for example, specimen P–62 from near Barrerito. This suggests that much of the gneiss described by Carnier (1911c), Goldschlag (1913a), and Boettner (1947), from the Río Apa region is closely related genetically and petrologically to the rocks of southern Paraguay that are here called "granites." Goldschlag's "biotite-gneiss" is said to extend over a large area from the Río Pitonoaga to the Río Apa. At Zanja Morotí it strikes N. 55°–60° E. and is cut by many small veins of "quartzite," aplite, and pegmatite. It does not extend beyond the Río Termentino. Goldschlag's specimens from Estancia Machuca-cué were found by him to consist of microcline, albite-oligoclase, and quartz, with biotite, green hornblende, sphene, magnetite, and epidote.

AMAMBAY REGION

Eckel saw in Asunción a rather large collection of specimens of metamorphic and igneous rocks that were reliably reported by their owner to have come from the "Amambay region, near Pedro Juan Caballero." There are no published geologic maps that show Precambrian rocks in the region cited and the locality description available is so vague that no attempt has been made to portray them on plate 1.

The specimens seen include crenulated mica schist, gneiss, and granite and quartz porphyry similar to the rocks exposed near Caapucú in southern Paraguay. Coarsely bladed specular hematite and sheets of muscovite mica, streaked with brown and black material and as much as 7 by 10 centimeters in size, were seen in the same collection.

TRES HERMANOS HILLS NEAR PUERTO GUARANÍ

Carnier (1913) mentions the Tres Hermanos hills, near Puerto Guaraní, as probably related in origin and rocks to the Pão de Açúçar. They are in the Gran

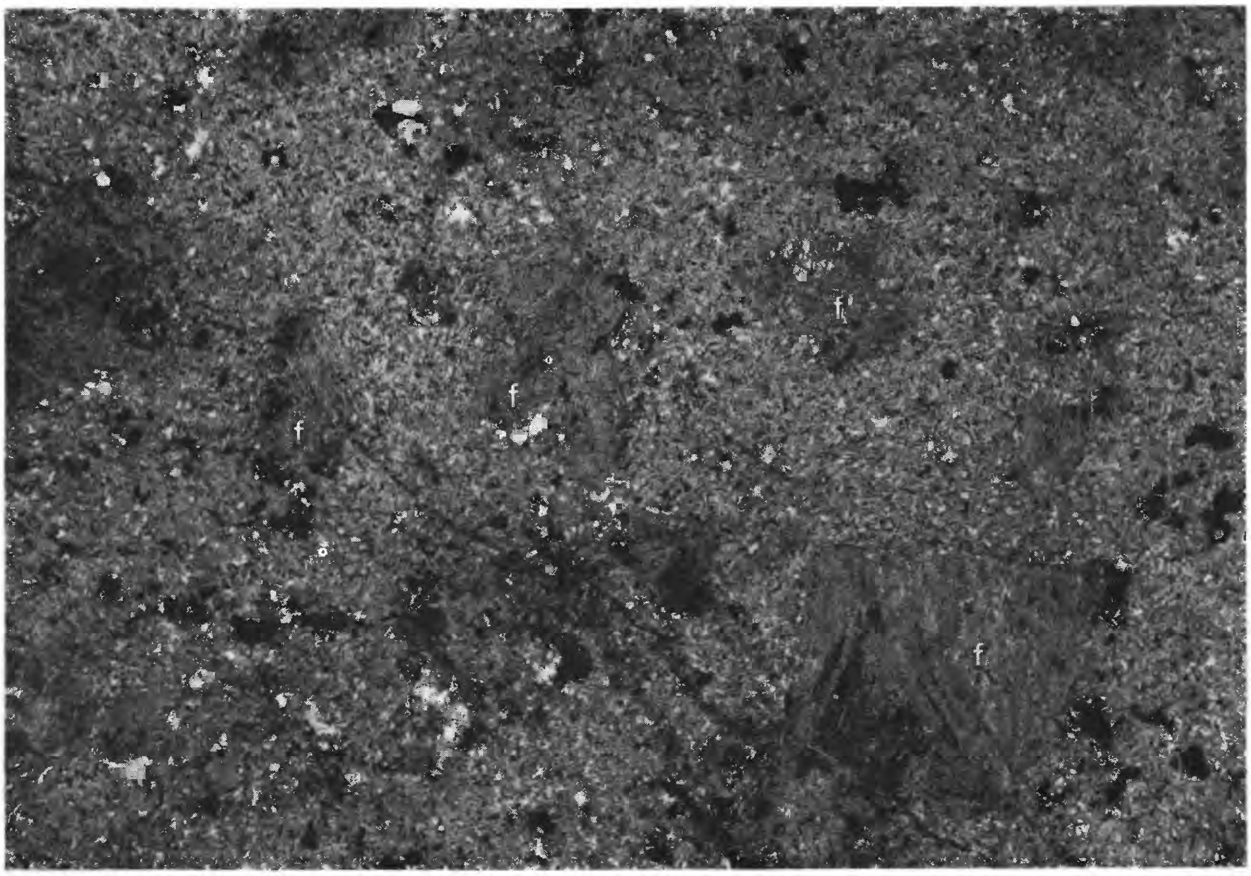

FIGURE 15.—Precambrian porphyry (specimen P-60), gray phase, associated with quartz porphyry of figure 14. Megascopically a gray stony rock with conspicuous grayish-white feldspar phenocrysts, the section shows sodic plagioclase phenocrysts, *f*, and a few small chloritized and epidotized mafic minerals in a felsic groundmass. Other specimens of similar appearance contain considerable quantities of quartz as phenocrysts. × 20.

Chaco, 20–30 kilometers northwest of the river, and are only 30 to 40 meters high. Quarried rock from these hills that was seen by Eckel at Puerto Guaraní resembled the Precambrian quartz porphyry more closely than the younger alkaline volcanic rocks and it is so mapped on plate 1.

FUERTE OLIMPO

According to DuGraty (1865), grayish-brown dense porphyry, with grains of quartz and plates of oligoclase, makes up the small hill on which Fuerte Olimpo is situated on the upper Río Paraguay. Several later writers have quoted him, but no further descriptions are known to the author. The body is shown in figure 2 as of younger Precambrian age. This assignment is supported only by the fact that most writers on Paraguay tend to characterize the Triassic or Tertiary igneous rocks as something other than porphyry, whereas this is the term used by most of them in describing the Precambrian quartz porphyries of the Río Apa and Caapucú regions. The porphyry is reported to contain barite deposits.

ANALYSES OF PRECAMBRIAN IGNEOUS ROCKS

Table 1 shows the results of chemical analysis of six of the Precambrian rocks collected by Eckel from central and southern Paraguay. To these are added three of Goldschlag's analyses of rocks from the Río Apa region.

An analysis of a specimen of rhyolite agglomerate (P–58b), collected by Eckel near the much younger caldera at Acahay, is also included, though discussion of its geologic setting and meaning is reserved for the section on alkalic rocks.

Also, because of the close similarity of the chemical analysis and other features, the analysis of a rhyolite porphyry from the highway quarry near Ypacaraí is given here. However, a Precambrian age for this rock is doubtful; the matter is discussed further on pages 42-43.

Spectographic analyses of Eckel's analyzed rocks, as well as of two pebbles of quartz porphyry collected by him from the Tubarão tillite, of Pennsylvanian or Permian age, are shown in table 2.

TABLE 1.—*Chemical analyses of Precambrian rocks of Paraguay*

[Analysts: For specimens P-31 to P-75, Lois D. Trumbull, U. S. Geological Survey; densities by L. N. Tarrant, U. S. Geological Survey; for specimens A, B, and C, Maurice Goldschlag. Spectrographic analyses for trace elements made for samples, except P-31, P-58b, A, B, and C, see table 2. Tr.=trace]

	P-31	P-34	P-58b	P-59	P-60	P-62	P-74	P-75	A	B	C
SiO_2	74.20	74.26	77.36	76.72	66.46	74.53	77.83	77.17	75.87	77.72	68.35
Al_2O_3	13.58	13.12	11.37	12.36	16.08	13.00	12.29	12.46	13.09	11.53	17.61
Fe_2O_3	.63	.47	1.22	.65	2.30	.89	.47	.62	------	------	3.44
FeO	.72	1.98	.90	.63	1.85	.94	.17	.48	1.80	2.18	.65
MgO	.26	.22	.16	.16	1.11	.46	.02	.01	.35	2.42	1.03
CaO	.79	1.53	.51	.62	2.74	1.39	.28	.19	.87	.53	1.22
Na_2O	3.80	3.80	3.03	3.50	4.71	3.47	3.42	4.14	4.21	4.37	3.12
K_2O	4.49	3.34	4.74	4.71	2.79	4.47	4.96	4.45	2.83	2.57	2.22
H_2O-	.17	.06	.05	.03	.09	.06	.07	.03	.19	.48	1.12
H_2O+	.47	.43	.08	.15	.78	.16	.26	.18	.41	------	------
TiO_2	.25	.23	.16	.14	.47	.27	.10	.07	Tr.	Tr.	Tr.
CO_2	.01	.16	.00	.04	.02	.01	.00	.00	------	------	------
P_2O_5	.06	.05	.03	.03	.20	.07	.01	.01	Tr.	.19	.17
SO_3	.04	------	------	------	------	------	------	------	------	------	------
S	.23	------	------	------	------	------	------	------	------	------	------
MnO	.07	.07	.05	.04	.13	.06	.01	.03	------	Tr.	------
BaO	.11	.05	.15	.07	.20	.07	.00	.00	------	------	------
	99.88										
Less	.12										
	99.76	99.77	99.81	99.85	99.93	99.85	99.89	99.84	99.62	101.99	98.93
Density	2.62	2.66	2.62	2.61	2.65	2.62	2.55	2.56	------	------	------
Norm	I·4·1·3	I·4·2·3	I·3·8·3	I·4·1·3	I·4·2·4	I·4·2·3	I·3·1·3	I·4·1·3	I·3·1·3	I·3·1·4	I·3·2·3

NOTE.—See following table for description of specimens and locality of collection numbers.

Field No.	Rock	Locality
P-31	Quartz porphyry	Country rock of Del Puerto deposit near Caapucú.
P-34	Rhyolite porphyry, dark phase.	Highway quarry near Ypacaraí.
P-58b	Rhyolite agglomerate	Acahay caldera.
P-59	Rhyolite porphyry	North of Caapucú on Quiindy road.
P-60	Porphyry (fine-grained)	Near Caapucú.
P-62	Coarse granite	Near Barrerito.
P-74	Aplite	Near Villa Florida-Caapucú road.

Field No.	Rock	Location
P-75	Aplite (porphyry)	Quyquyó road.
A	Aplite	Zanja Morotí, 100 kilometers north-northeast of Concepción.
B	Aplite	Pitonoaga near Estancia Machucacué, northern Paraguay.
C	Quartz porphyry	Northeast of Estancia La Paz, Cordillera de las Quince Puntas.

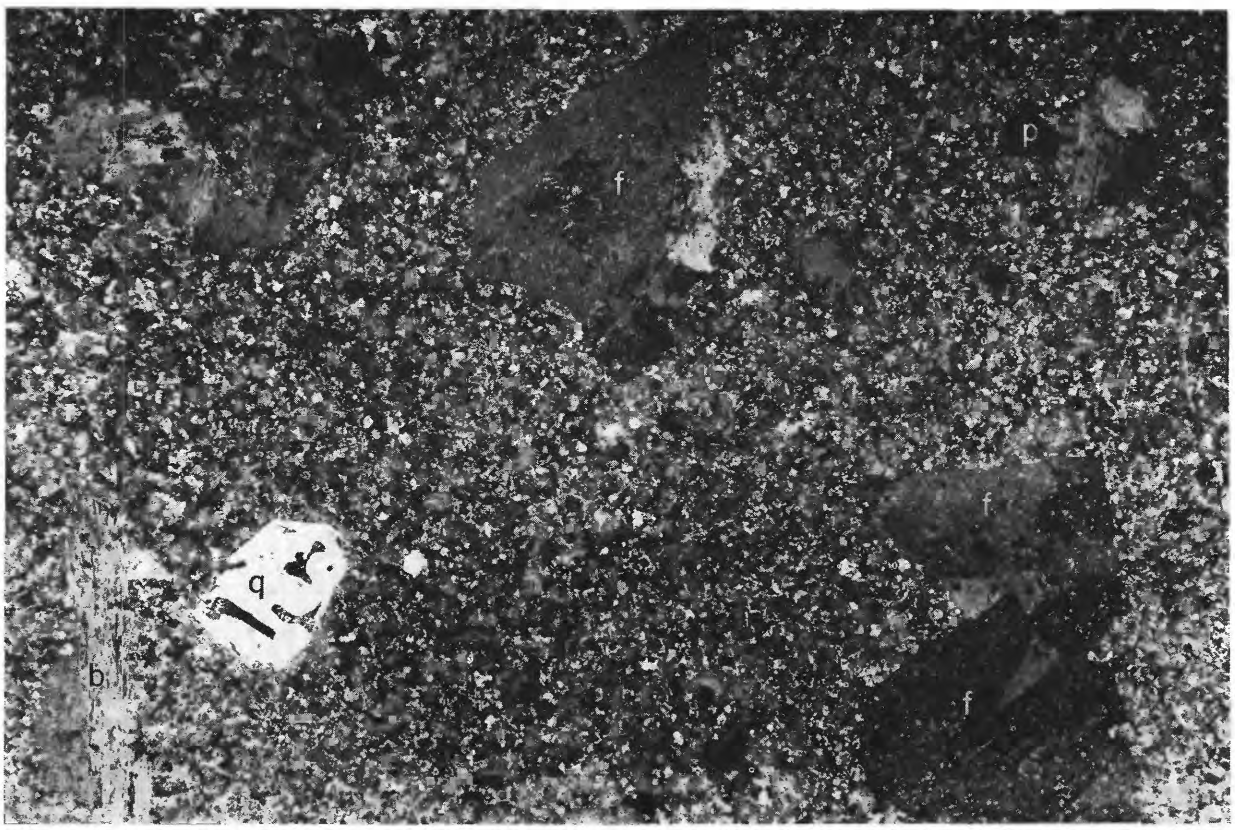

FIGURE 16.—Pyritic porphyry, wall rock of the Del Puerto pyritic hematite deposit north of Caapucú. This rock (specimen P-31) contains about half percent pyrite, *p;* quartz, *q;* feldspar, *f;* and chloritized biotite, *b.* ×15.

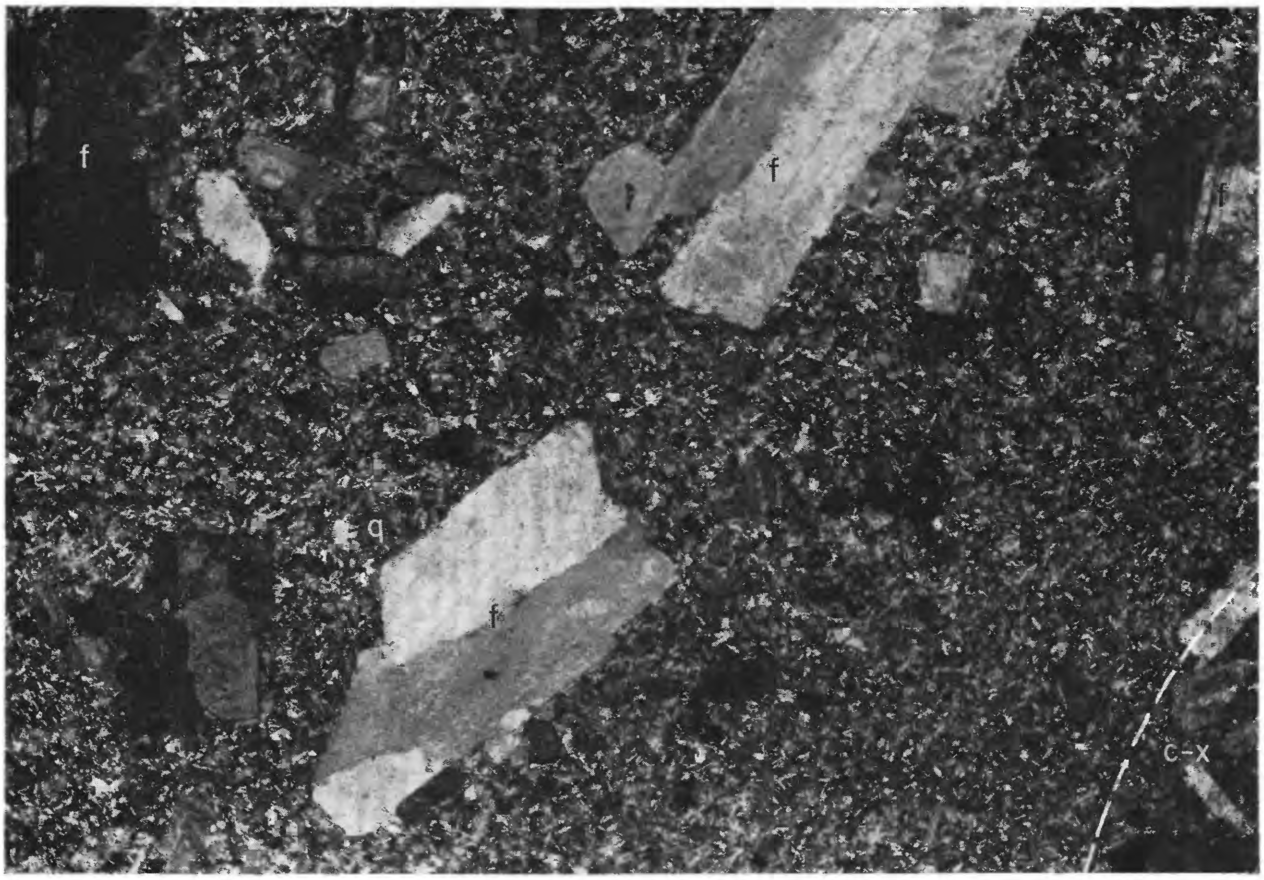

FIGURE 17.—Black porphyry (specimen P-32) from dike parallel to the Del Puerto vein near Caapucú shows andesinic phenocrysts, *f*, in finely crystalline matrix, a rather coarsely crystalline cognate xenolith, *c-x*, not discernible in the hand specimen, and quartz (*q*). × 20. Crossed nicols.

In the norm symbols (Washington (1917)), the following significance attaches to the four parts of the symbol.

The initial Roman numerals termed the "class" indicates the relation of salic to femic minerals, that is,

TABLE 2.—Spectrographic analyses of Precambrian rocks of Paraguay

[Analyst: Paul R. Barnett, U. S. Geological Survey. Tr.=trace; concentration uncertain. Looked for but not found, As, B, Bi, Cd, Ge, In, Pt, Sb, Ta, Th, Tl, U, and W]

	P-31	P-34	P-58b	P-59	P-60	P-62	P-74	P-75	P-101a	P-101b
Ag	0.0001	0	0	0	0	0	0	0	0.00004	0
Ba	.1	.05	.1	.07	.2	.07	.002	.004	.02	.1
Be	.0006	.0007	.0004	.0003	0	0	.0004	.0007	.0006	.0005
Co	.0002	.0002	Tr.	Tr.	.0008	.0003	0	0	.0005	.0005
Cr	.0003	.0004	.0002	.0001	.0003	.0001	.0001	Tr.	.002	.001
Cu	.003	.0007	.0003	.0002	.0007	.0003	.0002	.0002	.002	.001
Ga	.002	.002	.002	.001	.001	.001	.002	.003	.004	.001
La	.006	.006	.006	.006	0	.005	0	0	0	0
Mo	.0002	.0002	.0001	.0003	.0003	.0002	.0003	0	.002	.0002
Nb	.001	.001	.001	.001	.002	.001	.002	.003	.01	0
Ni	0	0	.0004	0	0	0	0	0	.001	.0008
Pb	.009	.002	.004	.003	.004	.003	.003	.005	.002	.003
Sc	.0005	.001	.0003	.0003	.001	.0004	0	0	0	.0004
Sn	0	0	0	0	0	0	0	0	.0006	0
Sr	.02	.02	.009	.009	.05	.03	.002	.0006	.002	.01
V	.002	.0009	.002	.0004	.004	.002	Tr.	Tr.	.007	.005
Y	.005	.007	.006	.005	.007	.004	.004	.007	.02	.004
Yb	.0004	.0007	.0004	.0004	.0003	.0002	.0004	.0008	.002	.0004
Zn	.2	0	0	0	0	0	0	0	0	0
Zr	.02	.03	.01	.04	.01	.02	.01	.03	.08	.01

NOTE.—See following table for description of specimen and locality of collection numbers.

Field No.	Rock	Locality
P-31	Quartz porphyry	Country rock of Del Puerto vein outcrop near Caapucú.
P-34	Porphyry, dark phase	Highway quarry near Ypacaraí.
P-58b	Rhyolite agglomerate	Acahay caldera.
P-59	Rhyolite porphyry	North of Caapucú on Quiindy road.
P-60	Porphyry (fine grained)	Near Caapucú.
P-62	Coarse granite	Near Barrerito.
P-74	Aplite	Near Villa Florida-Caapucú road.
P-75	Aplite (porphyry)	Quyquyó road.
P-101a	Granitic pebble	Tillite of Pennsylvanian or Permian age.
P-101b	Granitic pebble	Tillite of Pennsylvanian or Permian age.

quartz + feldspars + feldspathoids versus ferromagnesian silicates + oxides + carbonates + phosphates, and others. There are five classes.

The second numeral indicates the order, based on differences in the chief subgroup of the preponderant salic or femic group, and serves to distinguish those chemical characters that are dependent on the dominant acid-forming components of the magma, silicon, titanium, and ferric iron. For rocks not definitely femic in character, there are nine orders.

The third numeral indicates the rang, based on the proportions of alkalies to lime in the preponderant salic

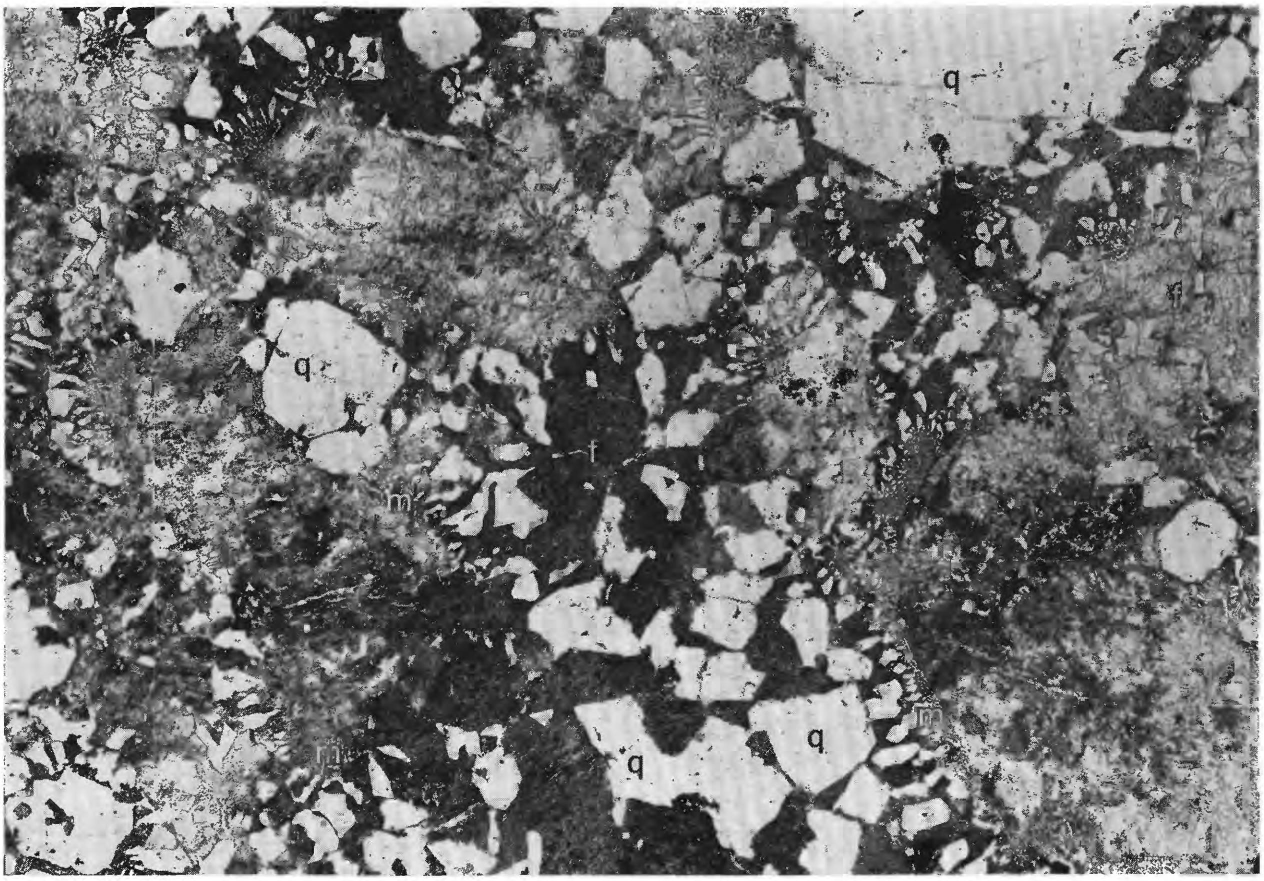

FIGURE 18.—Rhyolite (specimen P-30) from 9 kilometers south of Caapucú, with abundant myrmekite, *m*. *q*, quartz; *f*, feldspar (oligoclase and orthoclase). × 20.

minerals of rocks such as these under consideration, in which there are five rangs.

The fourth numeral, signifying the subrang, distinguishes between five divisions of the K_2O/Na_2O entering the feldspars or feldspathoids.

Inspection of the norm symbol for each analysis recorded in table 1 shows that for every one of these rocks, the class I, is that in which there is more than seven times as much salic minerals as femic; the order, either 3 or 4, showing a ratio of quartz to feldspar not over 5/3, but not less than 1/7; the rang, 1 or 2, showing K_2O+Na_2O/CaO in excess of 7/3; finally, the subrang is 3 or 4, indicative of K_2O/Na_2O less than 5/3 but greater than 1/7.

In view of this chemical constancy, as well as the similarities in petrography and in geologic settings described above there is a strong suggestion that these rocks are genetically related, or comagmatic.

The eight rocks of this suite collected by Eckel all occur within a radius of 50 kilometers east and south of Asunción. Similarly the three collected by Carnier and analyzed by Goldschlag occur within a similarly restricted area near the Río Apa in the north.

The consistency noted with respect to the major chemical constituents of these rocks appears to persist with respect to the so-called trace elements, as shown in table 2. It is difficult to assess this consistency quantitatively, yet it is evident, especially when comparison is made with data from the other rock types—basaltic, diabasic, and alkalic—which are discussed further on. The only marked enrichment, with respect to gold, copper, lead, and zinc, is in a pyritic rock from a mineralized zone, near Caapucú (specimen P-31). Certain elements, namely barium and strontium, depart widely from the mean, but these are the only two that do. As with the chemical analyses, the inference from the consistency that does exist in trace elements, is that these rocks are comagmatic, and presumably more or less contemporaneous. Unless positive stratigraphic or other evidence can be adduced to the contrary, mapping these rocks as related in age appears to be justified.

The last two spectographic analyses of specimens P-101a and P-101b are of interest in their obvious conformity to the others. They are of quartz porphyry pebbles or cobbles from the glacial till of the Tubarão series, of Pennsylvanian or Permian age. Their conformity, in respect to content of trace elements, with the other rocks shown in the table, suggests that the glaciers of Pennsylvanian or Permian time derived their pebbles, or some of them, from outcrops of Precambrian rocks similar to those that are now exposed in southern Paraguay and in the Apa region.

UPPER TRIASSIC OR JURASSIC LAVAS AND RELATED ROCKS

SERRA GERAL BASALTIC LAVAS

GENERAL FEATURES

The entire eastern and southeastern side of Paraguay is blanketed by basaltic lavas. The name Serra Geral is adopted by Harrington (1950) and for this report from current usage in Brazil (Oliveira and Leonardos, 1943, p. 499). Of Late Triassic or Jurassic age, these rocks constitute the westerly fringe of the great basalt field of the Paraná basin, which, as Baker (1923) points out, covers an area of 800,000 square kilometers in Brazil, Paraguay, Argentina, and Uruguay, and is nearly as large as the Deccan and Columbia Plateau lava fields combined. Oliveira and Leonardos (1943) ascribe an even larger area to the Serra Geral lavas—1.2 million square kilometers, of which 900,000 square kilometers are in Brazil.

The Serra Geral lavas are typical plateau-type basalts, with no known pyroclastic features or other evidence of explosive activity; the consensus seems to be that the magma rose quietly along fissures in various parts of the basin. They may possibly be related to the dikes, flows, and other bodies of basic alkalic igneous rocks that occur in other parts of Paraguay. Even more probably, they may be closely related to the intrusive diabasic rocks that are known in a number of places.

The only exposures of the Serra Geral lavas that were actually examined by Eckel are in the valley of the Río Paraná, near the town of Foz de Iguaçú (spelled Iguassú on Paraguayan maps and either Iguassú or Iguazú on Argentine maps) on the Brazilian side of the Paraná. This small port town is the gateway to the Brazilian Parque Nacional de Iguaçú that surrounds the spectacular cataracts on the Rio Iguaçú and which are also called Foz de Iguaçú on some maps. To avoid confusion, the falls are here called the "Iguaçú falls" whereas the name "Foz de Iguaçú" refers to the town, which is about 20 kilometers west of the falls and, as its name implies, is near the mouth of the Rio Iguaçú.

The specimens collected by Eckel at Foz de Iguaçú show an alkalic character that may possibly be an exceptional feature of the Serra Geral lavas. One other specimen of the Serra Geral rocks, specimen P-14, from about 200 kilometers southwest of Foz de Iguaçú was also obtained and is described on p. 30.

A good idea of the extent and geomorphologic character of the basaltic terrain in the uplands was gained by air views along several flight lines. The distribution of the lavas shown on plate 1 is probably more accurate than that of most other map units because the streams that drain the lava-covered areas follow angular courses that are almost certainly controlled by two or more intersecting joint systems in the underlying basalt. By interpreting stream forms as shown on air photographs and on large scale base maps it was possible to add appreciably to the detail of the map by Harrington (1950) without direct field observation. Although the characteristic stream drainage pattern is largely lost on a map at the scale of plate 1, it is clearly shown on the 1:500,000 scale U. S. Air Force charts from which plate 1 was compiled; on these charts there is an abrupt change in the pattern of virtually every stream as it leaves the sedimentary rocks farther east and enters the lava-covered area. The westerly contact of the lavas, therefore, is drawn to connect these changes in stream pattern.

The Serra Geral lavas once extended far west and south of their present outcrops in the northern pampas of Argentina. This is shown by their discovery in several deep borings in Santiago del Estero and Santa Fe provinces. Within Paraguay, however, it seems probable that the lavas never extended much farther west than is indicated by their present distribution, taking account of the few outliers that lie west of the main body. That they never reached the Gran Chaco region is clearly indicated by the absence of basalt or basaltic debris in any of the five exploratory holes that were drilled there. Moreover, even though the lavas are rather deeply weathered on the uplands west of the Río Paraná, they are far more resistant to erosion than most of the sedimentary rocks. It seems reasonable to suppose, then, that if they ever covered those rocks west of their present outcrop they would have protected the latter from erosion to the present day.

The lavas, called trap, dolerite, basalt, diabase, melaphyr, and other terms by various authors, range from andesite and augite porphyrite to typical limburgite with abundant olivine (Baker, 1923); in Paraguay, judging from published accounts, basalt with little or no olivine (tholeitic basalt) appears to be the predominant kind.

As seen in the vicinity of Foz de Iguaçú (figs. 19 and 20), individual flows range from less than 1 to 4 meters thick; at Iguaçú falls, a few kilometers east of the town, some flows are 10 or more meters thick. The rocks in the different flows vary widely in appearance, but this is due more to differences in structure and porosity than to composition. Many, if not most, flows are strongly amygdaloidal, others are massive, and a few show

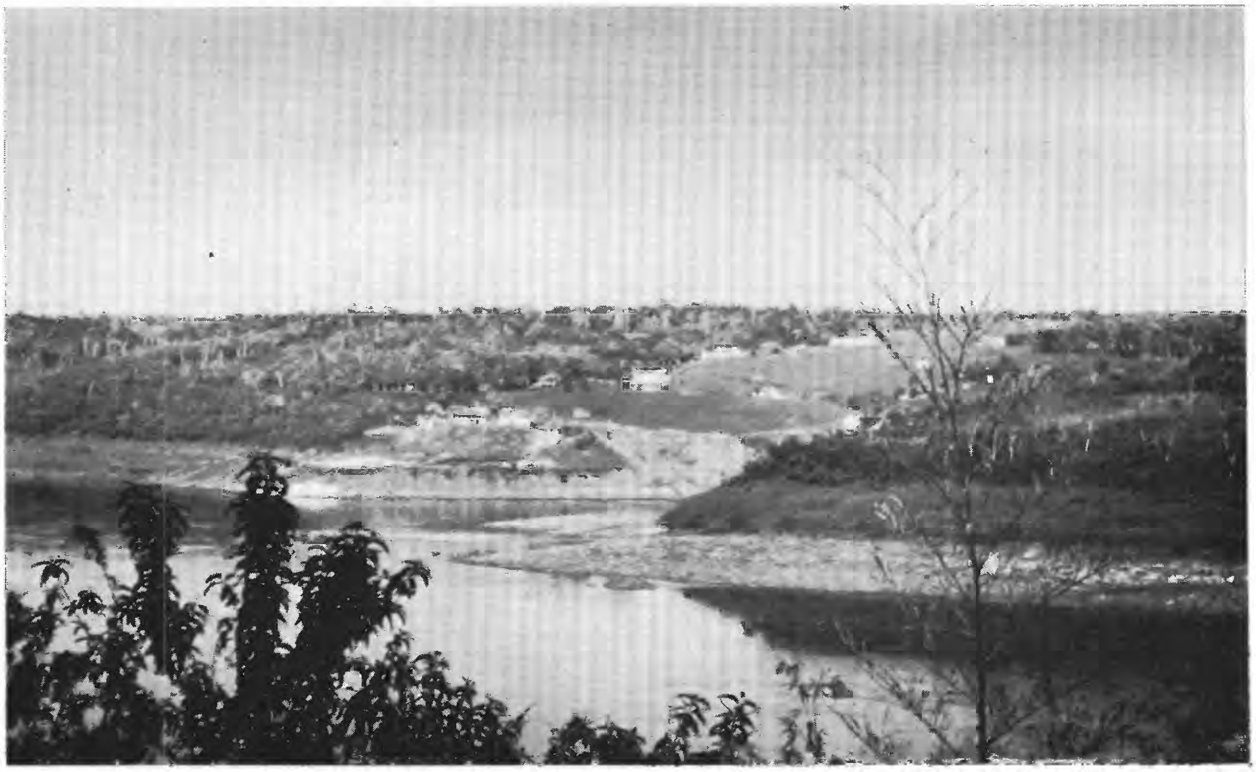

FIGURE 19.—Typical terrain, exposures, vegetation, and culture of Serra Geral basalt region in extreme eastern Paraguay. View westward across Río Paraná from point near Foz de Iguaçú, Brazil.

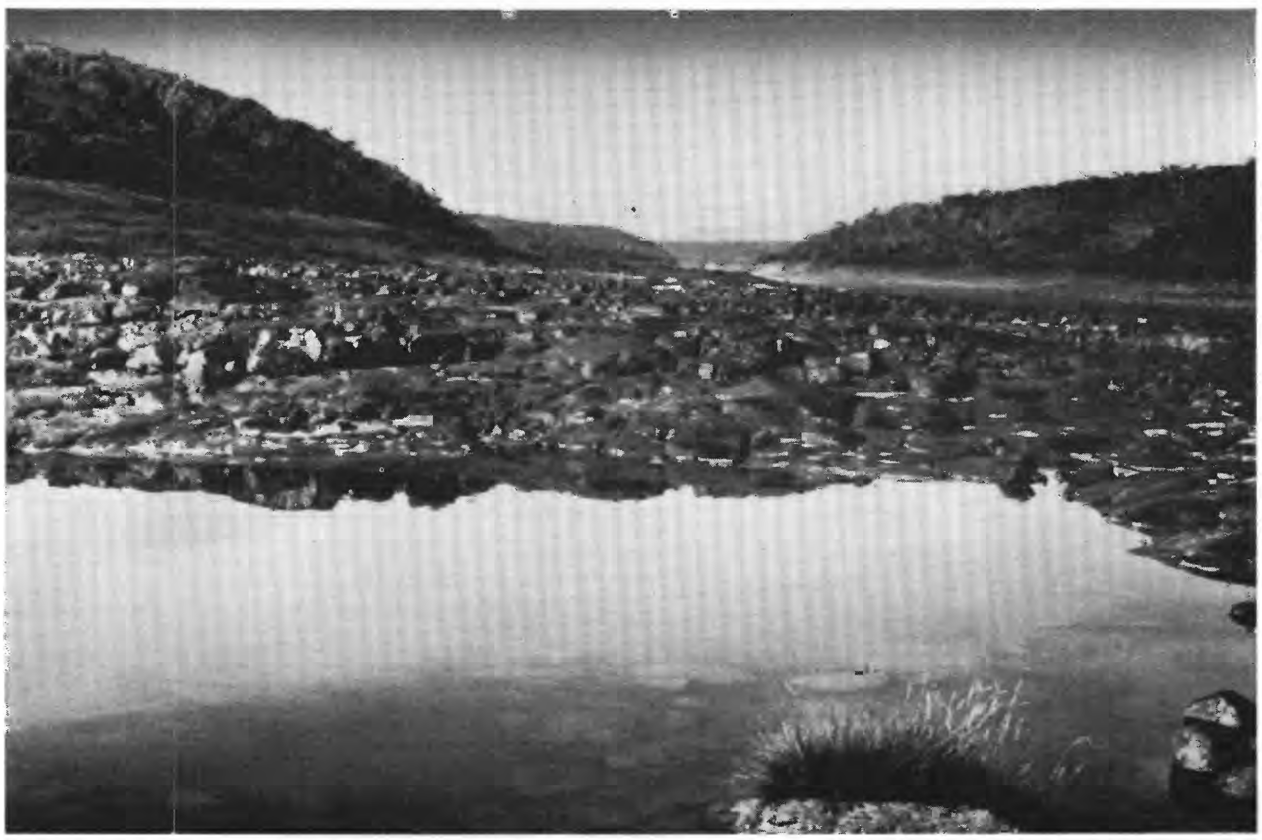

FIGURE 20.—Serra Geral basalt exposed between high and low water levels of Río Paraná. View down river from Foz de Iguaçú, Brazil. Paraguay is on the right bank.

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swirled flow structures that resemble pillow-structures. All the flows seen are dark brown to black and are dense glass with sparse small dark phenocrysts. Amygdaloidal fillings and irregular discontinuous veinlets consist of dull- to bright-green chlorite and various kinds of silica—chalcedony, agate, carnelian, opal, and clear to pale amethystine quartz crystals. Other authors have also recorded calcite, zeolites, native copper, and copper carbonate minerals in the amygdules. There is little doubt that copper minerals do occur in the basalts in places, but it also seems probable that most of the recurrent reports of discoveries of rich copper deposits in the lava-covered parts of southeastern Paraguay are based on misidentification of the green chlorite that characterizes many flows.

Structure sections drawn across the lava-covered area, such as sections *A–B* and *C–D*, plate 1, suggest that the total thickness of lava in southeastern Paraguay is not much more than 200 meters. This figure is based on assumptions that the lava dips very gently toward the southeast and that comparatively little lava has been removed by erosion. In the valley of the Paraná at Foz de Iguaçú, where neither top nor bottom is exposed, there is a little less than 100 meters of lava. Farther east, in Brazil, the entire series is generally at least 400 meters thick and locally as much as 800 meters (Gordon, 1947, p. 15).

The lavas rest on red beds of the Misiones sandstone. Conradi (1935) gives an excellent description of the irregularity of the contact between lava and sandstone in the vicinity of Pedro Juan Caballero and of the metamorphism of the sandstone there. Several authors including Washburne (1930) and Gordon (1947) mention the fact that beds of sandstone are interlayered with the lava flows, and are more numerous toward the base of the lava series than near its top. Such interlayering was not observed by Eckel, nor by Baker (1923), who examined the lavas along the entire length of the Paraná valley; Baker believes that interlayering may be confined to the edges of the Paraná basin but Washburne describes and pictures some of the red beds at Salto del Guairá. Whether the interlayering is due to intrusion of sills among the red beds, or to alternating deposition of red beds and surface flows is not known.

Unless the small body of sedimentary rock along the Paraná valley and northeast of Encarnación is of Cretaceous age, an unlikely possibility that is discussed in the section on the Misiones sandstone, the Serra Geral lavas are not covered by younger rocks anywhere in Paraguay. They are, however, overlain by continental sediments of the Cainá formation age in adjacent parts of Brazil. The Cainá, which is very similar to the underlying Botucatú (Misiones) sandstone, has been shown by Scorza (1952) to be of latest Triassic or earliest Jurassic age. It is possible that similar sediments once overlay the lavas in Paraguay, though Baker (1923) presents fairly convincing evidence that over most of the Paraná basin the lavas have been exposed to erosion ever since their deposition.

Since the Serra Geral lavas rest on beds of Triassic age, and are overlain in Brazil by Late Triassic or Early Jurassic age, the lavas themselves are quite probably also Triassic. Washburne (1939), Oliveira and Leonardos (1943, p. 500), and Harrington (1950) incline toward this view, but Baker (1923), Gordon (1947) and others consider them to be possibly or probably Jurassic. Even though the work of all these writers antedated that of Scorza (1952), who determined the age of the overlying Cainá, it seems safest here to assign the lavas to the Upper Triassic or Jurassic.

The only good exposures of the Serra Geral lavas in Paraguay, known to the author, are along the Río Alto Paraná and the lower reaches of some of its tributaries. Elsewhere the lava is weathered to depths of 3 to 8 or more meters to a chocolate-red clayey but crumbly soil; close to the surface even the chloritic and chalcedonic amygdule fillings have disappeared. The resultant deep soils support luxuriant vegetation everywhere and form, incidentally, the best coffee-growing lands in both Paraguay and southern Brazil.

The valleys of the Paraná and its tributaries tend to develop steplike profiles, both in longitudinal and transverse direction, due to differences in erodability of the flows. Except at major waterfalls, however, such as Guairá, Iguaçú, and the smaller ones on the Ñacunday and Monday rivers, the steplike pattern is not generally discernible on casual inspection.

The 30-meter zone between high and low water on the Paraná is a good field for study of erosion of resistant volcanic rock by slow-moving, relatively clear water. The Paraná carries remarkably few tools for erosion (silt, sand, or larger size pebbles), no doubt because the dense vegetation prevents active erosion of the deep soils. Yet the river has, since Jurassic time, carved a gorge several kilometers wide and 100 to 200 meters deep into the lavas. The dominant means of downcutting appear to be constant removal of chemically weathered rock by running water and abrasion by the little sand and silt carried by the stream. There are pot holes and undercut notches in some places (fig. 20), but they are rare. Angular blocks of rock tend to remain on the river bed close to their source, and there are almost no boulders, cobbles, or other large cutting tools. In many places the rock surfaces are beautifully etched, as if by a wire brush, and are evidently abraded by fine sand.

PETROGRAPHY OF THE BASALT AT FOZ DE IGUAÇÚ, BRAZIL

The basalt from near the town of Foz de Iguaçú appears to be somewhat variable lithologically, as indicated by the several specimens collected by Eckel. Conditions during crystallization, that resulted in variations in color of the rock from gray to brown and the action of hydrothermal solutions during the later stages of crystallization of the magma are reflected in variations that resulted in formation of vugs and replacement of rock by quartz-chlorite aggregates. Whether this variation is a special feature of the Foz de Iguaçú locality, revealed by the abundance of unweathered exposures, or whether the Serra Geral lavas less well exposed elsewhere would show comparable diversity, is not known.

A vuggy type of rather coarsely crystallized basalt (specimen P–92a) is shown in figure 21. There is a noteworthy amount of pseudobrookite as a result of the action of hydrothermal solutions acting on the ilmenite of the basalt (specimen P–92, figs. 22 and 23).

The pyroxene of this rock is almost completely replaced by opaque black oxide, perhaps ilmenite, $FeO \cdot TiO_2$. However, immediately adjacent to the vugs within the chlorite-chalcedonic quartz lining, this black oxide is mantled and in some places completely replaced by bright-golden-yellow prismatic pseudobrookite $Fe_2O_3 \cdot TiO_2$. This mineral characteristically has slight, hardly perceptible pleochroism and brilliant low-order ($0.030\pm$) interference colors, is biaxial and optically positive, and has negative elongation.

The conversion of ilmenite to pseudobrookite is thus: $2FeO \cdot TiO_2 + Fe_2O_3 + O \rightarrow 2Fe_2O_3 \cdot TiO_2$ or $3FeO \cdot TiO_2 + Fe_3O_4 + 2O \rightarrow 3Fe_2O_3 \cdot TiO_2$, and ilmenite is commonly associated with magnetite or hematite in basaltic rocks. Ramdohr (1950, p. 735–736) observes

So far, pseudobrookite is known almost without exception as a gaseous alteration product in titanium-rich magmas, in open cavities, intergrown therein with hematite; and, very rarely, as a constituent mineral of foyaite-pegmatite. In the first case, it is formed indirectly or directly from titanomagnetite, through oxidation at the temperature of hot fumaroles (e. g. Aranyer Berg, Thomas Range, and Katzenbuckel), thus: $3Fe_3O_4 + FeTiO_3 + 2O \rightarrow 4Fe_2O_3 + Fe_2TiO_5$. Apparently, the hematite thus formed may often be removed.

He also notes that pseudobrookite is easily produced by heating ilmenite and hematite in air.

Fries, Schaller, and Glass (1942) list 15 occurrences

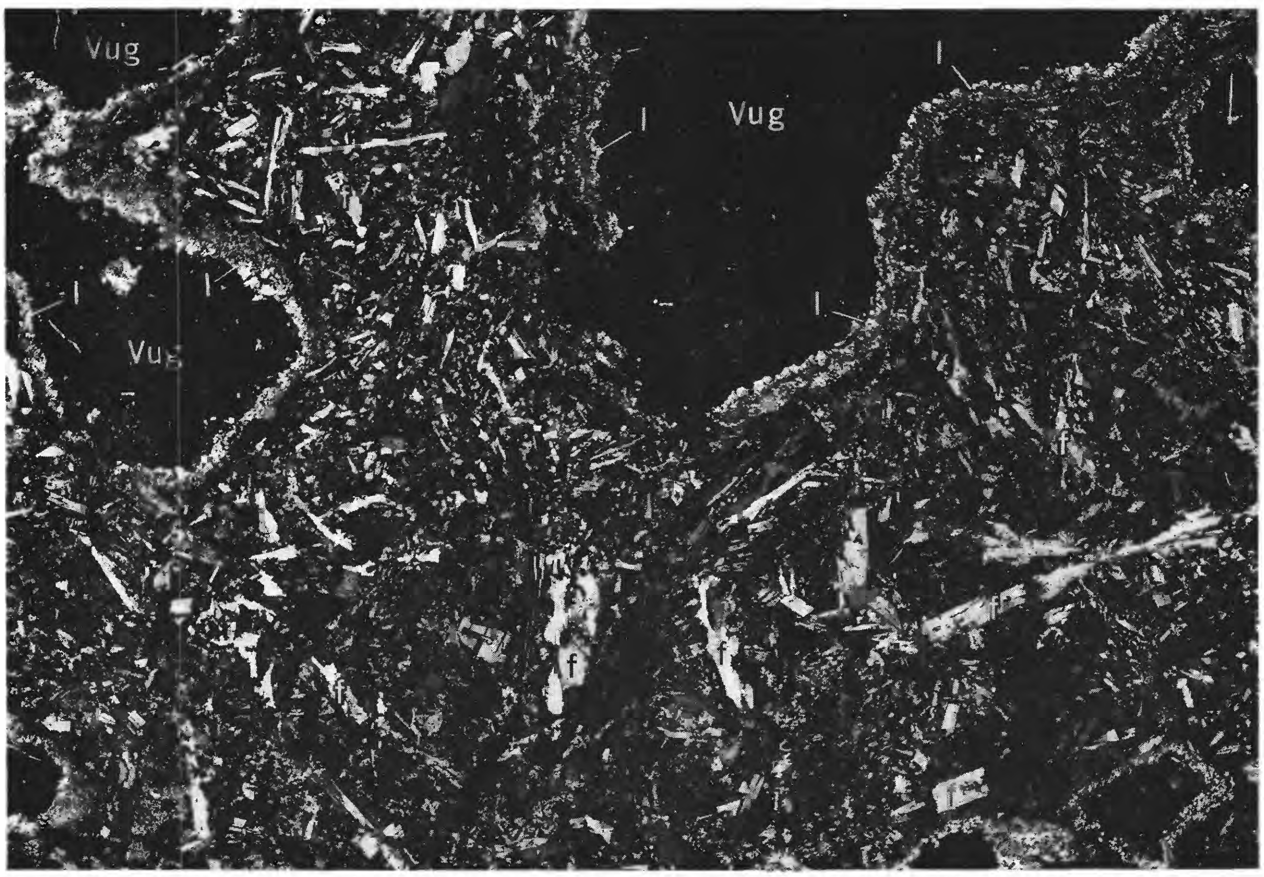

FIGURE 21.—Brown moderately fine grained vuggy basalt (specimen P–92a) from Foz de Iguaçú, Brazil. Well-formed calcic plagioclase phenocrysts, *f*, in a matrix of apparently similar but rather turbid feldspar. The black areas are pyroxene almost completely replaced by black iron oxide. Two large vugs are shown in the upper half of the illustration, with a lining, *l*, of chalcedonic quartz and pale-green chlorite. Pseudobrookite is formed around these vugs. × 15. Crossed nicols.

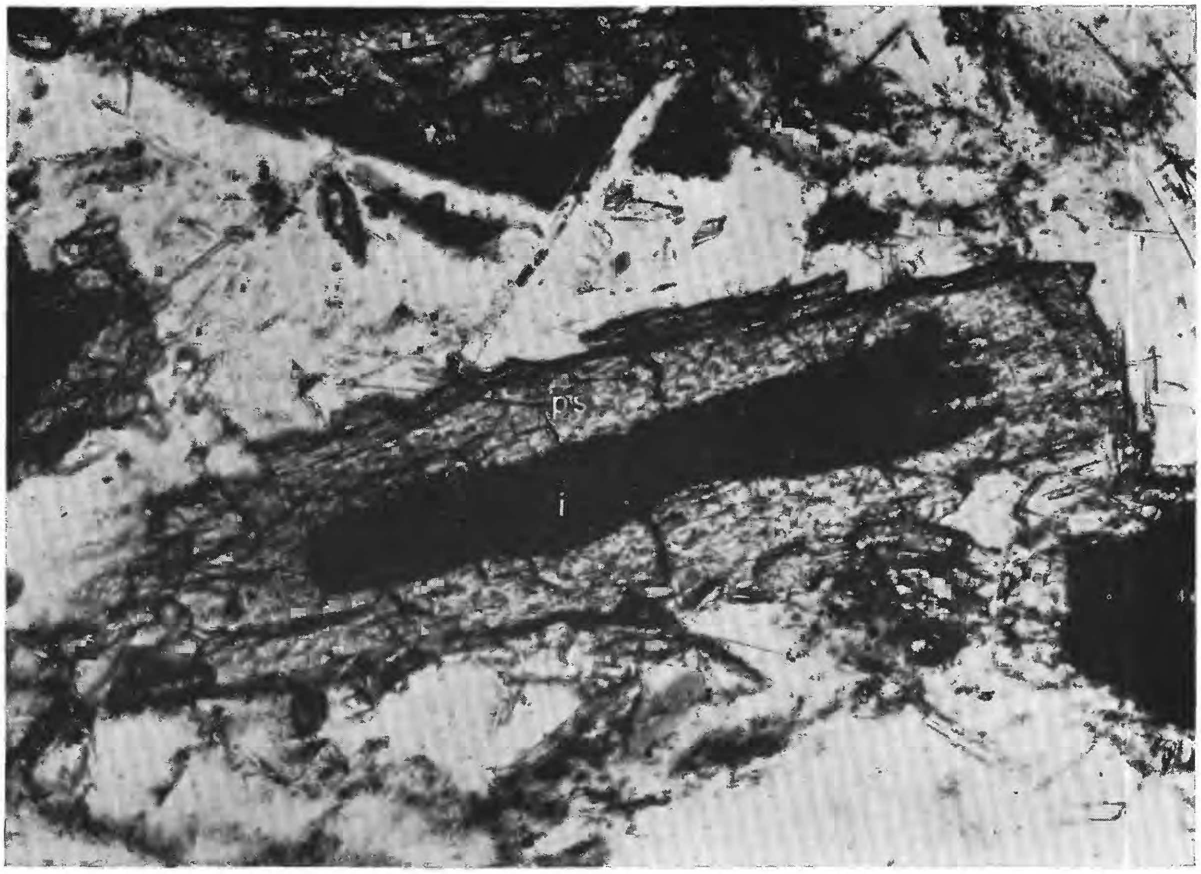

FIGURE 22.—Basalt (specimen P-92) from Foz de Iguaçú, Brazil, showing a core of ilmenite, *i*, with a hull of pseudobrookite, *ps*. × 300.

of pseudobrookite: all but two of them are in extrusive volcanic rocks in cavities and on fissure walls.

Other vugs are lined or filled: some with a dark-green micaceous mineral, others with a brown micaceous mineral accompanied by microscopic "dog-tooth" calcite crystals. Both of these platy minerals were studied by their X-ray diffraction pattern by J. M. Axelrod. He found the pattern of the dark mineral to resemble that of nontronite or saponite $Fe_2(OH)_2SiO_4O_{10}\cdot nH_2O$ or $9MgO\cdot Al_2O_3\cdot 10SiO_2\cdot 16H_2O$ (approximately) and that of the brown substance to be mainly similar but also with a 7Å spacing that may be chlorite, a kaolinite group mineral, or serpentine.

A fine-grained phase of the basalt (specimen P–92b), which presumably chilled early and thus was impervious to hydrothermal solutions, is shown in figure 24.

The relations of the basalt to the replacing quartz-chlorite aggregate are shown in specimen P–92, figure 25. Basalt is shown at the bottom of the photograph, with a bordering phase of incompletely absorbed basalt. Several partly assimilated basalt fragments are seen in the quartz-chlorite area. The basalt away from the contact appears to be normal olivine basalt, the brown olivine often being completely altered to iddingsite, although the pyroxene and calcic-plagioclase is unaltered. The light-gray turbid areas of the illustration consist essentially of almost isotropic fine-grained chalcedonic quartz and light-green chlorite, with scattered pyrite and bright-red hematite. The clear areas are quartz and radial chalcedony, containing abundant extremely minute long fibers, which may be rutile or, possibly, pseudobrookite. A small group of such, much larger than usual, are seen in the upper right center of the photomicrograph.

CARMEN DEL PARANÁ

Carmen del Paraná is 200 kilometers southwest of Foz de Iguaçú. It was not visited, but a representative specimen (P–14) from this locality was studied. The rock is quartz basalt, with amygdaloidal cavities, some lined with bright-green chlorite and filled with calcite, others with chlorite and quartz. The rock, believed by its owner to be copper ore, contains little if any copper; the conspicuous green "copper staining" is celadonite or a related chloritic mineral. Microscopically, the spherical cavity shown in figure 26 consists of chlorite with quartz. Irregularly shaped quartz particles, usually with chlorite, are strewn about. The darker areas are green chlorite, the white are quartz.

DIABASE

Throughout central Paraguay there are smaller bodies of diabase and similar rocks, mostly in the form of dikes, but including some flows and sills. The known bodies are shown on plate 1, but it seems probable that there are still many others that have not been reported. Because of their petrologic and chemical resemblance to the Serra Geral basaltic lavas, as well as of their suggestive geographic distribution, they are believed to be genetically related to the Serra Geral rocks and of approximately the same age.

CORDILLERA DE LOS ALTOS

Several dikes of diabase are known in the southern part of the Cordillera de los Altos, the eminence, made up principally of sandstone of the Caacupé series, that forms the east edge of the Ypacaraí depression.

Two dikes, each trending eastward, are exposed along the road that connects Paraguarí and Piribebuy with the main paved highway east of Caacupé. Several other northward-trending dikes are indicated in this area on plate 1. Mapping of the dikes is based entirely on lineations seen on aerial photographs; these lineations may represent faults or dikes of some other kind of rock than diabase.

Of the two dikes exposed along the road, one (specimen P–18) is about midway between Paraguarí and Piribebuy. It strikes N. 45° W. and dips 75°–80° NE. It is about 4 meters thick, and it cuts massive, cross-bedded sandstone that dips 15° SE. It can be traced several tens of meters toward the northwest, but apparently ends abruptly at the road, for it cannot be traced to the southeast, even though rock exposures there are relatively good.

The second dike (specimen P–37) is about 3 kilometers north of Piribebuy and is exposed in a small roadside quarry. The country rock is the white saccharoidal sandstone unit of the Caacupé series that here strikes due east and dips 10° S. The dike also strikes due east and is vertical. It is 12 meters wide and of unknown length; the sandstone wall rocks are sheared, slickensided, and strongly impregnated with iron oxides for about 4 meters on each side of the dike.

The fresh rock (specimen P–37) is extremely tough and hard and contains numerous brown glassy subhedral and euhedral crystals of augite or olivine as

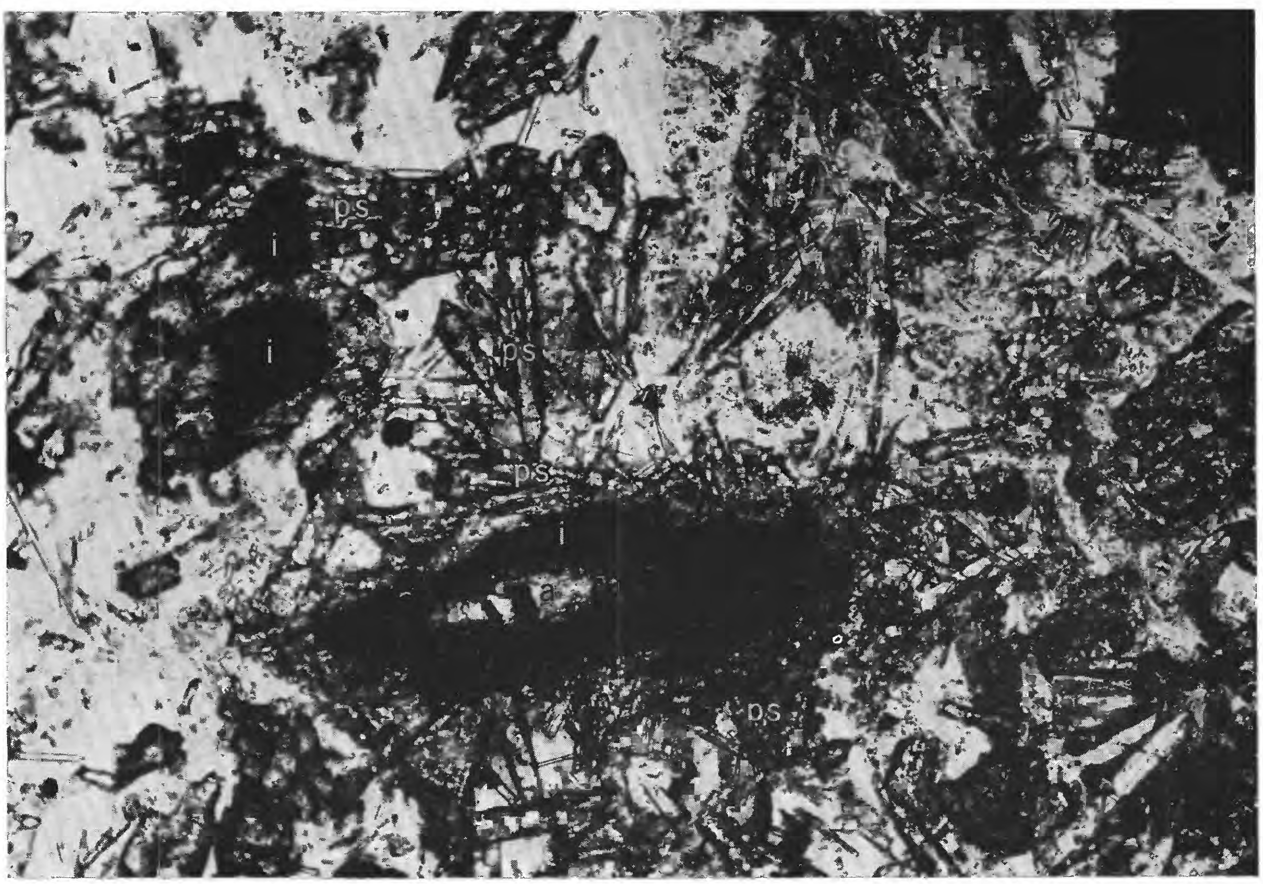

FIGURE 23.—Basalt (specimen P–92) from Foz de Iguaçú, Brazil, showing core of augite, *a*, incompletely replaced by ilmenite, *i*, with abundant pseudobrookite, *ps*. × 300.

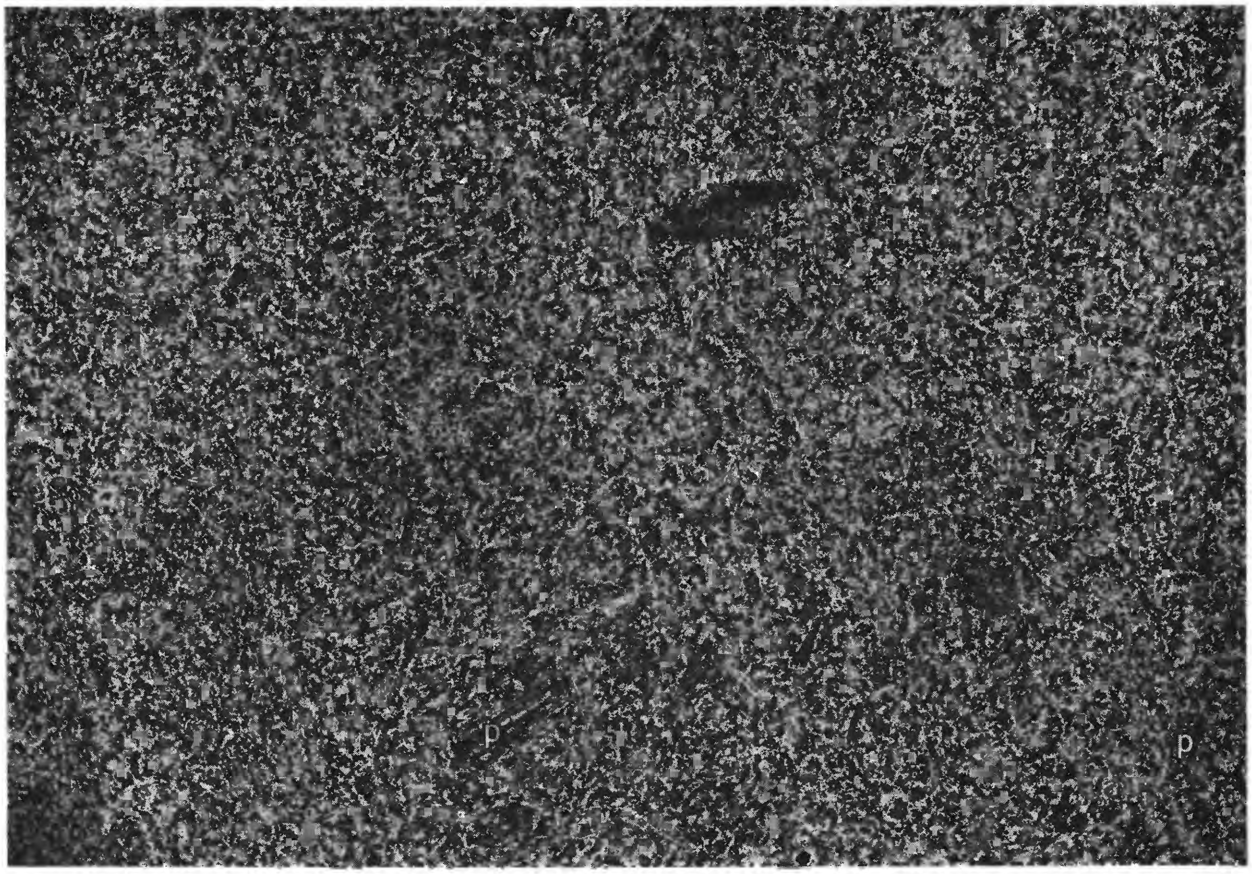

FIGURE 24.—Basalt (specimen P–92b) from Foz de Iguaçû, Brazil. A fine-grained dark-gray dense rock, similar to that in figure 21, but not vuggy and much finer grained. The pyroxene (olivine?) appears to be orthorhombic (parallel extinction), and occurs as sparse porphyroblasts, *p*. The groundmass consists of calcic plagioclase with abundant minute yellowish prisms of monoclinic pyroxene (strongly inclined extinction), and opaque black ore grains. The pyroxene (olivine?) is largely replaced by brown biotitic material. × 20.

much as 1 centimeter in diameter, in a relatively fine grained groundmass. Alteration, due to weathering or other processes, has proceeded deeply along all joints seen, so that the fresh rock is confined to nearly perfect spheres, 5 to 30 or more centimeters in diameter, surrounded by brown fibrous iron oxides and silicates and by red and brown clay minerals.

As shown in the illustration (fig. 27) the rock is a diabase showing the characteristic texture; mineralogically it consists essentially of calcic plagioclase and augite. No olivine or quartz was observed in the thin section.

The effects of layering in a large diabase body may produce striking differences in composition; thus the absence of olivine or quartz in the specimen studied by no means precludes their presence in lower or higher horizons, respectively.

OTHER OCCURRENCES OF DIABASE

Goldschlag (1913a, p. 28) describes a coarse-grained diabase from Arroyo Bolas-cué, a small stream 12 kilometers southwest of Caaguazú, on the road to Villarrica. It is a green to black rock that weathers to brown and consists principally of macroscopic crystals of andesine-labradorite feldspar and augite, with minor amounts of magnetite, apatite, and serpentine. No analysis is given.

Olivine diabase caps the sandstone beds that make up Cerro Domingo and Cerro Alberto, two of the peaks of Sierra Ybyturuzú, a part of the Cordillera de Caaguazú that is also known as Sierra Villarrica, east of Villarrica; there is also an amygdaloidal diabase on Cerro Domingo. Goldschlag (1913a), whose analyses are given in table 3, describes the olivine diabase at the latter locality as made up of visible crystals of albite-twinned andesine-labradorite, with augite and olivine; accessory minerals are apatite, zircon, and magnetite. The amygdaloidal rock, whose cavities are filled with quartz, chalcedony, and zeolite (chabazite), contains crystals of oligoclase-andesine feldspar, augite, and olivine in a glassy groundmass.

With the Cerro Domingo diabase Goldschlag describes an amygdaloidal phase with chabazite. The diabase overlies sandstone, which is found as xenoliths in the diabase.

Carnier (1911c) and Goldschlag (1913a) also describe a diabase porphyrite from Cerro Howyí. This hill is not shown by name on recent maps, but from Carnier's description it appears to be a prominent conical hill about half way between Yataity and Coronel Martínez, west of Villarrica. It contains phenocrysts of augite, olivine, and feldspar as much as 0.5 centimeters long in a glassy groundmass that contains smaller crystals of feldspar, brown hornblende, magnetite, and apatite. The chemical analysis of this rock is given in table 4.

OLIVINE BASALT NEAR ASUNCIÓN

Thick layers of columnar basalt characterized by prominent phenocrysts of olivine cap Cerro Tacumbú, on the south edge of Asunción; Cerro Lambaré, a few kilometers south; and several other hills both northeast and southeast of the city. Most of these deposits are quarried extensively for building and paving stone. They appear to be remnants of a once-extensive lava flow, but the fact that similar basalt has been found in several deep water wells in Asunción indicates that the basalt may be, at least in part, intrusive and sill-like in form, rather than wholly extrusive.

Milch (1895) described the rock on Tacumbú as a feldspar-free olivine basalt or limburgite. The rock is dense dark brown to black, with many large phenocrysts of olivine and some of augite and magnetite. The olivine phenocrysts, some showing rapid growth in one direction, are colorless to light green and very fresh, with only a little iron hydroxide on some fracture planes. Some crystals are homogeneous olivine, but others contain greater or smaller amounts of magnetite and glass as inclusions. The augite phenocrysts are generally larger than those of olivine. They are light in color, hence, only slightly pleochroic; zonal structure is clearly recognizable. The groundmass consists of augite crystals very irregularly distributed through glass. The augite forms stubby prisms as well as angular and rounded grains; with magnetite it tends to rim the phenocrysts. Some of the glass is entirely free of inclusions but elsewhere it is filled with thin small green or colorless prisms and needles. Some of these crystals are believed by Milch to be feldspar, but they are so few that the rock is designated as essentially feldspar free.

Harrington (1950) also briefly describes the basalts on Cerro Tacumbú and Cerro Lambaré, in particular emphasizing the amygdular character and absence of olivine (at least macroscopic) in the latter place.

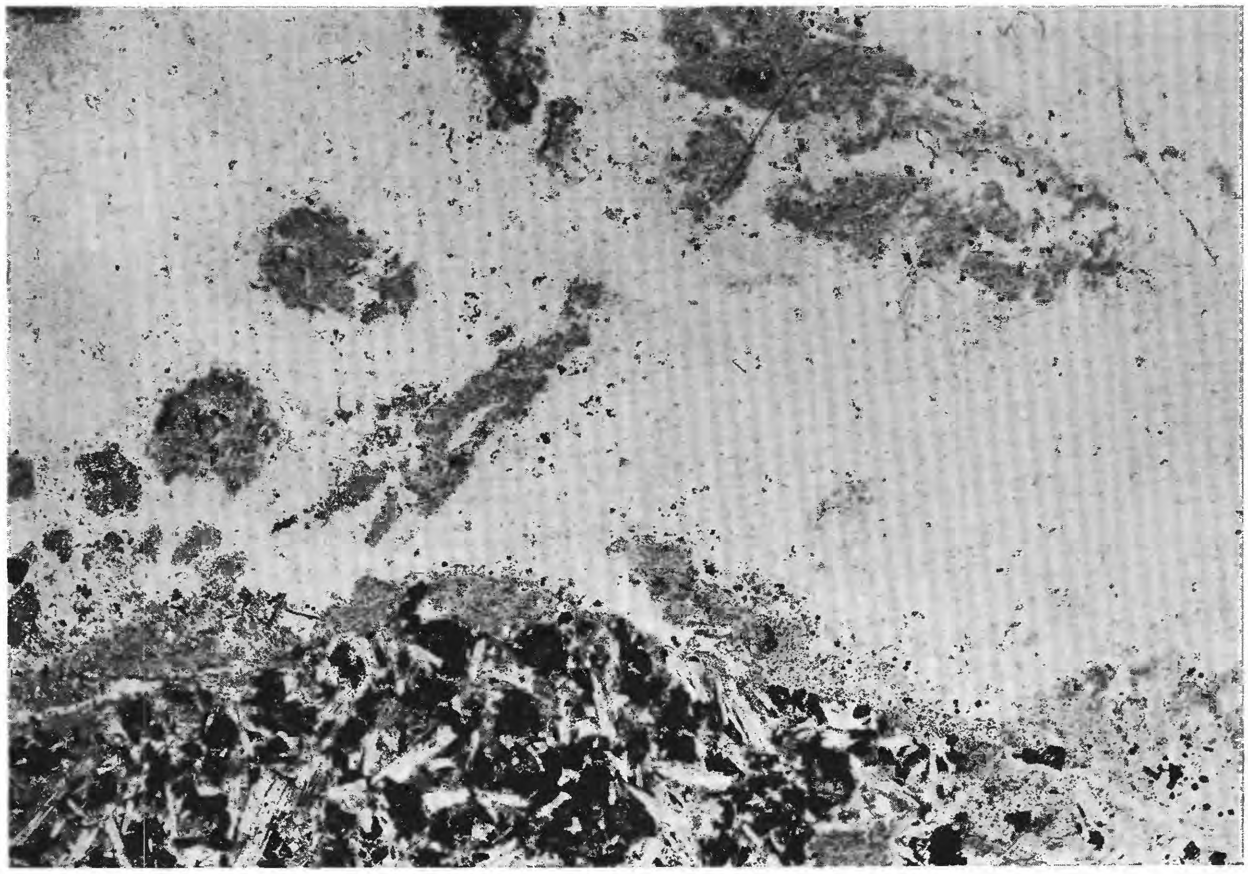

FIGURE 25.—Basalt (specimen P-92) from Foz de Iguaçú, Brazil. Shows basalt dissolved in chalcedony-chlorite vein material. × 20.

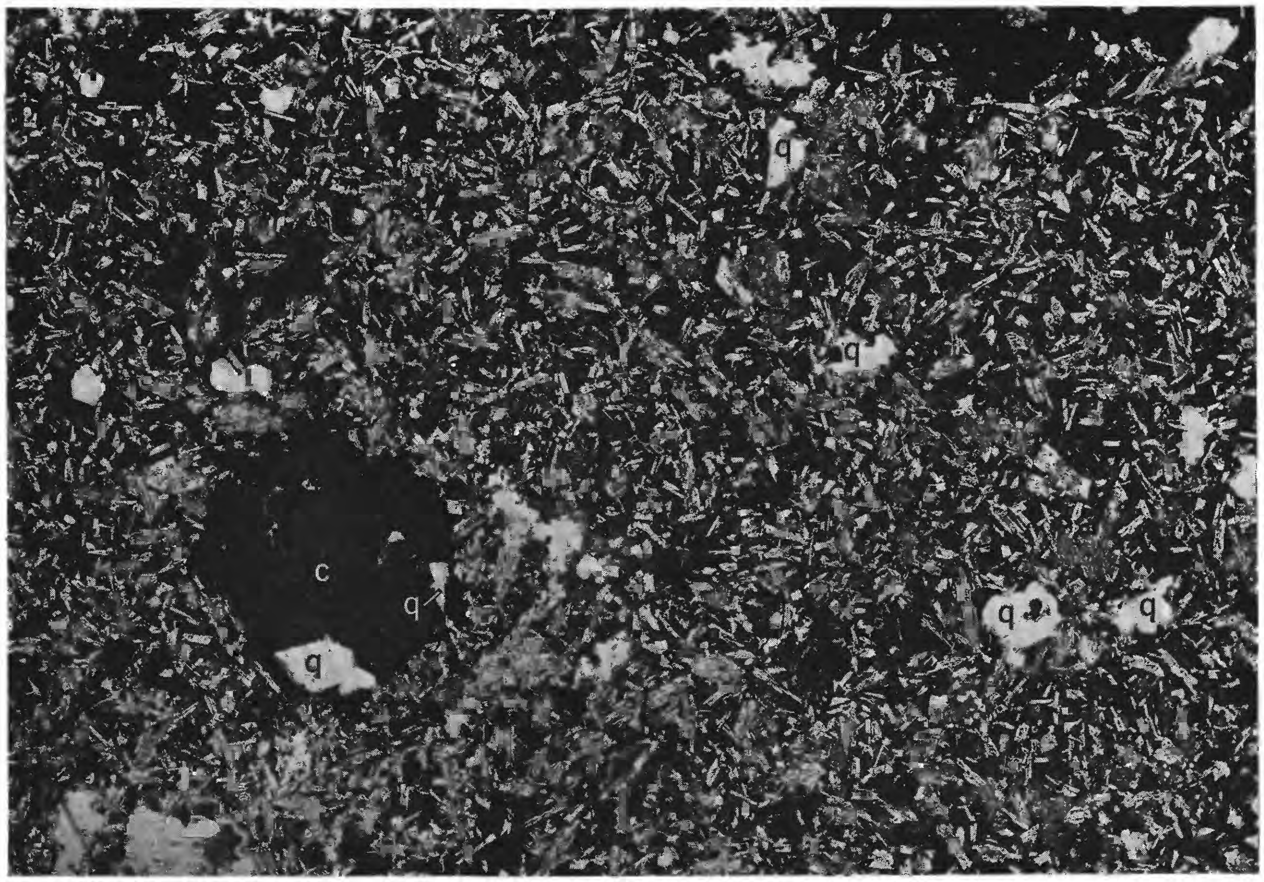

FIGURE 26.—Serra Geral basalt (specimen P-14) from near Carmen del Paraná is quartz basalt with bright-green chlorite, *c*. Light areas are quartz, *q*. Other vesicles (not shown) are filled with calcite. × 20.

"PSEUDOTRACHYTE" NEAR AREGUÁ AND LUQUE

On the hills south and west of Areguá there are several small bodies of arkosic sandstone that, in both external appearance and in geologic relations, closely resemble trachytic igneous rock. At least one similar body is reported near Luque. The deposits are so unusual that they deserve mention here, even though their origin cannot be explained.

The body that crops out on a small hill just south of the main road to Areguá, and about 2 kilometers south of the town is representative. There, several small quarries have been opened to remove "pseudotrachyte" for use as building stone material in walls, walks and the like. The country rock is red Misiones sandstone of Triassic age that strikes N. 60° W. and dips 36° SW. The pseudotrachyte is interbedded with the sandstone in a layer about 2 meters thick. This layer is strikingly characterized by perfect columnar jointing similar to that in columnar-jointed basalt flows except that the columns are parallel to the bedding rather than normal to it. The individual columns, some as much as 3 meters long, range from 4 to 15 centimeters in diameter and have from 5 to 8 smooth, sharply defined sides. On and near their surfaces they appear to be made up of small quartz grains set in a matrix of finer quartz grains and white clay. The interior parts of the columns, however, are fresher and have the megascopic appearance of dense light-colored igneous rock in which quartz, pink and white feldspar, and a little biotite can be distinguished. Under the microscope, however, the rock is seen to be unquestionably arkose, consisting of subrounded to angular grains of quartz and feldspar embedded in a turbid feldspathic matrix. Under crossed nicols the quartz grains are seen to have grown into the matrix, each grain being surrounded by a turbid outer zone in parallel optical orientation.

More study is needed to determine the character and origin of this rock. It may represent a clastic intrusive sill or it may merely represent local metamorphism of the sedimentary rocks by some of the nearby basaltic or diabasic rocks.

ANALYSES OF SERRA GERAL LAVA AND RELATED ROCKS

Chemical analyses of a specimen of the Serra Geral basalt from Foz de Iguaçú, as well as of four chemically similar rocks, are shown on table 3. Spectrographic analyses of the Foz de Iguaçú rock and of two of the alkalic rocks from Mbocayaty (p. 44), are given in

SKETCH OF AN EXTINCT VOLCANO NEAR ACAHAY, SOUTHERN PARAGUAY

Drawn from air photographs.

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FIGURE 27.—Diabase (specimen P-37) on the road north of Piribebuy showing characteristic holocrystalline aggregate of calcic plagioclase, *f*, and augite, *py*, with magnetite-ilmenite, *m-i*. × 15. Crossed nicols.

TABLE 3.—*Chemical analyses of Serra Geral lava and related rocks of Paraguay*

	P-58a [1]	P-92 [1]	A	B	C	D
SiO_2	51.27	50.05	48.63	48.38	49.65	40.95
Al_2O_3	15.72	12.95	12.49	10.42	9.26	15.37
Fe_2O_3	8.61	5.79	11.72	12.11	15.25	6.36
FeO	1.53	8.20	9.08	4.99	4.12	4.38
MgO	3.72	4.25	2.37	3.53	3.21	10.46
CaO	5.98	8.38	8.75	7.98	8.82	11.67
Na_2O	3.71	2.50	2.46	4.74	4.39	3.97
K_2O	4.15	1.50	.64	1.50	1.75	1.26
H_2O-	.87	1.18	.79	.96	.33	.86
H_2O+	1.82	.80	.80	1.97	2.43	3.93
TiO_2	1.64	3.56	2.20	2.58	1.42	.25
CO_2	.01	.00	------	------	------	------
P_2O_5	.43	.53	.77	1.04	.43	.09
MnO	.17	.25	------	Tr.	------	Tr.
BaO	.18	------	------	------	------	.10
Cr_2O_3	------	------	------	------	------	.19
	99.81	99.94	100.70	100.20	101.06	99.84
Density	2.73	2.81	------	------	------	2.932
Norm	II·5·2·3	III·4·3·4	III·4·3·4	III·5·1·4	III·5·1·4	III·6·3·4 III·7·3·4

[1] Spectrographic analyses for trace elements made. Densities by L. N. Tarrant, U. S. Geological Survey.

NOTE.—See following table for explanation of field numbers.

Field No.	Rock	Analyst
P-58a	Basalt, Acahay caldera	Lois D. Trumbull, U. S. Geol. Survey.
P-92	Basalt, Foz de Iguaçú, Brazil	Lois D. Trumbull.
A	Olivine diabase, Cerro Domingo, Sierra Ybyturuzú.	Maurice Goldschlag.
B	Olivine diabase, Cerro Alberto, Sierra Ybyturuzú.	Maurice Goldschlag.
C	Diabase porphyrite, Cerro Howyí.	Maurice Goldschlag.
D	Limburgite, Cerro Tacumbú	Lindner (Milch 1905).

TABLE 4.—*Spectrographic analyses of Serra Geral lava and related rocks of Paraguay*

[Analyst: Paul R. Barnett, U. S. Geological Survey. Looked for but not found: As, Ag, Au, B, Bi, Cd, Ge, In, Pb, Pt, Sb, Sn, Ta, Th, Tl, U, W, Zn]

	P-58a	P-92	P-54d	P-54g
Ba	0.2	0.06	0.2	0.2
Be	0	0	0	0
Co	.004	.004	.002	.004
Cr	.0005	.003	.002	.04
Cu	.005	.03	.005	.005
Ga	.002	.002	.002	.002
La	.01	0	.02	.01
Mo	.0004	.0005	0	0
Nb	.004	.005	.008	.005
Ni	.002	.005	.001	.03
Pb	.002	.002	.003	.003
Sc	.002	.004	.001	.002
Sr	.2	.09	.3	.2
V	.04	.05	.02	.03
Y	.009	.008	.006	.005
Yb	.0002	.0002	.0002	.0001
Zr	.03	.02	.07	.04

NOTE.—See table below for explanation of field numbers.

Field No.	Rock	Locality
P-58a	Basalt (Tertiary)	Acahay caldera.
P-92	Basalt (Serra Geral)	Foz de Iguaçú, Brazil.
P-54d	Nepheline syenite	Mbocayaty.
P-54g	Shonkinite (analcite)	Do.

table 4. Analyses of basalt from the Acahay caldera are included in both tables.

Five of the six analyses of basalt and related rocks shown in table 3 are obviously similar, indicating that despite the variation in names, the rocks are essentially similar. The diabase porphyrite (proterobase) from Tagaruassú in Mato Grosso, Brazil, described by Goldschlag (1913a, p. 25) is also similar. The Acahay basalt (specimen P–58a), however, is chemically more related to the group of alkalic rocks discussed below. Further, both the shonkinite from Mbocayaty, and the phonolite from Centurión, are chemically similar to the five basaltic rocks. The spectrographic analysis (table 4) appears to confirm this relationship.

All these rocks (and the alkalic types described below) differ both in major and minor chemical relationships from the granitic-porphyritic Precambrian rocks. Whether any valid conclusions as to relation of chemical similarities to age of the rocks are possible cannot be said from the data at hand.

ALKALIC ROCKS OF UNKNOWN AGE

Alkalic rocks have been reported from many localities in Paraguay and nearby Brazil. One body of these rocks at Mbocayaty, was studied by Eckel and a number of specimens from it have been analyzed (specimens P–54). A second locality of possibly alkalic rock that was visited is a mica-porphyry dike 10 miles east of Villarrica (specimen P–50).

The Acahay volcanic mass and a group of porphyries and agglomerates from near Ypacaraí are also described here, though from the scanty evidence at hand these bodies appear to be complex and not all of the rocks associated with them are alkalic.

From the available data (Pohlmann, 1886; Carnier, 1911, 1913; Goldschlag, 1913), it appears that at Centurión in the northern Río Apa region and at Mbocayaty, in the central region, there are very similar occurrences of alkalic rocks. Likewise, similar rocks occur at Cerro Ybytymí, part of the Cerro Apitaguá (Hibsch, 1891), near Sapucaí (Milch, 1895), and the Pão de Açúcar region in Brazil, and adjacent Paraguay (Lisboa, 1909; Carnier, 1913; Gerth, 1935; Oliveira and Leonardos, 1943).

Data are not at hand for any satisfactory discussion of the alkalic rocks of Paraguay. The few analyses available leave uncertain what relationship may exist between the undoubted alkalic rock types and the basaltic rocks of Paraguay.

The age of the alkalic rocks is not known. Some seem to be closely related geographically and petrographically to the Serra Geral lavas of Triassic or Jurassic age and some of particularly youthful appearance, as parts of the Acahay body and the one at Pão de Açúcar, Brazil, are no older than Late Tertiary. All the alkalic rocks are shown on plate 1 as "age unknown, possibly Triassic through Tertiary."

NORTHERN AREA

PHONOLITE AT CENTURIÓN

Goldschlag (1913a) describes phonolite from the Río Apa region, 2–3 kilometers west-southwest of Centurión. This probably is the "felsite porphyry" mentioned by Carnier (1911c) as occurring in this general vicinity. According to Carnier, dikes of syenite and felsite cut muscovite schist, metamorphic sandstone, and quartzite. This is the only reported occurrence of alkalic rocks in the Río Apa region except for the nepheline basalt and olivine kersantite described by Pohlmann (1886).

Goldschlag says that the phonolite near Centurión is bluish green, characterized in hand specimen by phenocrysts of pyroxene (as much as 1 centimeter long) and secondary zeolites. Under the microscope phenocrysts of aegirine augite, orthoclase and andesine-labradorite in poorly defined crystals, olivine partly altered to serpentine, and biotite are seen. Very small crystals of noselite, magnetite, and apatite are dispersed through a groundmass composed largely of feldspar. The groundmass is zeolitized; there is also secondary calcite and part of it appears as well-formed crystals. Goldschlag's analysis of the rock is given in table 5 (analysis C). It is evident from comparison with Mbocayaty shonkinite (P–54g, table 5, analysis B) that the rock analyzed by Goldschlag is similar and that the phonolite described by Milch from Sapucaí (table 5, analysis D) is also a similar rock. Olivine-kersantite from the limestone of Colonia Santa María del Apa, was described by Pohlmann (1886); it is associated with nepheline-basalt. Pohlmann does not describe the field relations, and no analysis is available.

SYENITIC ROCK OF PÃO de AÇÚCAR, BRAZIL

The prominent Pão de Açúcar is on the Brazilian side of the Río Paraguay, just north of Pôrto Murtinho, Brazil, and about 35 kilometers north of Puerto Palma Chica, Paraguay. It is included here because small bodies of rock that appear to be related to it appear in Paraguay. The Pão de Açúcar rises nearly 400 meters abruptly from the river's edge; it is about 5 kilometers in diameter. With steep sides and a jagged top, from the air it appears to be a relatively young complex volcanic cone, not unlike the caldera at Acahay (p. 38), but considerably modified by erosion.

Several much smaller and lower hills form the Paraguayan bank of the river just southwest of the Pão de Açúcar. From the air they appear to belong to the same rock mass, separated from it only by the river alluvium. This mass of rocks is dated as post-Permian by Lisboa (1909, p. 51–53), as of probable Tertiary age by Carnier (1911c) as part of the Serra Geral eruptive rocks of Triassic age by Gerth (1935, pt. 2, p. 244) and as Triassic (Rhaetic) by Oliveira and Leonardos (1943, p. 99). The apparent youthfulness of the cone strongly suggests a late Tertiary age.

Carnier (1913) describes the Pão de Açúcar as augite syenite. Lisboa (1909, p. 51–53), however, says that it is made up principally of nepheline syenite (foyaite) with lesser amounts of augite syenite, bostonite, and phonolite. He characterized the mass as a relatively young volcano, but dates it only as post-Permian. He says that the nepheline syenite, which forms the major part of the body, has a granitoid texture and is made up mainly of orthoclase, nepheline, and acmite, which is nearly opaque and without crystal form. The augite syenite, which Lisboa says forms the north part of the mass and extends into Paraguay, is coarse-grained, with anorthoclase the only feldspar. Biotite, with some acmite and magnetite, is abundant, and sphene is a very abundant accessory. Black pyroxenes give the rock a porphyroid appearance. He notes that this differs materially from the rock described by Evans (1894) from the same locality. That rock contained both orthoclase and plagioclase, as well as hornblende, augite, apatite, and sphene. Lisboa's phonolite is a nearly black rock with fluidal texture. It contains large phenocrysts of orthoclase and rare ones of nepheline and acmite in a fine-grained to spherulitic groundmass of the same minerals. The bostonite is very fine grained, with trachytic texture. It consists of a microcrystalline aggregate of orthoclase and prisms of pyroxene that are partly altered to magnetite. Treatment with hydrochloric acid produces the gelatinization characteristic of nepheline.

There is confusion in some bibliographies between this Pão de Açúcar and a mountain of the same name in Departamento de Maldonado of southeastern Uruguay; the latter is remarkably similar in composition to the Brazilian Pão de Açúcar on the banks of the Río Paraguay (Willmann, 1915).

CENTRAL AREA

Milch (1895) describes limburgite from Cerro Tacumbú; an abstract of his description with analysis (Milch 1905) is given in the section of this report on the Serra Geral lavas (p. 33) but the rock may possibly belong with the alkalic rocks.

NEPHELINE BASALT AT YBYTYMÍ

According to Hibsch (1891), the top of Cerro Ybytymí, south of the town of that name, is made up of nepheline basalt. The exact location of this hill is not known, but the rock is doubtless a part of, or closely related to, the elongate body of alkalic volcanic rocks shown on plate 1 as Cerro Apitaguá. The mapping of this relatively large body, incidentally, is based on interpretation of aerial photographs and on the two descriptions by Hibsch and Milch. The igneous rocks may cover less of the area than shown on the map, but the entire area appears to be nearly homogeneous on the photographs. The rock described by Hibsch is dark gray to black, with brown weathered surfaces; it is porphyritic, with phenocrysts of augite and cavities filled with zeolites with radial structure. Microscopically, it is seen to be made up of phenocrysts of augite and olivine in a groundmass that contains grains of magnetite, small crystals of augite and magnesian mica, nepheline, and sanidine.

PHONOLITE FROM SAPUCAI

A sample of phonolite described by Milch (1895) came from a railroad cut through a ridge at or near the town of Sapucaí. The size or character of the rock body from which it came is not known, but it is almost certainly related to the large body of alkalic rocks that make up Cerro Apitaguá and vicinity. Milch describes the rock as yellow brown, compact, and marked by phenocrysts of a dark mineral in thick prisms. Biotite, hornblende, and aegirine-augite all occur as phenocrysts, but they are much less abundant than sanidine, a member of the hauyne-nosean family, and nepheline. All the phenocrysts are obscured by alteration—weathering, resorption, and zeolitization. The groundmass consists of aegirine-augite, with some aegirine, small prisms of feldspar, small grains of ore; and an aggregate of decomposition products that include zeolites, carbonate, and iron ore. The alkali feldspar sanidine is the chief constituent of the groundmass. It appears as long prisms which ramify as trichites. This structure, together with the almost complete zeolitization of the nepheline, gives a trachytoid appearance to the rock.

In 1905 Milch published an analysis of this rock, (see p. 47, table 5, D). Washington (1917, p. 905) lists the rock as altered by weathering, a reasonable inference from the nearly 4 percent H_2O, and 1½ percent CO_2. Milch likewise mentions the weathering of this rock. Nevertheless, a norm has been computed, which (I·6·2·4) places the rock with other nepheline syenites and phonolites in Washington's tables.

MICA PORPHYRY FROM EAST OF VILLARRICA

The mica porphyry (specimen P-50) occurs as a dike, 4 meters thick, trending N. 25° E. in sandstone near the base of the Independencia series; locally it spreads out as a thin sill along a bedding plane in the sandstone. It does not resemble any of the other specimens from Paraguay, but because of the highly alkalic composition of the rock it is grouped with the alkalic rocks. Superficially it resembles the "weathered peridotites" that are known from Ithaca and Syracuse, N. Y., Pennsylvania, Kentucky, Illinois, and elsewhere, but microscopically it is seen to contain no mafic mineral other than biotite.

This specimen is a dull-reddish-gray rock, with abundant large conspicuous plates of golden-yellow mica. The plates have almost a metallic lustre, and are as much as a centimeter across, with hexagonal outline. The matrix is fine grained, and has an earthy aspect.

Despite the seemingly advanced decomposition of the rock, a thin section shows a fairly recognizable mineralogy. The alteration observed seems more of a hydrothermal nature than simple weathering. However, mechanical effects—crumpling of biotite plates—are evident too. The rock consists essentially of potassic feldspar (sanidine?), some of it radially crystallized, with what appears to be nepheline (very low birefringence, negative uniaxial), brown biotite in both large ragged grains and fresh-looking sharply euhedral small plates (some showing zoning) and black ore grains. No chloritization of the biotite is seen.

The photomicrograph (fig. 28) shows an area of sanidinic(?) feldspar with nepheline(?) in the right center of the field. Upper center is a large biotite grain, peripherally replaced by a black oxide aggregate. The dark gray is largely altered mica; the black represents ore particles.

BASALT, RHYOLITE, AND SCORIA OF ACAHAY CALDERA

The Acahay volcanic cone or caldera, 7 kilometers northwest of the town of Acahay (pl. 1), is a prominent feature of the landscape in southern Paraguay. It is rudely oval in plan, with a maximum diameter of 5 to 6 kilometers. Its base is about 200 meters above sea level and the highest point on its southwest rim is 500 meters in elevation. A sketch, (pl. 2) drawn from photographs, shows the shape of the body. This body was not visited by Eckel, but it was observed from the air, and the rocks are doubtless related to, if not identical with, the flow rocks seen on the road between Carapeguá and Acahay, and also those between Paraguarí and Carapeguá.

The mass has the typical form of a volcanic caldera, with a large central crater, steep sides, an irregular rim, and several flows and dikes that radiate from the vol-

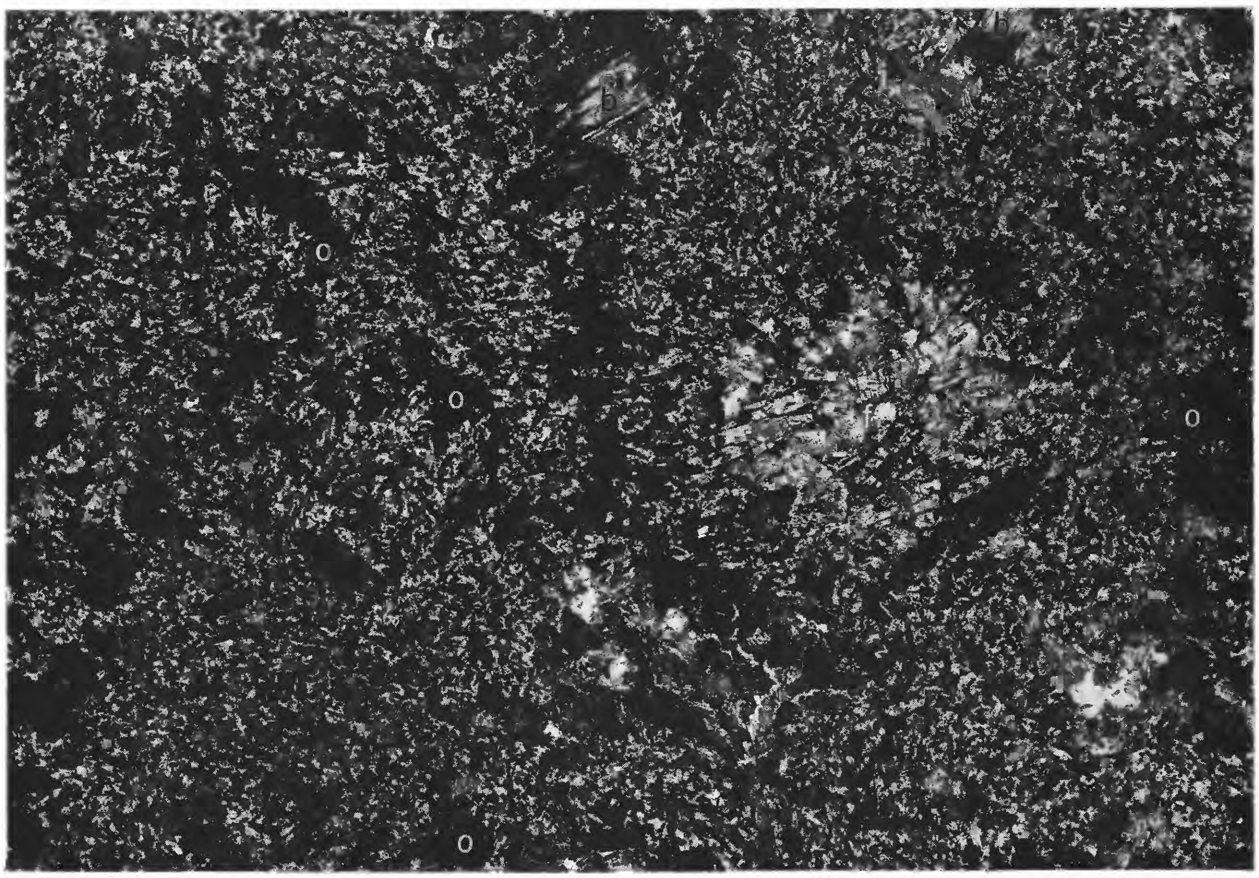

FIGURE 28.—"Mica porphyry" (specimen P-50) found 16 kilometers east of Villarrica. Photograph shows rather obscurely crystallized aggregate of alkalic feldspar, *f*, and biotite, *b*, with abundant opaque grains of iron oxide, *o*. × 20.

canic pile itself. The shape may be due to erosion of a single volcanic cone, but it seems more likely to have been formed as a series of more or less coalesced cones, since dimly seen flow structures along the rim appear to be related to individual cones. No ash or cinders were seen, but in at least two places along the Acahay road there are exposures of red to black scoria.

The plains east and northeast of the volcano are dotted with smaller cones and a number of dikes can be seen on aerial photographs.

The age of the Acahay volcanism is not known, but it must be relatively young. The Acahay volcanic pile itself, as well as the smaller nearby cones, are so typical in shape that they could not have been greatly eroded. Moreover, except for a little soil that supports small farms in the crater of the volcano and along its outer slopes, all the volcanic rocks seen in this area are very fresh, even at the surface.

Another bit of evidence that strongly indicates the youthfulness of the volcanism is that the flows and cones are related to the present topography—in valleys or on broad plains—that could hardly have survived since Triassic time.

Harrington (1950, p. 43) refers briefly to this occurrence in his description of the "necks and small plutons in the Carapeguá-Ybycuí-Quiindy district," and notes the presence of "granular phanerocrystalline facies—gabbros, syenites, or basic diorites" besides the dominant dark olivine basalt.

Three specimens collected from the outer fringes of the volcanic cone, along the road between Carapeguá and Acahay, represent three different rock types. All, however, are such as have been observed in many places in connection with basaltic eruptions: basaltic rock proper (P–58a), rhyolitic agglomerate (P–58b) and scoriaceous material. The first two may be flows, the third ejected material.

The basalt is illustrated in figure 29. It is a fine-grained brown rock, with few if any phenocrysts. Microscopically, it is an even textured aggregate of minute pale-green pyroxene and opaque iron oxide in a groundmass of sodic plagioclase, with a few porphyritic iddingsitized brown olivine crystals. Some of the groundmass may be glass. It resembles the Serra Geral basalt from the Foz de Iguaçú, Brazil, referred to Triassic or Jurassic age.

A rhyolitic agglomerate (specimen P–58b) that occurs in the vicinity of the Acahay caldera, along the road

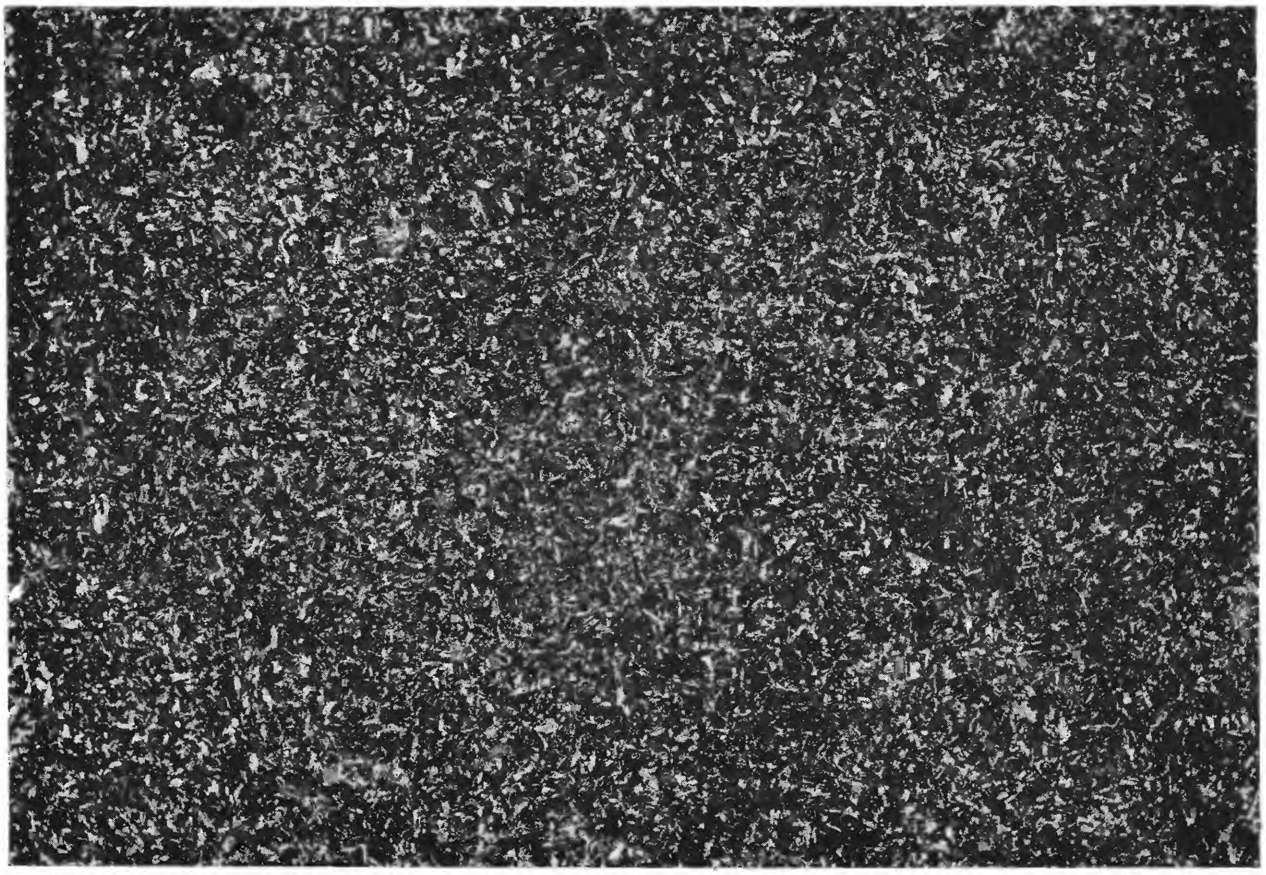

FIGURE 29.—Basalt (specimen P–58) from flow just east of the Acahay caldera. Photomicrograph shows uniform fine-grained texture, with sparse altered olivine (?) in upper left corner. × 20.

north of Acahay, is a fine-grained dark-gray rock, with minute quartz veinlets, reddish spots and a little pyrite visible with a hand lens. The weathered surface is bleached white to a depth of 1 centimeter. Close to the north edge of the town there are exposures of red basaltic scoria also.

Microscopically, the agglomerate is seen to be a siliceous rhyolite agglomerate. Anhedral quartz and sodic plagioclase phenocrysts are enclosed in a microcrystalline felsic aggregate (fig. 30).

The chemical analysis of this rock, specimen P–58b, table 1, resembles those of the Precambrian granite, porphyry, and aplite. The question naturally arises as to whether this is another instance of the commonly observed association of basalt and rhyolite or merely a spatial association of two unrelated rocks. If the former is true, then the rhyolite would be contemporary, broadly speaking, with the Acahay basalt, and therefore far younger than the Precambrian age attributed to the other granitic and rhyolitic rocks of Paraguay discussed in this report. Field studies should decide this.

PORPHYRY AND AGGLOMERATE FROM THE YPACARAÍ HIGHWAY QUARRY

The quarry that yielded most of the rock for the paved highway between Asunción and Eusebio Ayala is just east of the railroad and about midway between Ypacaraí and Pirayú. Though mapped as a single body of igneous rock on plate 1, there are actually five small rounded knolls, each appearing to be geologically complex. The knolls are rudely circular in plan and range from 200 to 1,000 meters in diameter. They rise only 10 to 50 meters above the swampy plain of the Ypacaraí depression.

Only the easternmost knoll of the cluster (the one on which the quarry was opened), was examined by Eckel, but, from nearby ground and aerial observation the other four appear to be similar in shape and geologic makeup.

The quarry, part of which is shown in figure 31, is nearly circular, with an irregular floor. It is about 100 meters in diameter and 10 meters deep along its western, or highest, edge.

The dome-shaped hill consists of black to brown shale, siltstone, and sandstone—all intruded and brec-

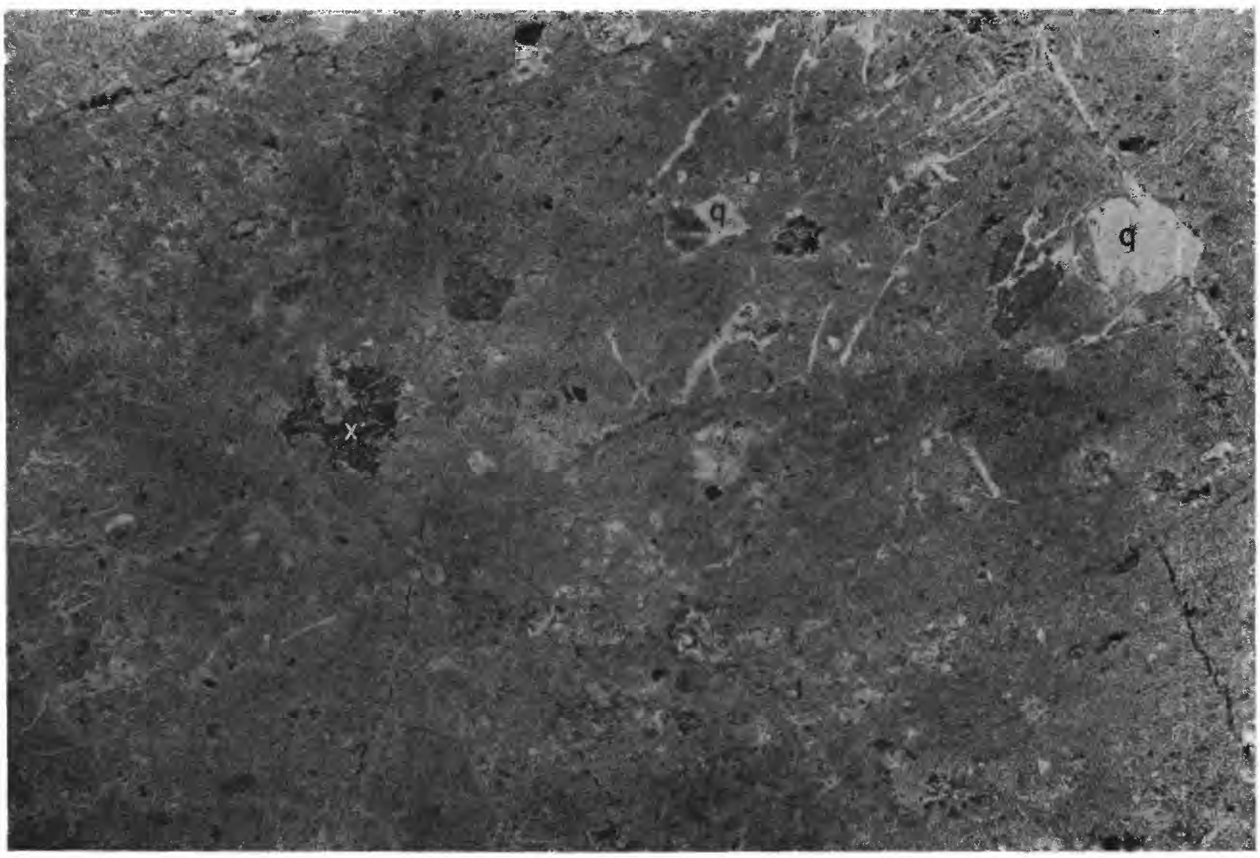

FIGURE 30.—Rhyolite agglomerate (specimen P–58b) from the Acahay caldera has a microprotoclastic texture with quartz, *q*, filling microscopic fractures. The dark patch, *x*, to the left is a xenolith. × 20.

FIGURE 31.—Panorama of highway quarry at Ypacaraí. The rocks are largely rhyolite agglomerate, with intrusive breccia made up of altered sedimentary rocks in igneous matrix.

ciated by two kinds of porphyry. One kind, which appears to be the older, is brown and contains much glass, scattered small phenocrysts of pink feldspar, and many small phenocrysts of dark-gray smoky quartz. The other porphyry is gray to black, with white feldspars in a nearly black groundmass and with only a few phenocrysts of quartz. In thin section, however (figs. 33 and 34) the igneous rock (apart from xenolithic inclusions) appears to be essentially the same in both the brown and the gray varieties.

The sedimentary rocks are all very metamorphosed and very hard; even those that retain evidence of original bedding contain veinlets and scattered crystals of feldspar. All the rocks, both igneous and sedimentary, are dense, tough and hard, and break with hackly jagged fractures. Both kinds of porphyry contain angular inclusions of metamorphosed sediments. These inclusions range in quantity from one to each cubic meter of rock to intrusive breccia with only a little igneous matrix cementing the fragments.

These hills appear to represent the top of a small complex stock, or possibly a group of small laccoliths, that broke through older sedimentary rocks, crushed some of them, and converted others to igneous rock by partial replacement. The age of the igneous activity is unknown; the body is shown on plate 2 as belonging to the alkalic rocks of Triassic(?) to Tertiary(?) age. This age assignment is based in part on certain similarities of these rocks with the agglomerate near the Acahay caldera (specimen P–58b) but in greater part on the fact that so far as can be determined now the host rocks must belong to the Tubarão series—hence the intrusive rocks must be at least post-Permian in age.

The single sample of the Ypacaraí igneous rocks that has been analysed (specimen P–34, table 1) is much closer in chemical composition to the younger Precambrian granitic rocks than it is to any of the much younger alkalic rocks (see table 5). That the Ypacaraí rocks may themselves be of Precambrian age seems unlikely, however, because although the intruded sediments show evidence of baking and other contact metamorphic effects, there is no evidence whatever that this contact metamorphism has been superimposed on regional metamorphism such as would be expected if the sediments were of Precambrian age. The Ypacaraí

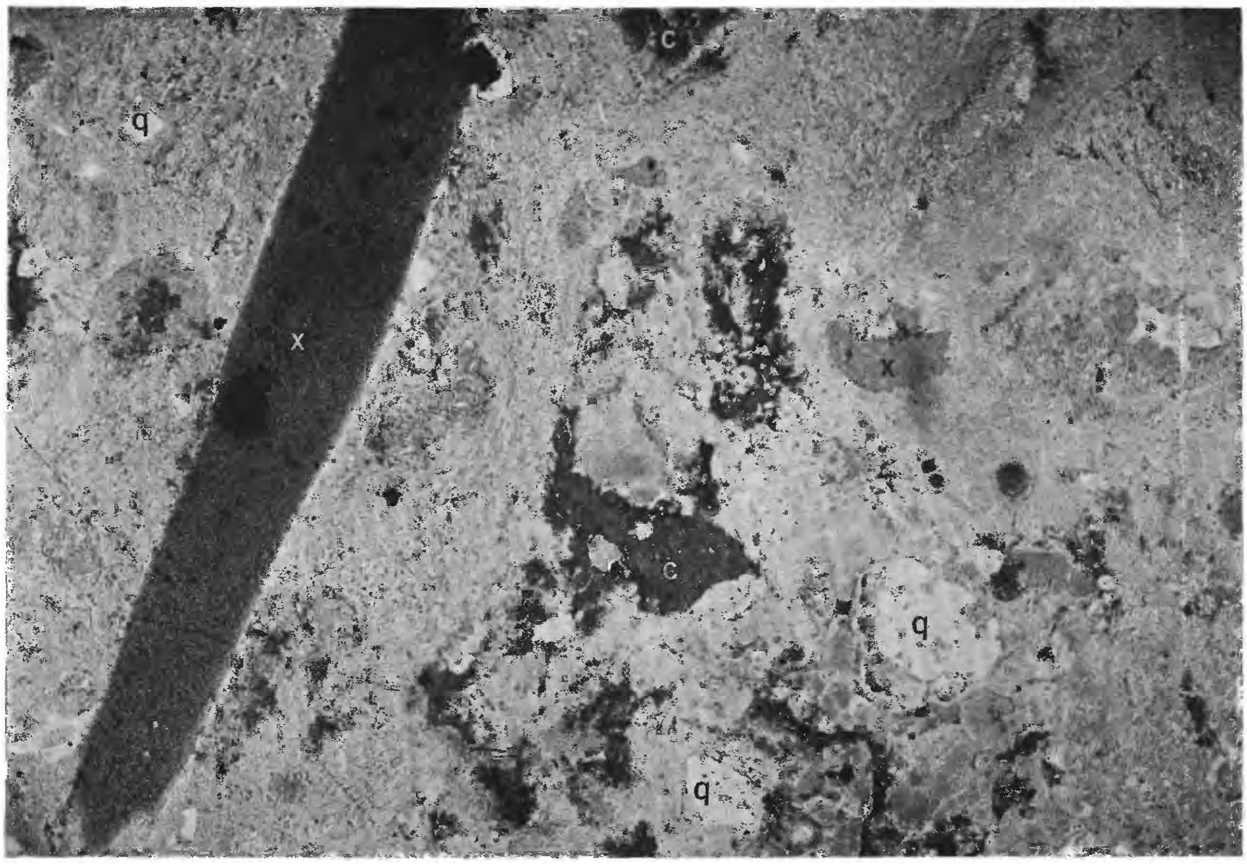

FIGURE 32.—Rhyolitic-breccia tuff (specimen P–35) from the highway quarry at Ypacaraí contains a conspicuous elongated cognate xenolith, *x*, and many less conspicuous xenoliths; irregular chloritized hornblende areas, *c*, and partly resorbed quartz crystals, *q*. Flow structures in the rock are apparent. × 15.

agglomerate contains inclusions of sedimentary rocks and shows considerable evidence of replacement of sediments by igneous material; one would therefore expect great variability in chemical composition from one sample to another.

The brown phase of the porphyry (specimen P–35) is a dark-brown dense rock, with red (not whitish-gray) feldspathic and glassy quartz areas. It is fragmental, as seen microscopically, though this is not obvious in hand specimens. The photomicrograph (fig. 32) shows an elongated fragment of very fine-grained rock. The irregular dark areas are chloritized hornblende. Several embayed quartz phenocrysts may be seen, as well as flow structure in the rhyolite. Near the center are several strongly sericitized plagioclase phenocrysts (gray).

The brown, relatively fine grained rock, such as shown in figure 32, grades into much coarser volcanic breccia, with strongly contrasting fragments of fine-grained, light- to dark-gray sandstone or siltstone, cemented by quartz rhyolite porphyry (specimen P–36, fig. 33).

The dark phase (specimen P–34) of the porphyry is fine grained dark gray with whitish-gray feldspar and glassy quartz. Microscopically, it is seen to consist of andesine and quartz, with some chloritized biotite in a felsic groundmass. The feldspars are only slightly sericitized. The analysis of this rock is given in table 1. It is illustrated in figure 34.

BASALT FLOW BETWEEN PARAGUARÍ AND CARAPEGUÁ

The broad grassy flat plains drained by Arroyo Caañabé, which heads not far from Ybytymí and flows westward to the swampy land north of Lago Ypoã, is shown on figure 2 as underlain by basaltic flow rocks. This designation is based on observation of only one exposure, supported to some extent by an interpretation of physiographic forms as seen in the field and in aerial photographs.

Near a bridge on the main road between Paraguarí and Carapeguá, and about 4 kilometers northeast of the latter town, there is an extensive shallow quarry in basalt. In that vicinity the loamy cover of the plain is underlain at depths of 60 to 130 centimeters by a layer of basalt that is at least 5 meters thick. Locally the top of this flow rock is dull red and scoriaceous, but most of the rock is dense, dark gray to black, and cryptocrystalline.

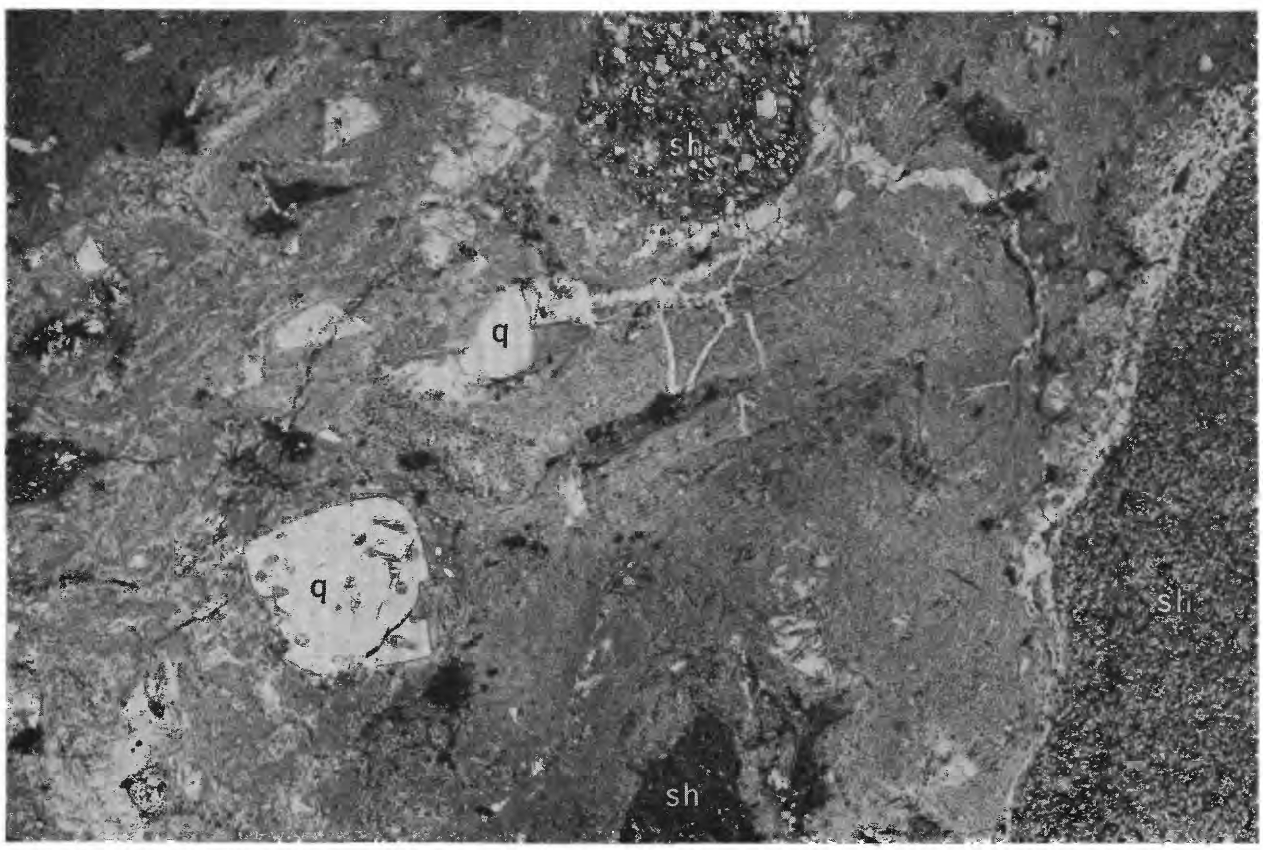

FIGURE 33.—Porphyry (specimen P-36) from highway quarry at Ypacaraí. Photomicrograph shows rounded resorbed shale fragments, *sh*, and quartz, *q*, in rhyolite porphyry. × 20.

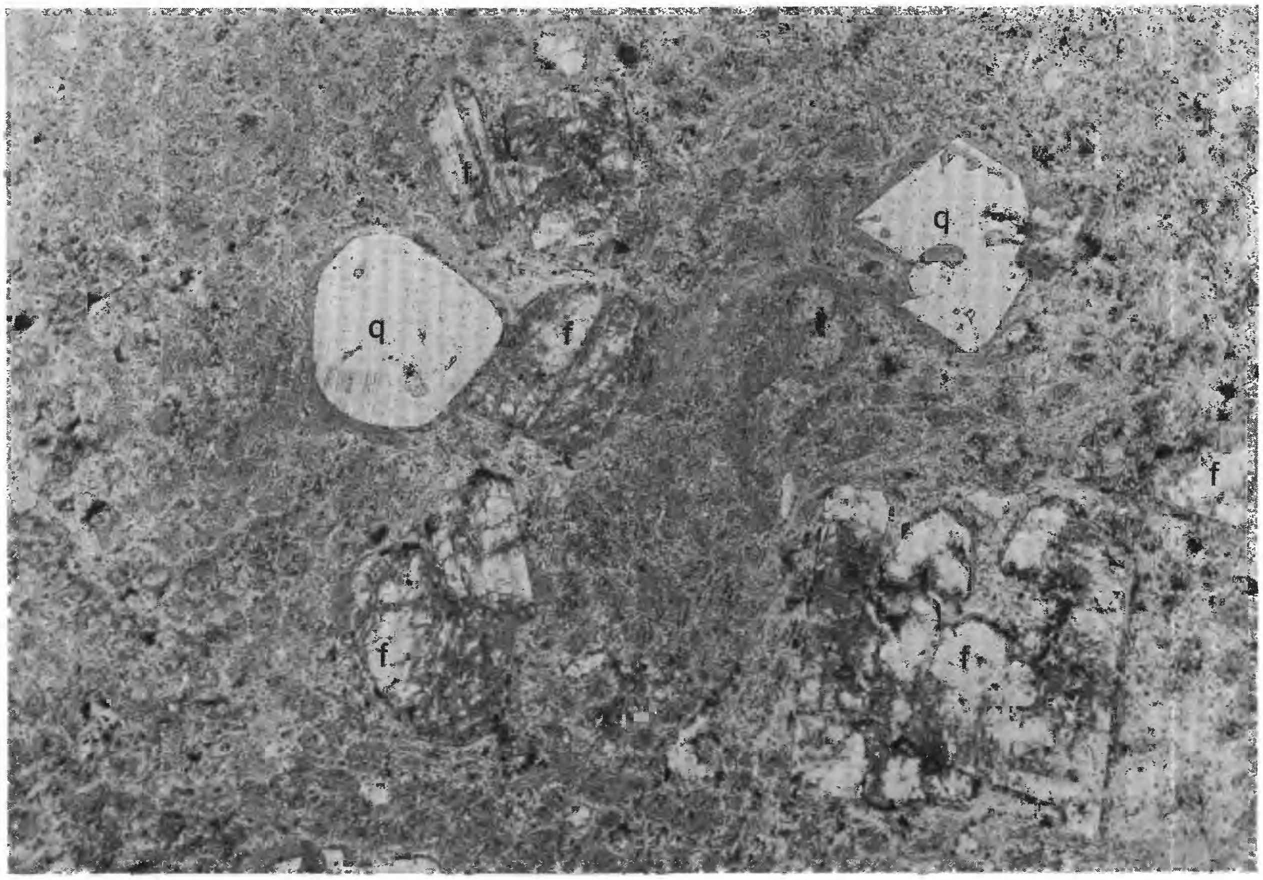

FIGURE 34.—Porphyry (specimen P-34), dark phase, from the highway quarry at Ypacaraí. Photomicrograph shows partly resorbed quartz crystals, *q*, and slightly sericitized andesinic plagioclase, *f*, in rhyolitic groundmass. × 25.

No other exposures of this rock are known in the extensive plain along the Arroyo Caañabé, but the uniformity of its virtually flat surface and of the vegetation growing on the plain suggests that the entire area is, as mapped, underlain by basalt that is covered by a thin mask of silty loam. This conclusion is strengthened by the fact that several volcanic cones rise from the plain not far east of the Paraguarí-Carapeguã road; these and the nearby volcanic piles of Acahay and Cerro Apitaguã would seem to be likely sources for lava flows that moved westward down the broad valley of Arroyo Caañabé to or beyond the longitude of Yaguarón. No specimens were collected so that it is impossible to state whether this basalt is similar to the alkalic basalt (specimen P–58b) (p. 39), that came from closer to the Acahay caldera.

NEPHELINE SYENITE AND SHONKINITE AT MBOCAYATY

An interesting assemblage of alkalic shonkinites, very similar to those in the Highwood Mountains of Montana, are exposed in a quarry at the northwest edge of Mbocayaty. The quarry is on a small rounded hill, about 25 meters high and 75 meters in diameter, that stands above the nearly level plain cut on tillites and other sediments of the Tubarão series of Pennsylvanian age. A fairly large quantity of rock has been quarried for road surfacing and rough building stone; most of the quarried rock apparently consisted of loose blocks that had been separated from the main mass by weathering, but some shallow drilling and blasting was also done. Figure 35 shows one of the larger quarry openings.

The hill is made up of rocks that differ widely in texture, though all of them are shown by microscopic examination to be alkalic rocks, such as nepheline syenite, shonkinite, and closely related types. The most abundant type is a dark-gray coarse-grained rock, containing clear green crystals of olivine that resembles gabbro in the hand specimen. There is also much material that appears to be an intrusive breccia and contains angular fragments of most of the textural types found on the hill. Smaller quantities of a spherulitic phase, and of an exceedingly tough rock made up of coarse interlocking crystals of sanidine in a dense black groundmass, are also to be seen. The relations of the

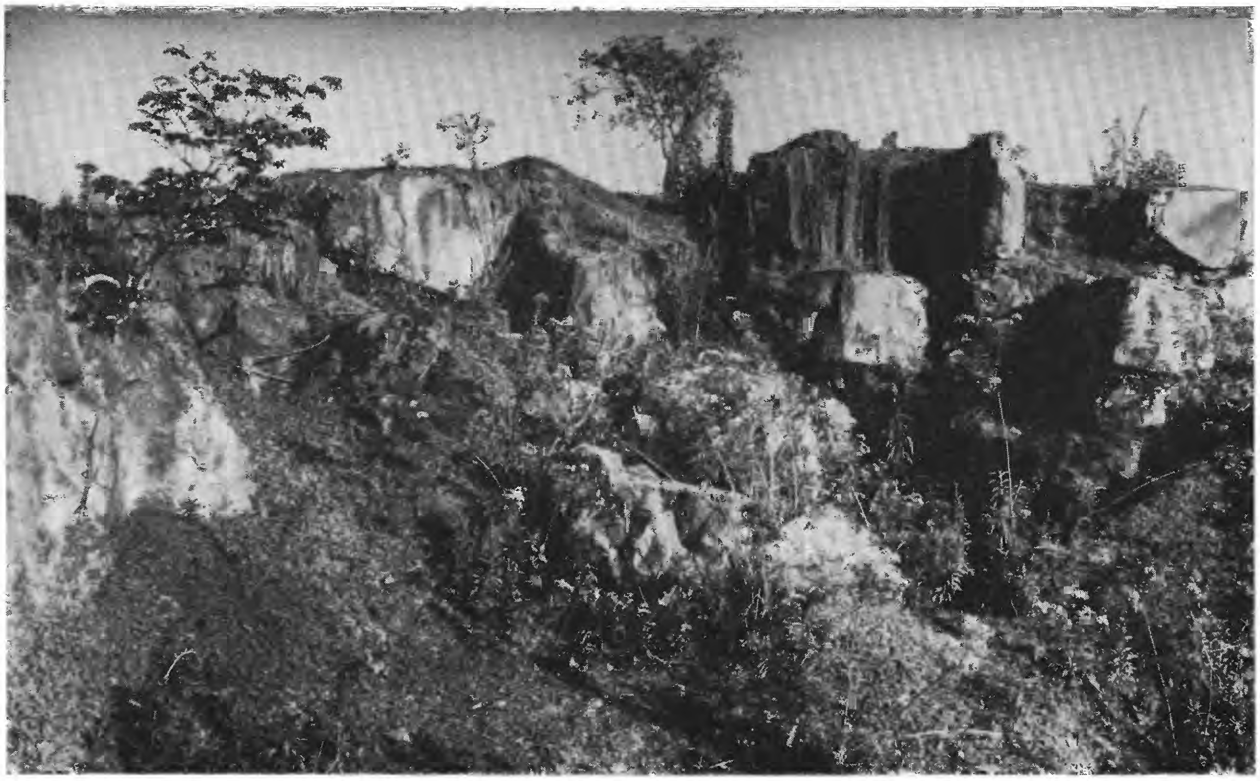

FIGURE 35.—Quarry in alkaline rocks (mostly shonkinite) on the outskirts of Mbocayaty.

different textures could not be deciphered on hasty examination.

Different parts of the rock body differ widely in their degree of weathering, but there is no apparent relationship between weathering and the different textural types. Some parts are almost completely disintegrated whereas other parts are extremely fresh. Weathering tends to proceed along the strong vertical and nearly horizontal joints that characterize the body; there is some tendency toward spheroidal weathering in places.

There are no indications of the shape of the Mbocayaty body, but it appears most likely to be a plug or small stock, intruded into the surrounding beds of the Tubarão series, that has suffered multiple injections of alkalic magma. No similar rocks were found elsewhere by Eckel, but several of the other small masses of igneous rock shown on plate 1 in the general vicinity of Mbocayaty are reported by highway engineers and others to be similar in appearance to this material.

Seven specimens, respectively P–54, a–g, were studied and are described in order below. All except specimen P–54b are dark rocks; this one is light colored and resembles a coarse porphyritic syenite. The others have a gabbroic aspect.

P–54a, shonkinite.—Specimen P–54a (fig. 36) is a coarsely crystallized gabbroic-textured rock, with dark mafic patches strewn in feldspathic groundmass. The abundant mafic minerals, more or less subhedral, are strewn in a groundmass consisting largely of sanidinic orthoclase. It has replaced nepheline, which is converted to the hydronephelite aggregates shown in figures 36 to 42, inclusive. The replacement appears to be progressive, the final stage being the graphic structures shown in figures 36 and 38. Apatite and ore grains are in the feldspar. The mafic minerals include colorless (in section) olivine, brown biotite, pale-green titanaugite, and titaniferous amphibole related to kataforite. The latter is described in detail (p. 46), in connection with specimen P–54g, where it also was noted.

"Hydronephelite" is a rather ill-defined replacement of nepheline. It is listed as a species by Dana (6th edition p. 609) and more recently by Tröger (1952). Dana lists it with ranite and spreustein. In Maine it replaces sodalite, in Norway, nepheline (Dana). Apparently it consists of natrolite, epinatrolite, hydrargillite, and diaspore (Thugutt, 1932).

P–54b, nepheline syenite.—Specimen P–54b (fig. 37) is a rather coarsely crystallized feldspathic rock, with dark sodic(?) augite as the chief visible mafic. The feldspar laths are several millimeters long, well shown on the weathered surface of the rock. The dark constituents are interstitial to the feldspar.

Microscopically the rock has the features shown in figure 37 as follows: coarsely crystallized orthoclase (sanidine?) comprises the bulk of the rock. Near the lower right corner a large black grain of iron oxide has hydronephelite (on the left of it) with rectangular outlines; it is uniaxial positive, with indices lower than feldspar and birefringence slightly higher; hexagonal cross sections show irregular triangular fields under crossed nicols. With it is green aegirine(?) augite (the smaller dark grains). Another large augite is seen at the middle right edge. Small

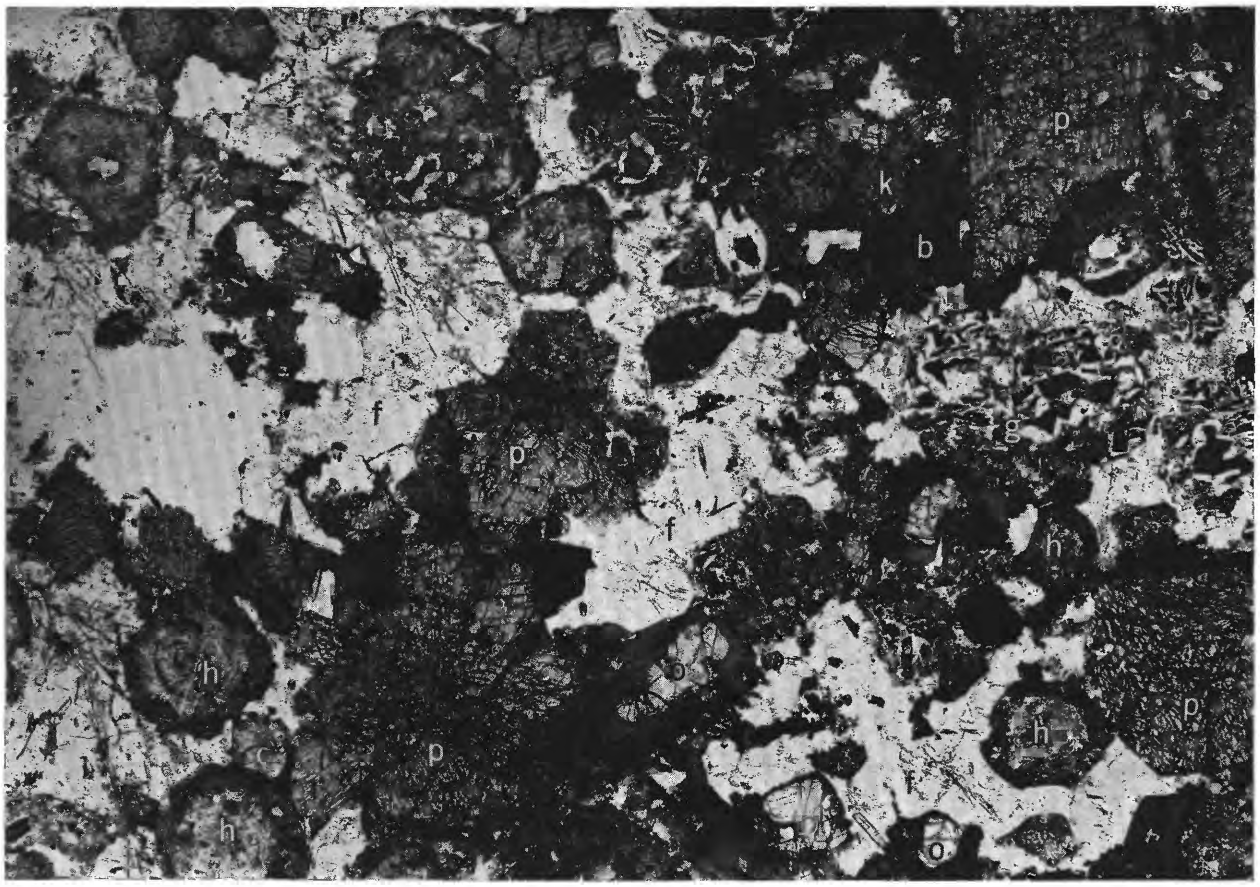

FIGURE 36.—Shonkinite (specimen P–54a) from Mbocayaty. Note the large rounded hydronephelite, *h*, crystals at left. At the center right are "graphic" remnants of nepheline or hydronepheline, *g*, that have been partly replaced by sanidine. Light-green monoclinic pyroxene, *p*, showing good cleavage, and dark-brown biotite, *b*, are abundant; olivine, *o*, in the lower right edge, is enclosed in biotite. Pale-bluish apatite and black iron oxide are accessory minerals. × 15.

strongly pleochroic brown biotite grains, sphene, and apatite are also present.

P–54c, shonkinite.—Specimen P–54c is similar to specimen P–54a, described above. Numerous olivine crystals are seen in figure 38 (just upper left of center, just left of middle lower edge, and elsewhere). Large pyroxene crystals, showing good cleavage, are also abundant. In the middle of the left half of the field is a large crystal of hydronephelite. The white areas are sanidinic feldspar.

P–54d and P–54e, shonkinite.—Specimens P–54d and P–54e are similar. Both are rather coarse-grained medium-dark rocks with prominent tabular feldspars. They are variants of specimens P–54a and P–54c and differ essentially in having no olivine, and very little titaniferous amphibole. Titaniferous amphibole shows normal absorption in deep brown parallel to c, unlike the kataphorite amphibole found in the other rocks from this locality. Specimen P–54d has been analyzed (table 5).

Figure 39 (specimen P–54d) shows the abundant tabular (laths in cross section) feldspar, and titaniferous augite. Under crossed nicols, many of the clear feldspars show turbid cores, indicating perhaps replacement of an earlier generation of feldspar.

Specimen P–54e contains some analcite, with clear feldspar apparently replacing nepheline. Many of the feldspar crystals have turbid inner zones.

P–54f and P–54g, shonkinite.—Specimens P–54f and P–54g are similar, and differ from the others somewhat. No definite lath-shaped feldspars are seen; instead there are abundant rounded whitish areas, as much as 0.5 centimeter across, which are replacements of nepheline. Figure 40 shows specimen P–54f, in which two such replacements (with more or less hexagonal outline) are seen in the upper half of the field. The smaller and clearer one is isotropic, and may be analcite; the other appears to be hydronephelite. In the center of the field, to the right of a large augite, is more of the hydronephelite aggregate enclosing clear feldspar. There is an abundance of mafic minerals, including olivine, in this rock. Hornblende, though, is absent.

Specimen P–54g, shown in figure 41, contains abundant well-formed crystals of colorless fresh olivine, augite—colorless inside but usually with a thick outer green zone (aegirine-augite)—fresh red-brown biotite, and some kataphorite amphibole. This mineral shows a strong and unusual pleochroism: X, pale yellow, Y, wine-red brown, Z, yellow; a small optic angle; strong dispersion, $v > p$; and the amphibole type of cleavage, against which an extinction of about 15° can be measured.

This amphibole resembles a kataphoritic amphibole named magnophorite by R. T. Prider (1939) from a leucite-bearing

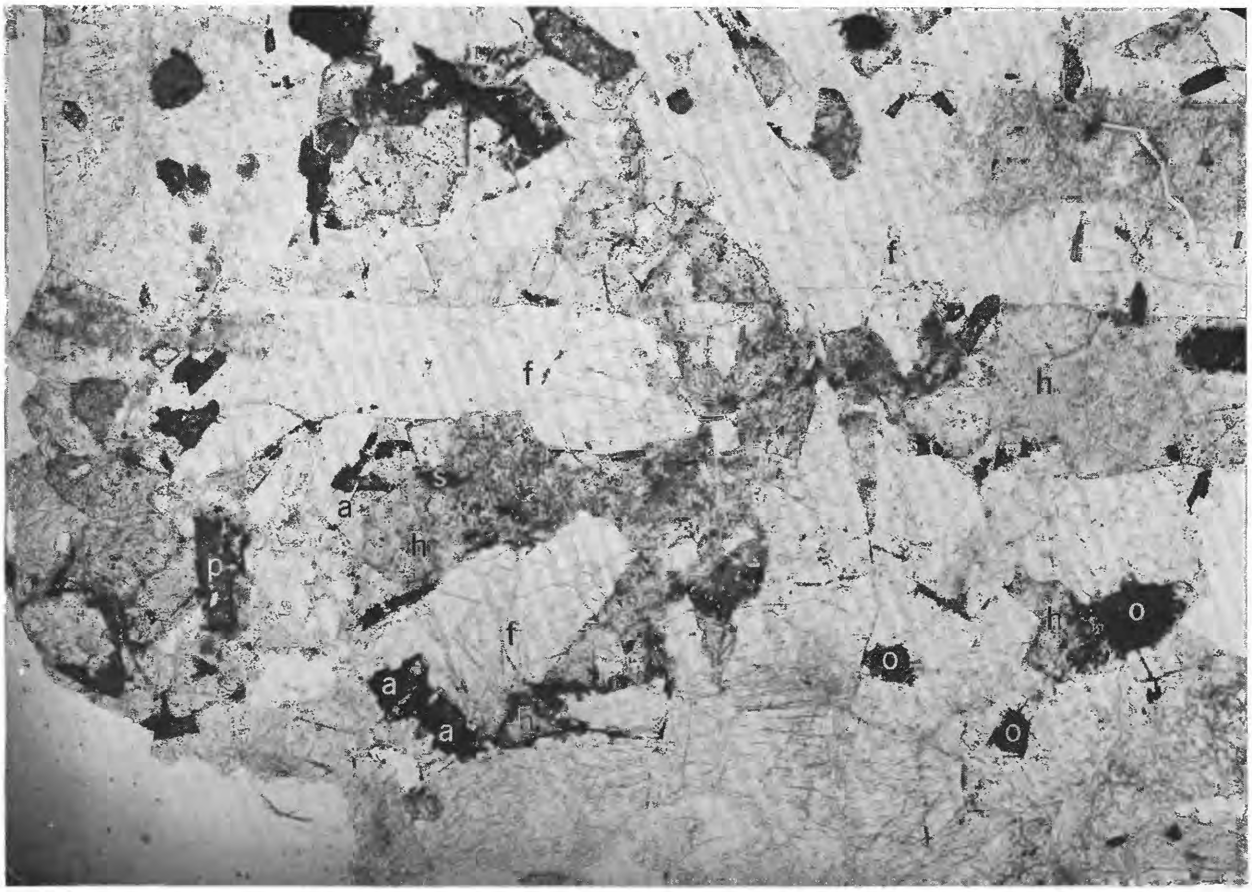

FIGURE 37.—Nepheline syenite (specimen P–54b) from Mbocayaty. Coarsely crystallized orthoclase, *f*, with hydronephelite, *h*, after nepheline, which is slightly darker, and sphene, *s*. The darker small areas are green pyroxene, *a*, and black ore grains, *o*, of magnetite-ilmenite. Much of the hydronephelite retains the characteristic stubby hexagonal prism shape of the original nepheline; however, it is uniaxial positive with appreciably higher birefringence than nepheline. × 15.

TABLE 5.—*Chemical analyses of alkalic rocks*

[Analyses of A, B, and E by Trumbull with densities by L. N. Tarrant; analysis of C, by Goldschlag; D, by Lindner]

	A P-54d	B P-54g	C	D	E P-58a
SiO_2	53.29	50.41	48.55	52.20	51.27
Al_2O_3	16.10	11.17	11.97	20.67	15.72
Fe_2O_3	4.50	3.50	5.73	3.26	8.61
FeO	2.98	5.05	4.41	1.38	1.53
MgO	2.32	9.23	4.77	.48	3.72
Cao	3.78	7.73	10.06	4.43	5.98
Na_2O	3.45	2.31	4.86	6.61	3.71
K_2O	9.42	7.10	4.30	4.90	4.15
H_2O-	.20	.12	} 2.62	{ .36	.87
H_2O+	1.23	.76		{ 3.56	1.82
TiO_2	1.11	1.61	3.04	.14	1.64
CO_2	.02	.00	------	1.54	.01
P_2O_5	.71	.41	Tr.	.12	.43
SO_3	.50	.12	------	.04	------
S	.03	.03	------	------	------
MnO	.13	.14	------	.09(Mn_2O_3)	.17
BaO	.19	.20	------	.09	.18
	99.96	99.89	100.31	99.87	99.81
Less O	.02	.02			
	99.94	99.87			
Density	2.68	2.87	------	2.463	2.73
Norm	II·5·1·2	III·6·1·2	III·6·1·3	I·6·2·3	II·5·2·3

NOTE.—See explanation of specimen designations below.

Specimen No.	Rock	Locality
A (P–54d)	Nepheline syenite	Quarry at Mbocayaty.
B (P–54g)	Shonkinite (analcite)	Do.
C	Phonolite	2.3 km west-southwest of Centurión.
D	do	Sapucaí, Ibytymí district.
E (P–58a)	Basalt	Acahay caldera.

rock from Western Australia. Prider gives an analysis. A second paper by Wade and Prider (1941) gives a further description, with illustration of a peculiar "herringbone" structure which is also present in the Mbocayaty mineral. Figure 42 shows this amphibole, with "herringbone" structure.

The amphibole also resembles an amphibole from Wyoming, described by Cross (1897), which Cross states is almost uniaxial, and with a color scheme X, a pale yellow, b, red similar to hypersthene, Z, a bright yellow.

ANALYSES OF ALKALIC ROCKS

Five chemical analyses of the alkalic rocks of Paraguay are available, three new ones (of nepheline syenite

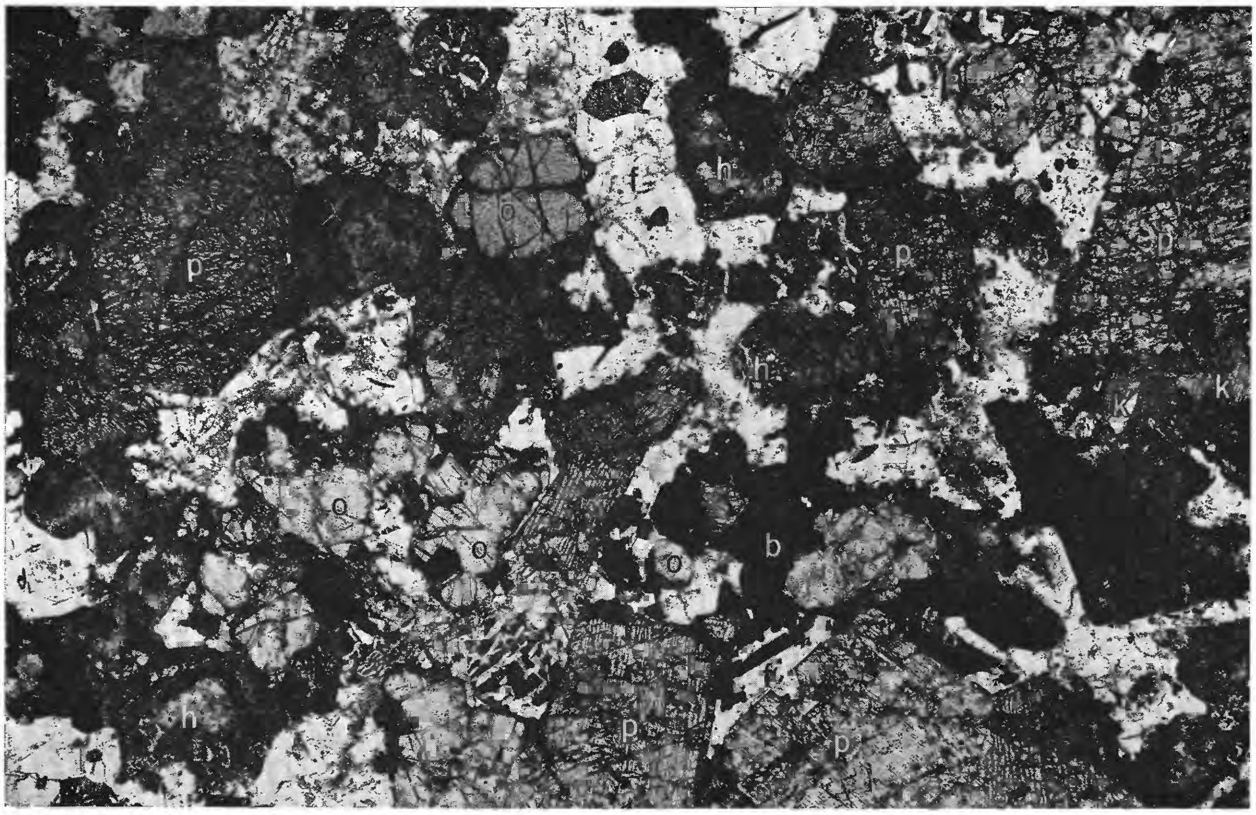

FIGURE 38.—Shonkinite (specimen P-54c) from Mbocayaty is similar to sample P-54a (fig. 36) but shows abundant hydronephelite, *h*. The large grains with good cleavage are pyroxene, *p*; another large grain, *o*, showing a few fractures but no cleavage is olivine; *k*, is kataforite amphibole; and orthoclase, *f*, is myrmekitic replacement of hydronephelite. The black areas are brown biotite, *b*, and opaque ore grains. × 15.

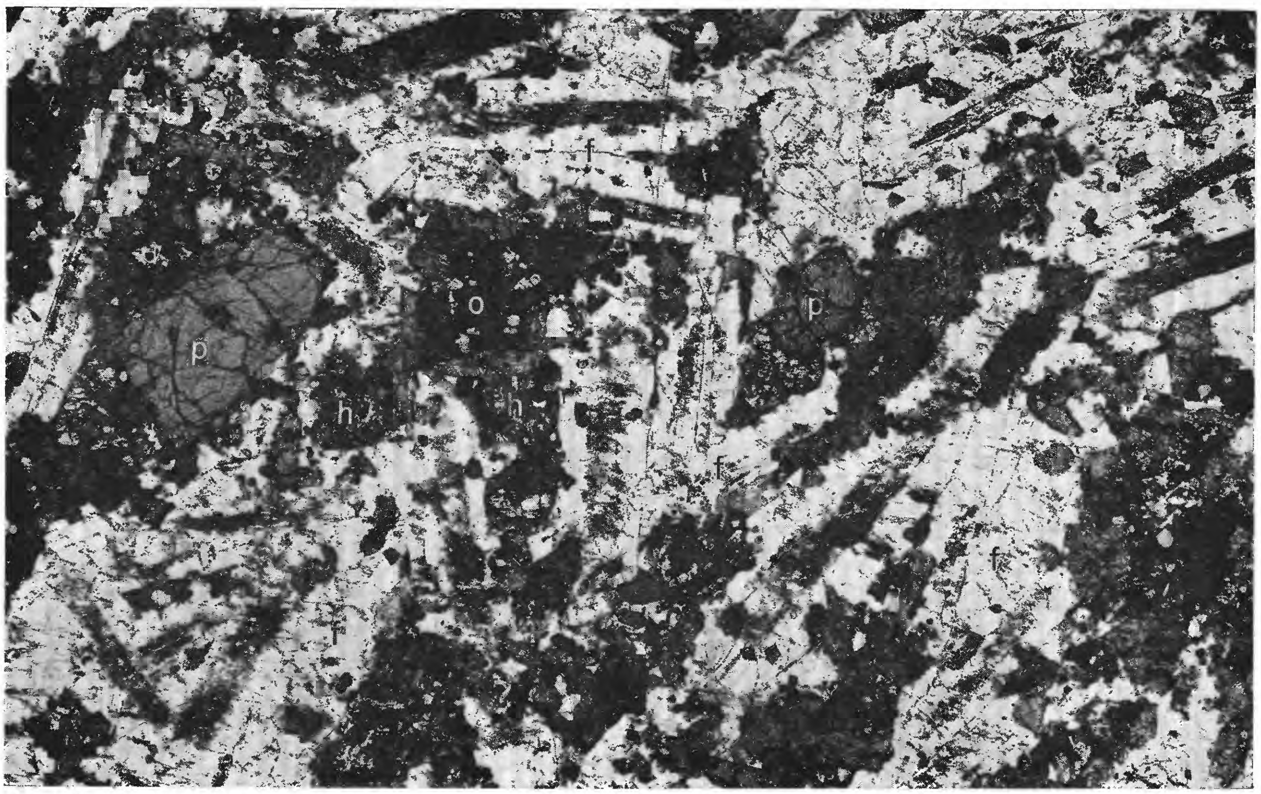

FIGURE 39.—Shonkinite (specimen P-54d) from Mbocayaty. Aggregate of orthoclase, *f*; pyroxene, *p*; hydronephelite, *h*; magnetite-ilmenite ore, *o*. Brown biotite and brown hornblende are sparse. × 15.

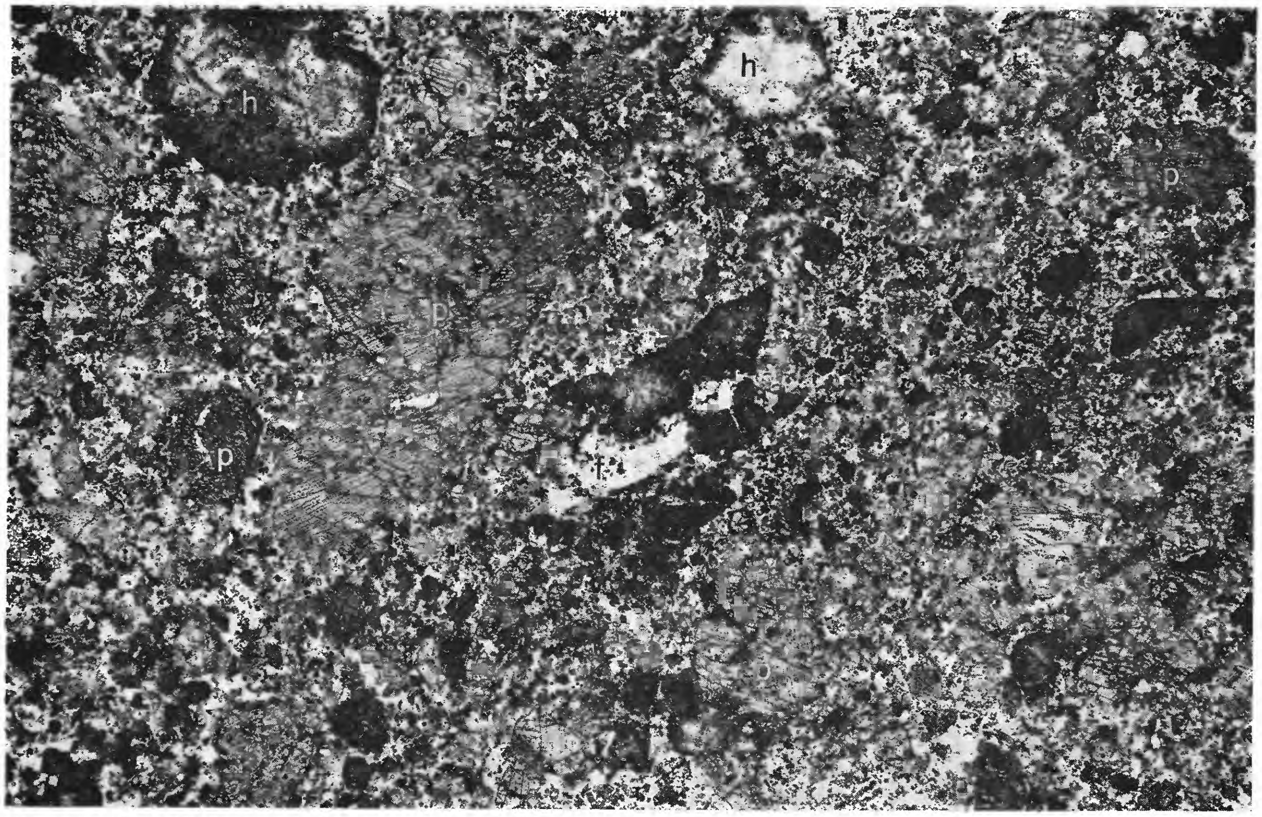

FIGURE 40.—Shonkinite (specimen P-54f) from Mbocayaty. Near the upper edge are two large hydronephelite replacements, *h*, of nepheline. The replacement near the middle appears to be isotropic analcite. Feldspar, *f*, is inconspicuous, forming the groundmass of the crowded pyroxene, *p*, olivine, *o*, biotite, and other crystals. × 15.

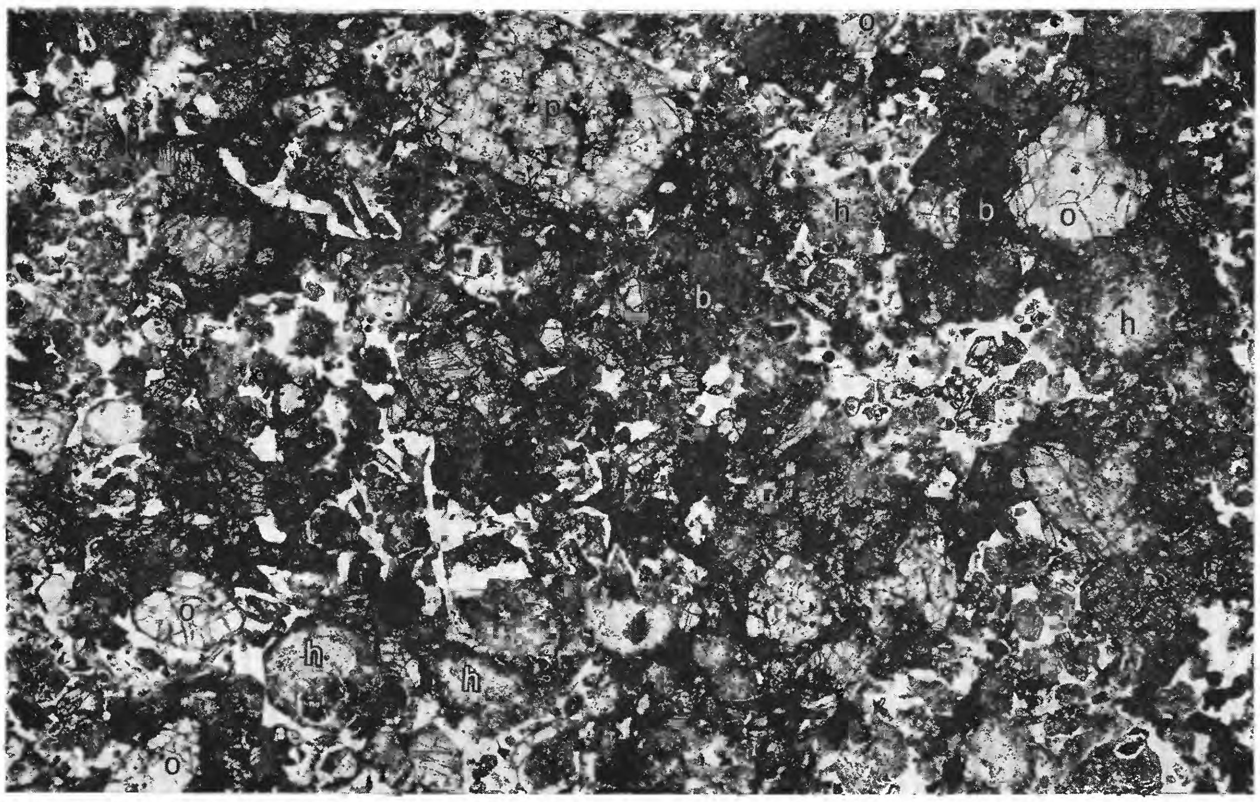

FIGURE 41.—Shonkinite (specimen P-54g) from Mbocayaty. Diopsidic pyroxene, *p*, augite; olivine, *o*; brown biotite, *b*; iron oxide; and euhedral hydronephelite, *h*—all in clear matrix of sanidine. × 15.

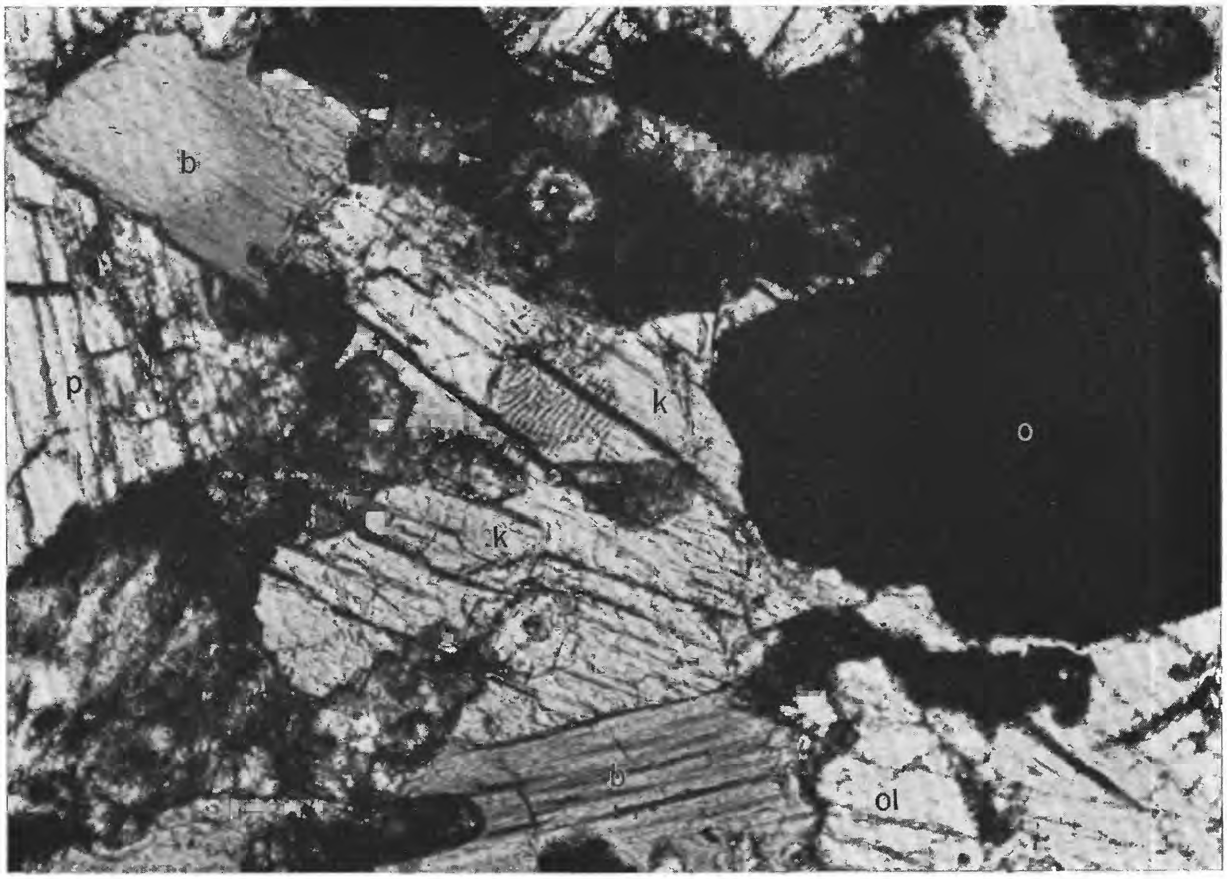

FIGURE 42.—Shonkinite (specimen P-54a) from Mbocayaty, showing katoforite amphibole, with "herringbone structure" *k*; biotite, *b*; magnetite-ilmenite ore, *o*; olivine, *ol*, and pyroxene, *p*, × 300.

TABLE 6.—*Spectrographic analyses of alkalic rocks*

[Analyst: Paul R. Barnett, U. S. Geological Survey. Looked for but not found: Ag, As, Au, B, Be, Bi, Cd, Ge, In, Pt, Sb, Sn, Ta, Th, Tl, V, W, Zn]

	Specimen No.		
	P-54d	P-54g	P-58a
Ba	0.2	0.2	0.2
Co	.002	.004	.004
Cr	.002	.04	.0005
Cu	.005	.005	.005
Ga	.002	.002	.002
La	.02	.01	.01
Mo	0	0	.0004
Nb	.008	.005	.004
Ni	.001	.03	.002
Pb	.003	.003	.002
Sc	.001	.002	.002
Sr	.3	.2	.2
V	.02	.03	.04
Y	.006	.005	.009
Yb	.0002	.0001	.0002
Zr	.07	.04	.03

NOTE.—See explanation of field numbers below.

Field No.	Rock	Locality
P-54d	Nepheline syenite	Mbocayaty.
P-54g	Shonkinite	Do.
P-58a	Basalt	Acahay volcanic cone.

and shonkinite from Mbocayaty and of basalt from Acahay), one of the Sapucaí phonolite by Lindner, and one made by Goldschlag of the phonolite from Centurión (table 5). The basalt from the Acahay volcanic cone is included here because of its similarity to that of the Mbocayaty nepheline syenite (specimen P-54d). The analyses are shown in tables 5 and 6.

Specimen P-92, "Triassic or Jurassic basalt" from Foz de Iguaçú (see tables 3, 4) resembles chemically both Mbocayaty analcite shonkinite and the Centurión phonolite (norms respectively III·4·3·4, III·5·1·2, III·6·1·3). Also there is a chemical resemblance between the nepheline syenite at Mbocayaty and the basalt of the Acahay volcanic cone (norms respectively II·5·1·2 and II·5·2·3).

SEDIMENTARY ROCKS

EASTERN PARAGUAY

CAMBRIAN AND ORDOVICIAN SYSTEMS(?)

ITAPUCUMÍ SERIES

A series of calcareous and dolomitic limestone deposits, which contain a few beds of shale or argillite, almost surround the body of Precambrian rocks south of the Río Apa and east of the Río Paraguay. It is named the Itapucumí series by Harrington (1950) for the good exposures at the village of Itapucumí and is thought to be the equivalent of the Corumbá series of Brazil. No fossils have yet been found in these rocks and, in view of differences and fairly frequent changes in the opinions of geologists as to the ages of these rocks and of their supposed equivalents in Brazil and Bolivia, no closer age assignment than that of Cambrian(?) and Ordovician(?) seems justified.

The distribution of the series and the attitude symbols, as shown on plate 1, are based on ground and air observations by the author along the Río Paraguay, particularly in the vicinity of the Vallemí cement plant, on his interpretations of aerial photographs, and on various published observations by Carnier (1911c), Kanter (1936), Boettner (1947) and Harrington (1950). Several relatively small outliers of the Itapucumí series rise from the alluvium along and near the Gran Chaco side of the Río Paraguay. Most of them form low rounded hills scarcely more than 5 to 10 meters high, but the largest one, Cerro Galbán, just southwest of Puerto Casado, rises 140 meters above the swampy plain and is about one kilometer long. It is sketched and described by Krieg (1931) as made up almost entirely of limestone, with a small hillock of red sandstone near its eastern end. The limestone from the main hill, which is quarried for various uses at Puerto Casado, is dark blue gray and crystalline.

The series is almost continuously exposed along the east bank of the Río Paraguay from near San Salvador to the mouth of the Río Apa (pl. 1). Over much of this distance there are conspicuous cliffs 15 to 20 meters high (figs. 21 and 23), backed by rounded and heavily forested hills that are 100 to 200 meters high. Eastward from the river the limestone is more or less continuously exposed as far as the Apa highland, in the vicinities of Cerro Paiba and Loma Pora. There they were seen by Carnier (1911c) to rest on or against older Precambrian rocks, unconformably in some places and in fault contact in others. The belt trends southward around the end of the Precambrian body but is apparently not well exposed there for it is not described by any investigators. It reappears along the east side of the Precambrian rocks, where it is described and sketched by Boettner (1947) between Arroyo Ytaguy and Arroyo Hermosa.

The Itapucumí series is thought by Harrington (1950) to be about 300 to 400 meters thick. This is only an approximation, however, since no detailed mapping has been done and the general pattern of folding, indicated on plate 1 by scattered observations of attitude, has yet to be worked out.

Figure 43 shows the character of the limestone and a description of the rocks exposed in the Vallemí quarry is given in the section on cement. In general, the series is made up of light- to dark-gray limestone in well-defined, relatively thin beds. Locally the beds are thick and massive, alternating with shaly limestone and marly shale. All the rocks are hard and dense and most of them are fine grained, but some are partly or entirely recrystallized and cut by veins of calcite or dolomite. Oolitic and lithographic limestone, as well as various kinds of green- and pink-toned marble have been reported from a number of places.

The rocks range from nearly pure limestone with 95 percent or more calcium carbonate to nearly pure dolomite. The analyses below are believed to be fairly representative. As noted on page 80, the purer limestone at Vallemí contains approximately 95 percent calcium carbonate, whereas the varieties that are streaked green by chloritic material contain 80 to 85 percent calcium carbonate.

Analyses of typical limestones of Itapucumí series

[M. Goldschlag (1913c), analyst]

	1	2	3	4
Insoluble	3.34	3.90	1.12	3.38
CaO	50.90	52.69	52.85	30.91
MgO	0.93	----	----	17.94
$(Fe, Al)_2O_3$	2.97	1.97	3.03	2.54
H_2O	1.75	----	0.36	1.85
CO_2	40.98	41.30	42.20	43.79
Organic	----	0.69	----	----
	100.95	100.55	99.66	100.41

NOTE.—Explanation of localities of samples:
1. Limestone, Cordillera de las Quince Puntas, 10 kilometers west-northwest of Centurión.
2. Oolitic limestone, 35 kilometers north-northwest of Puerto Max on Río Paraguay (near Puerto Fonciere).
3. Limestone, Cerro Paibá, 10 kilometers southwest of San Carlos.
4. Dolomitic limestone, left bank of Río La Paz, east of San Luis de la Sierra.

The limestone series rests uncomformably on the Precambrian basement rocks that make up the Potrero Saty. They are shown on plate 1 as everywhere overlain directly by the Tubarão series of Pennsylvanian or Permian age but only in the extreme northeastern part of their belt of outcrop, near Santa Luisa, is this contact actually known. Not far from the town of Santa Luisa, and along Arroyo Hermosa, Boettner (1947) found tillite of the Tubarão beds, with striated pebbles, resting on the Itapucumí limestone.

It appears certain that the Itapucumí beds do not extend far into southern Paraguay, because Silurian and younger beds rest directly on the Precambrian basement in many places farther south. According to available knowledge, none of the wells drilled by the Union Oil Company were deep enough to have reached these beds, so it is not known whether the Itapucumi rocks extend beneath the Gran Chaco. Quite possibly they do not, for no rocks of similar character seem to be known in the eastern Andes, where the deeper beds of the Gran Chaco basin reappear at the surface (Ahlfeld, 1946, geologic map).

Boettner (1947) notes that marble was once quarried at Puerto Max for ornamental stone and DuGraty

FIGURE 43.—Outcrops of limestone of Itapucumí series, Cambrian and Ordovician age, on the east bank of the Río Paraguay just south of Vallemí. Joints in the rock are characterisically enlarged close to river level; some evidence of horizontal niching by the river can also be seen. Patches on the distant water surface are floating islands (camalotes) of flowering water plants.

(1865) describes two dolomitic marbles from Itapuguazú. This locality is not shown on modern maps, but the name clearly refers to one of the more prominent cliffs along the east bank of the river. One marble described by DuGraty is rosy white and contains a little more than 93 percent calcium and magnesium carbonate; the other is nearly white but lightly veined with rose, and contains 99 percent combined carbonates. A report on "Concurrencia del Banco Agrícola del Paraguay" (Anon., 1911) reports that President Mariscal López (circa 1860) had a table made of all classes and colors of Paraguayan marble, and sent it to Napoleon III of France, who had it prominently displayed in the Tuilleries for a long time.

The rocks of the Itapucumí series appear to be unfossiliferous and their age is unknown. The series is thought by Almeida (1945) and Harrington (1950) to be probably equivalent to the Corumbá series of Mato Grosso, Brazil. Both authors trace the history of attempts to date this series and conclude that it, and hence the Itapucumí series is probably of Ordovician age.

The cliffs along the river are deeply notched at and near the present water level, but not above it. Moreover, joints in the limestone, though tight in the higher parts of the cliffs, are enlarged by solution to tent-shaped caves at river level. (See p. 78.)

Except along the cliffs just mentioned, the Itapucumí limestone beds are weathered to a dark-gray to black clayey soil that is commonly less than 2 meters thick and is characterized by many outcrops of limestone and by poor drainage. On the uplands the soils support luxuriant vegetation, but in the poorly drained lowlands the principal tree is the black or carandai palm. Were it not for the clayey texture and poor drainage the soils would doubtless be among the best agricultural soils of Paraguay, despite their thinness, for they are the only ones that contain lime in any quantity.

The limestone forms the basis of a considerable lime industry, as well as providing raw material for the country's cement plant. In addition to these uses, there is a strong possibility that many of the rocks could be used for attractive ornamental stone. Many small kilns, which supply nearly all the lime used in the country, are scattered along the limestone cliffs on the east bank of the Río Paraguay. This industry is said by Boettner (1947) to have been begun between 1825 and 1840, under the regime of President Francia, who effectively closed the country to all foreign commerce.

SILURIAN SYSTEM

CAACUPÉ SERIES

The Caacupé series, at least 700 meters (2,300 feet) thick, consists largely of arkosic sandstone with a basal conglomerate and with some beds of clay and shale. Fossil evidence shows it to be of Early Silurian age. The probable correlatives of these beds in the Gran Chaco basin, as determined by deep exploratory wells and as described in another section in this report, are largely black marine shale with comparatively little sandstone.

As shown on plate 1, the Caacupé series occupies much of the heavily populated west central part of the country extending southward from the banks of the Río Paraguay above Asunción to Quiindy and Mbuyapey and from Ypacaraí eastward to the longitude of Eusebio Ayala.

The Caacupé series can be divided into four lithologic units, as follows:

	Approximate thickness (meters)
Top.	
1. Sandstone, red to brown, massive, fossiliferous; highly micaceous in part; underlain by soft light-colored shale or clay with thin beds of sandstone	200
2. Sandstone, white, saccharoidal	100
3. Sandstone, brown to red-brown, fine- to coarse-grained, arkosic; several fossiliferous clayey horizons near base	400
4. Basal Paraguarí conglomerate	1–50

These units, which are described below, cannot be shown separately on plate 1, but more detailed geologic studies will almost certainly prove them to be easily mappable units that may ultimately deserve the status of formations or members. It is also possible that the upper unit may be subdivisible into a lower shaly unit and an upper one of sandstone.

Paraguarí conglomerate.—The lowest unit of the series is a basal conglomerate that grades both laterally and upward to conglomeratic sandstone. It was named the Paraguarí conglomerate by Harrington (1950) for the excellent exposures just northeast of that town. There it is 40 to 50 meters thick, but elsewhere it appears to be thinner and is probably no more than 2 or 3 meters thick in most places. The conglomerate rests unconformably on the weathered surfaces of the Precambrian rocks and is overlain gradationally by coarse-grained crossbedded sandstone. According to Harrington, it is exposed along the entire length of the Ypacaraí depression, from San Bernardino to Paraguarí, at the foot of the Cordillera de los Altos that forms its eastern side. Harrington, who thinks that a conglomerate at Pirayú, on the west side of the depression, may belong to this unit, also mentions the exposures farther south that are described below.

The typical conglomeratic rock consists of a great number of pebbles in a coarse-grained sandy matrix. The pebbles are smooth, ellipsoidal to well-rounded, and 1 to 30 centimeters in diameter. They consist exclusively of siliceous materials—vein quartz, quartzite, and various forms of chert and jasper. There are no igneous and metamorphic rocks except quartzite.

The most easily studied exposure of the conglomerate is probably that at the north edge of San Bernardino, a resort town on the east shore of Lago Ypacaraí. Even here the actual contact with underlying rocks is poorly exposed. The lower part of a small hill at San Bernardino is made up of coarse Precambrian granite, fresh near the lake level, but strongly weathered and crumbly upward. The top of the hill is made up of coarse-grained brown to red-brown sandstone, at least 7 meters thick. It is strongly crossbedded and contains many thin lenses of conglomerate with pebbles 1 to 2 centimeters in diameter. Between the weathered granite and the conglomeratic sandstone there is a covered interval less than 6 meters thick. The soil and slope wash in this interval, as well as on the uppermost part of the granite slopes, contain an abundance of pebbles, 2 to 10 centimeters in diameter, of quartz, chert, and quartzite. These indicate that at least a part of the interval is made up of a true basal conglomerate, though it seems probable that even here there is a considerable amount of sandstone matrix.

The basal conglomerate is well exposed in many places along the highway between Quiindy and Caapucú, at Quyquyó, south of Acahay, and elsewhere. At all of these places it marks the contact between Precambrian igneous and metamorphic rocks and erosional remnants of the lower part of the Caacupé series. Nowhere in this southerly area does the conglomeratic horizon appear to be much more than one meter thick. It grades upward to typical brown or red-brown sandstone of the Caacupé, and its weathered surfaces are liberally strewn with rounded to semirounded pebbles of quartz, quartzite, and varicolored chert. As elsewhere, pebbles of granite and quartz porphyry, that form the surface on which the conglomerate was deposited are conspicuously absent in the conglomerate.

Arkosic sandstone.—The arkosic sandstone, which makes up more than half of the Caacupé series, constitutes the bulk of the rocks that are called the Piribebuy sandstone by Harrington. It grades downward to the basal conglomerate of the series and is overlain, with little or no gradation, by the thick white saccharoidal sandstone unit. The unit consists almost entirely of a monotonous succession of arkosic sandstone, mostly light brown to light reddish brown but marked by thick dark brown to dark-red soils in many places. It is coarse grained locally but mostly fine to medium grained, is usually poorly cemented, and consists of well rounded grains of quartz and feldspar, with considerable quantities of mica. It occurs in thin beds, most of them strongly crossbedded.

At several places along the western side of the Ypacaraí depression the sandstone beds contain intercalated layers of light-colored fossiliferous clay several meters thick, probably the partly weathered product of soft gray or black shale. According to the author's interpretation of the structure, all of these are in the lower part of the unit.

The arkosic sandstone unit is exposed along the entire western front of the Cordillera de los Altos; its upper part is most accessible and most easily studied in the cuts along the main Asunción-Caacupé highway where it traverses this front and rises more than 200 meters between the lake level and the crest of the hill. The unit also makes up the western part of the Cordillera de los Altos, where it extends a little east of Caacupé, as well as most of the area between Asunción and Ypacaraí. Except for one hill just southeast of Carapeguá, which is capped by the white saccharoidal sandstone unit, all the southern body of Caacupé rocks is made up of the arkosic sandstone unit, underlain by the basal conglomerate. (See fig. 44.)

The following more detailed descriptions of specific localities give some picture of the nature of the intercalated clay layers mentioned above and of the enclosing sandstone.

One clay deposit that was examined is on the west side of the railroad, 1 to 2 kilometers southeast of Areguá. There, clay underlies a low-level bench, 100 meters or so wide, that parallels the shore of Lago Ypacaraí. Clay is exposed in a large number of pits to depths of 3 to 4 meters. It is very micaceous, white to light gray and mottled near the surface with brown and red; it is used for making bricks of excellent quality and rich-red-brown color. In the dense woods at the base of a slope just above the broad bench, hence just above the clay stratigraphically, there is a small building-stone quarry in buff to brown, fine-grained micaceous sandstone in beds 1 to 2 meters thick. This sandstone, which yielded a few poorly preserved fossils and which strikes N. 65° W. and dips 32° SW., is overlain by thin-bedded, very shaly sandstone that is also micaceous but redder in color than the lower beds. Rocks that form the upper parts of the hill are poorly exposed, but fragments in the soil and slope wash make it evident that there is a series of buff-colored sandstone beds, at least 60 meters thick, fine to medium grained, quartzitic in places, and locally rich in iron oxides. An intermediate bench suggests that there is at least one more thick bed of clay like the one near lake level, but it is not exposed.

The Vargas Peña clay pit, 2 kilometers northwest of the town of Ypacaraí, which is described by Harrington (1950, p. 21–22, 48) and is one of the key fossil localities now known in Paraguay, provides another good example of the relations of clay beds and sandstone. The beds strike N. 55° W. and dip 12° SW. Clay is exposed in two pits, about 25 meters apart vertically. The clay is white, very micaceous, contains little or no

FIGURE 44.—Sandstone hills of the Caacupé series southeast of Paraguarí. The dark hill at the left is basal conglomeratic sandstone of the series.

sand, and is richly fossiliferous. In places it is stained red, yellow and brown and contains an abundance of layers and veinlets of siderite, which is largely altered to limonite. Massive, crossbedded micaceous light-brown to red sandstone crops out between the upper and lower clay pits. Similar sandstone appears to overlie the clay in the upper pit. The relations are not clear, but it is believed that the lower sandstone lies between two distinct layers of clay, each several meters thick. Possibly, however, the clay represents a single bed of altered shale that has been repeated by dropping along a northwestward-trending fault.

The two series of sandstone and clay just described probably belong in the lower part of the arkosic sandstone member of the Caacupé series not far above its base. The one near Areguá is probably a few meters lower in the section than that near Ypacaraí, but they may be actually or very nearly equivalent.

White saccharoidal sandstone.—The white saccharoidal sandstone is one of the most striking and most easily recognized of all the sedimentary rocks in Paraguay. About 100 meters thick, it rests on the arkosic sandstone unit and is overlain by a unit of alternating clay and sandstone. Its main outcrop is a broad, southward-trending belt on the eastward flank or dip-slope of the Cordillera de los Altos, and along the west side of the Río Piribebuy valley. Thus it extends through the towns of Tobatí and Piribebuy and thence southwestward to make up the prominent hills east of Paraguarí. The southeastward-trending hill just south of Carapeguá is capped by an outlier of the same unit.

The sandstone is so friable, at least near the surface, that it fails to crop out in many places, but on some of the hills east of Caacupé and in the general vicinity of Piribebuy, it forms extensive outcrops. Probably the best exposures are near Tobatí (see figs. 45 and 46). There the road from Tobatí to Caacupé crosses the base of the unit about 3 kilometers north of Caacupé. The contact itself is obscured, but it is marked by an abrupt change from the red sandy soil derived from the arkosic sandstone unit to white or light-gray sandy soil. From this point to Tobatí the road skirts prominent and impressive hills, roughly 50 meters high, that are made up of the white sandstone. Near the base the sandstone is thinly bedded in layers 15 to 60 centimeters thick, but the remainder of the unit is in massive beds, locally crossbedded, and as much as 17 meters thick. The beds dip at low angles toward the east and southeast, with occasional minor rolls. A series of vertical eastward-trending joints, 3 to 70 meters apart are so eroded

FIGURE 45.—Typical weathering pattern, resembling mudcracks on case-hardened joint faces of white sandstone unit of Caacupé series of Silurian age. Three kilometers west of Tobatí.

Figure 46.—Typical joint pattern and pitted surface of the white sandstone unit of the Caacupé series near Tobatí.

as to form flutings and deep, almost vertically walled ravines that give the outcrops the appearance of limestone weathered in an arid climate (fig. 46). Along a few of the joints the sandstone contains much white and ocherous clay, possibly of hydrothermal origin, which forms the basis of a tiny industry at Tobatí for manufacture of ocher, laundry bluing, and billiard chalk. (See figs. 47 and 55.)

Except for the few clay-bearing localities just mentioned, the sandstone is made up of clean quartz sand with a little calcareous cement and no other impurities except widely scattered fine grains of magnetite. The fine quartz grains are uniform in size, but very irregular in shape, ranging from round grains to euhedral crystals. The surface of the rock is commonly casehardened to depths of 5 to 30 centimeters but its interior is saccharoidal. It may well be that the friable nature of the rock as seen in outcrops is a near-surface feature, caused by solution of the intergranular cement, and that the rock is better consolidated at depth. There are no available facts to confirm this possibility, however. Many of the surfaces, especially horizontal ones, exhibit polyhedral cracks, resembling mudcracks (fig. 45), that seem to be as characteristic of the unit as are the weathered joints and pitted, limestonelike, weathered surfaces elsewhere.

Upper shale and sandstone unit.—The uppermost unit of the Caacupé series, about 200 meters thick, is even less well known that the other units. Scattered information suggests that the lower half is made up largely of soft shale or clay, with thin beds of sandstone, whereas the upper half is largely micaceous sandstone with comparatively little clay or shale. The following notes, arranged stratigraphically, represent all the information on this unit that is available.

Just east of the town of Tobatí the white saccharoidal sandstone unit dips beneath the surface of the broad valley of the Río Piribebuy. The underlying beds are covered almost everywhere by as much as 6 meters of river-deposited clay, silt, and sand. A few low forested hills, or "islas," and occasional outcrops in the banks of the main stream serve to give some idea of the older rocks. They consist of brown, fine-grained cross-bedded sandstone, dipping eastward at low angles and directly overlying the white saccharoidal sandstone. Despite the evidence of these exposures, the general character of the valley, as well as the rarity of exposures make it appear probable that the valley is carved in a series of very soft shale or shaly sandstone beds, with only a few relatively thin beds of harder sandstone.

Cerro Aparipí, from which Beder and Windhausen (1918) and later Harrington (1950) collected an exten-

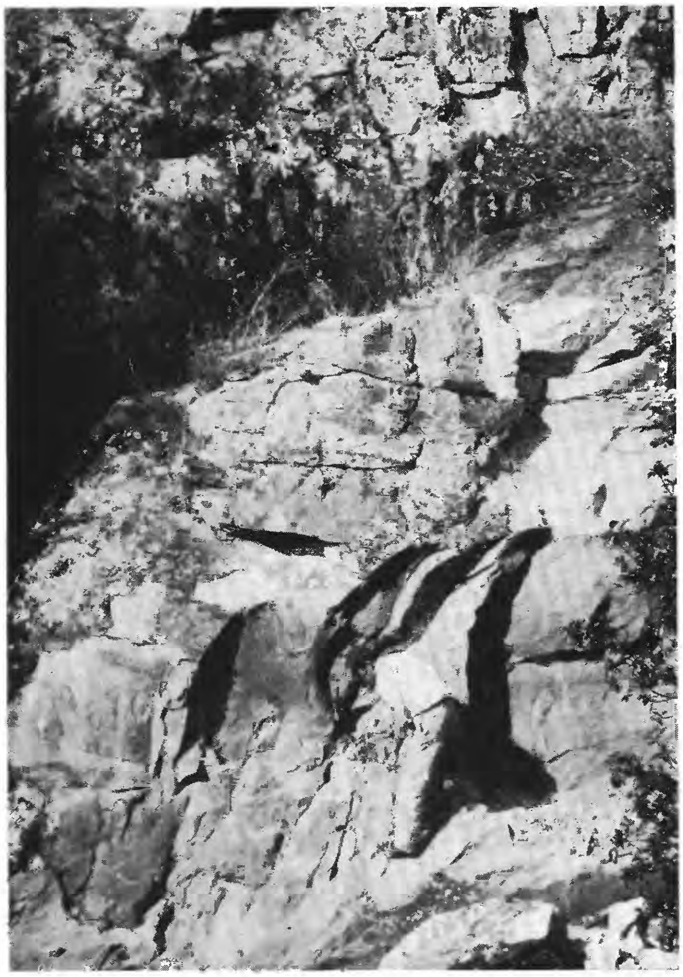

FIGURE 47.—Ocher quarry near Tobatí. The white sandstone unit of the Caacupé series contains ocher-yellow clay between interstices of the sand grains.

sive fauna, is on the east side of the Piribebuy valley, hence the beds described by these authors would seem to be stratigraphically above those of the main valley. Cerro Aparipí, which was not visited by the present author, is a conical hill, 30 meters high and 300 meters long, about 4 kilometers north of Río Piribebuy and almost due north of Tobatí. According to Beder and Windhausen, the lower part of the hill is made up of very fine grained, highly micaceous sandstone, with a few intercalations of white to gray clay. This sandstone is succeeded by 20 meters of white to grayish-white fossiliferous clay, locally tinted yellow by veinlets of limonite. The layer of clay is overlain by medium-grained grayish-red, thick-bedded sandstone that caps the hill.

The beds exposed on Cerro Aparipí are overlain by a thick massive sandstone. This is exposed in a number of places along the road between Tobatí and Arroyos y Esteros between points 2.5 and 6.5 kilometers southwest of the latter town. The sandstone is soft, dull red, very micaceous, and contains such an abundance of red ochre that it gives a bright-red greasy streak. Poorly preserved fossils are widespread. At the northeast end of this exposure, 2.5 kilometers southwest of Arroyos y Esteros, a fairly large collection of fossils was made from a freshly quarried pile of building stone identical with that just described.

Stratigraphically above the red micaceous sandstone, and extending 2 kilometers northeast of Arroyos y Esteros, is massive quartzose sandstone with little mica or feldspar. It is yellow to brown, but weathers to soil that is nearly as red as that on the underlying red sandstone farther southeast. This sandstone dips beneath the valley of Río Manduvirá. It probably marks the top of the Caacupé series and is overlain by softer and more shaly beds of the Itacurubí series of Devonian age.

The author's interpretation of the Caacupé series, as given in preceding paragraphs and shown on the geologic map, plate 1, differs somewhat from that of Harrington (1950, p. 19–24, fig. 3, and geologic map). The differences have to do with the place of the two major fossiliferous localities in the stratigraphic section, and with the relative stratigraphic position of the white saccharoidal sandstone unit.

Harrington's general description of the rocks of the Caacupé series is essentially the same as that given above. He says it is made up of a succession of light-colored sandstone beds that commence with a strongly developed basal conglomerate. These basal beds he calls "Paraguarí conglomerate," using the name "Piribebuy sandstone" for the main part of the series. His Piribebuy sandstone beds are crossbedded in the lower part and contain a few thin layers of clay. They grade upward to light-colored saccharoidal sandstone, which caps the Caacupé series.

Harrington believes the fossiliferous clay of Cerro Aparipí and of the Vargas Peña clay pit at Ypacaraí to be at or about the same stratigraphic horizon, which he places as probably high in the crossbedded sandstone series but beneath the saccharoidal sandstone unit. Unfortunately, the faunas from the two main localities shed no light on the problem. Unless there is an undiscovered fault along the Río Piribebuy that brought the beds at Cerro Aparipí up on its east side, and another between Arroyos y Esteros and the Río Manduvirá that again dropped the whole Caacupé section beneath the surface, the facts available indicate that the fossiliferous clays at Cerro Aparipí are near the top of the series and well above the saccharoidal sandstone unit. The place of the clay beds at Ypacaraí is much more open to question than those just discussed. The author believes they are very near the base of the Caacupé series, but this is based more on his interpretation of the structure than on real knowledge of the stratigraphy.

If, as shown on plate 1 and discussed in the section on structural geology, Harrington's concept of a graben along the depression is correct, then the fossiliferous beds at Ypacaraí may be anywhere within the Caacupé series—though almost certainly within the main arkosic sandstone unit and beneath the white saccharoidal sandstone.

Paleontology.—Much confusion exists as to the age of the Caacupé series and of the Itacurubí series, described on succeeding pages. Available facts on identifications and age assignments of the few fossils from these series that have been made by various paleontologists are given below. It is evident from these conflicting reports that no satisfactory definition of the ages of the Caacupé and Itacurubí series can be made without studies of large collections of fossils that are tied to detailed geologic maps. Indeed, it seems probable that solution of the paleontologic problems may well have to await the establishment, somewhere in South America, of some standard section of the Paleozoic rocks that can be used as a point of reference throughout the continent.

The first known fossils from what is here called the Caacupé series were from Cerro Aparipí, south of Arroyos y Esteros. They were collected and described by Beder and Windhausen (1918). These authors also collected fossils from a pile of building stones in the town of Arroyos y Esteros which they say were taken from a quarry a few kilometers north of the town. They identified the following species:

Leptocoelia flabellites Conrad
Calmonia subseciva Clarke
Tentaculites crotalinus Salter
Tropidoleptus carinatus Conrad

Beder and Windhausen's assignment of the beds that yielded these fossils to a Devonian age stood in the literature until Harrington (1950) visited the same locality and recognized the fauna to be of lower Silurian age. Harrington describes the following species from Cerro Aparipí and from the Vargas Peña quarry at Ypacaraí:

	Cerro Aparipí	*Ypacaraí*
Lingula sp	----	X
Atrypina(?) *paraguayensis* Harrington	X	-----
Ctenodonta(?) sp	X	-----
Palaeoneilo constrictiformis Harrington	----	X
Nuculites opisthoxystomus Harrington	X	X
Hyolithes sphenomorphus Harrington	----	X
Calymene boettneri Harrington	X	X
Dalmanites sp	----	X
Climacograptus innotatus var brasiliensis Ruedemann	X	X
Diplograptus modestus Lapworth var	----	X

Harrington points out that the trilobite described by Beder and Windhausen as *Acaste* (*Calmonia*) *subseciva* Clarke is in reality the form he describes as *Calymene boettneri* Harrington.

A J. Boucot of the U. S. Geological Survey has the following comment concerning the faunal lists just given:

The faunal list in Beder and Windhausen indicates lower Devonian age for the Cerro Aparipí, and it is difficult to see how they could have misidentified *Leptocoelia flabellites*. On the other hand the graptolites identified by Bulman (Harrington, 1950) are certainly not of Devonian age. Is it possible that the flat-lying beds on the top of the hill are Devonian and that the Silurian fossils could have been obtained from the bottom of the hill?

Boucot's question can be answered in the negative. Harrington, in written communication to the author, states that there is but one tiny quarry on Cerro Aparipí and that it is certainly the place that yielded Beder and Windhausen's collection as well as his own collection that contained graptolites. He adds that he is personally convinced that Beder and Windhausen's identification of *Leptocoelia flabellites* was in error.

The present author, in company with Ricardo Mazó U., failed to find the Cerro Aparipí locality, but like Beder and Windhausen, did make a collection of fossils from a large pile of building stone in a field 2 kilometers south of Arroyos y Esteros. Quite possibly these stones came from the same quarry mentioned by the earlier workers. The rich fossil locality at the Vargas Peña clay pit near Ypacaraí was found, quite accidentally, and a few fossils were found in a stone quarry 1.5 kilometers southeast of Areguá and in pottery clay reported by the owner to come from a clay pit 3 kilometers north of Itauguá. The latter locality is probably at about the same stratigraphic horizon as that at the Vargas Peña quarry. The fossils collected from these localities were examined by paleontologists of the U. S. Geological Survey, whose reports follow:

A. J. Boucot reports on a small lot of poorly preserved fossils from the stone quarry 1.5 kilometers southeast of Areguá as follows:

This lot contains an unidentified plicated brachiopod, probably a rhynchonellid, whose brachial valve bears a median septum. It resembles the genus *Camarotoechia*. Also present is an unidentified smooth pelecypod and *Tentaculites* sp.

A. R. Palmer reports as follows on trilobites from the same collection just noted:

This collection contains a cephalon of a Phacopid trilobite that could belong to either the subfamily Acastinae or Calmoninae. Trilobites of this type have not been reported from rocks younger than lower Devonian. If a pygidium in the collection belongs with the cephalon, then the general lack of spines on the species would eliminate the subfamily Calmoninae from consideration.

It is not possible to identify the genus within the Acastinae to which the Paraguayan specimens might belong. The cephalon shows resemblances to the Silurian genus *Scotiella* and the Devonian genus *Phacopina*. Again, if the pygidium belongs with the cephalon, then its lack of a median spine would eliminate it from comparison with *Scotiella*. Because of the uncertainty of association of the parts and the imperfect nature of the specimens, they cannot be dated more closely than Silurian or lower Devonian.

R. J. Ross reports as follows on a collection from the lower Vargas Peña quarry, 2 kilometers northwest of Ypacaraí:

The fauna secured from this collection is:

1. *Climacograptus innotatus* var. *braziliensis* Ruedemann
2. *Calymene* cf. C. *boettneri* Harrington
3. *Anabia* cf. *A. paraia* Clarke
4. *Cleidophorus*(?) cf. *C. brasilianus* (Clarke) (this species may be referable to *Nuculites*.)
5. *Anodontopsis*(?) cf. *A. austrina* Clarke
6. Small taxodont concentrically ornamented pelecypod.
7. *Ulrichospira*(?) sp.
8. Gastropod with general form of *Hormotoma*.

This fauna is strikingly similar to that described by Clarke (1897) from the "Middle" Silurian of the Rio Trombetas, a northern tributary of the Amazon; although his studies lacked graptolites and trilobites, the occurrence of the same species of *Climacograptus* was reported in 1922 from what is presumed to be the same locality. The presence of this genus and species eliminates the possibility of a Late Silurian dating; in fact other species of its are known from Middle and Upper Ordovician strata elsewhere. A species of the trilobite genus *Calymene* is here present and appears to be conspecific with that described by Harrington as *C. boettneri* from the same Paraguayan locality. None of the specimens is as well preserved as Harrington's and all lack the critical frontal portion of the cephalon by which various subgenera are distinguished. There is nothing to suggest that they are not assignable to *Calymene sensu strictu*, which is not found below the Silurian in Great Britain.

There can be little doubt that this Paraguayan fauna is correlative with that from Rio Trombetas, Brazil; the age of the latter has been redesignated as Early Silurian by Maury (1929), and there is no reason here to question this dating, which agrees also with that of Harrington for this locality.

A. J. Boucot reports on the author's collection of fossils from a pile of building stone 2 kilometers south of Arroyos y Esteros:

This lot contains an unidentified orthoceracone, a pelecypod possessing taxodont dentition which may belong to the genus *Nuculites*, several other fragmentary pelecypods, two gastropods (one possibly belonging to the genus *Bucanella* whereas the other may belong to the genus *Tropidodiscus*), and several unidentified brachiopods. The brachiopods may possibly belong to the genus *Schuchertella*, in which case the fauna is probably not any older than the Devonian, or to a strophomenoid resembling *Leptostrophia* although identity with an orthoid-like Rhipidomella cannot be ruled out because of the poor quality of the fossils.

A. R. Palmer reports as follows on the trilobites in the same collection:

Dalmanites(?) sp. *Homalonotus* sp. Lack of associated pygidia of *Dalmanites*(?) sp. makes generic identification difficult. There is no surety that this collection is Devonian, but it is probably as good an assignment as can be made with the material and present knowledge.

This collection has a distinctly Siluro-Devonian aspect, but it is not possible to make any definite age determination based on the available collection.

DEVONIAN SYSTEM

ITACURUBÍ SERIES

A series of micaceous shale and arkosic sandstone beds, that contain marine fossils of Early Devonian age in places, extends in a comparatively narrow band between the Silurian and Pennsylvanian beds and trends northwestward from the Río Tebicuary-mí to the Río Paraguay not far below Rosario. They were named the Itacurubí series by Harrington (1950, p. 24–27) for the town of Itacurubí, sometimes known as Itacurubí de la Cordillera; they are seemingly equivalent to the Furnas sandstone and the Ponta Grossa shale of southeastern Brazil and possibly to the Los Monos and Iquirí beds of the Andean foothills of Bolivia (Ahlfeld, 1946). They are stratigraphically above the beds near Arroyos y Esteros that were designated as Devonian by Beder and Windhausen (1918) and are here included in the Caacupé series of Early Silurian age.

Several outcrops of quartzitic sandstone in the northern part of the Gran Chaco, west of the Río Paraguay, are correlated with the Itacurubí series. In addition, two exploratory wells, the Santa Rosa and the Picuiba, demonstrated that the Lower Devonian beds lie beneath a part of the Gran Chaco sedimentary basin, where they are a variable, but locally great, thickness of marine shale, siltstone, and sandstone (p. 74).

The distribution of the Itacurubí series in eastern Paraguay, as shown in plate 1, is based largely on Harrington's map (1950) with some changes and additions from the present author's field observations and his interpretations of aerial photographs. The series is best exposed in a belt 10 to 20 kilometers wide and 50 kilometers long that extends from near Caraguatay to a point south of San José. In this area, cuts along the roads that connect Eusebio Ayala with Itacurubí and Caraguatay, as well as the road between Itacurubí and Santa Elena, present the best and most easily accessible exposures.

There are a few isolated hills of these beds south of San José, but generally speaking the series is lost beneath the swampy lowlands of the Río Tebicuary-mí drainage basin and the distribution shown on the map is very largely imaginative. North of Caraguatay the beds are again obscured beneath the swampy alluvium of the Arroyo Yhaguy and the Río Paraguay, though sandstone that may belong to the lower part of the section is poorly exposed just east of Arroyos y Esteros.

The series is about 250 to 300 meters in thickness. Harrington (1950, p. 24–27) gives a good description of its general characteristics. According to him, the lower third of the series consists largely of yellow to cream fine-grained sandstone, crossbedded in places, and with some intercalations of shale. The sandstone units are thin-bedded near the base but become thicker bedded upward. The middle third of the series consists largely of sandstone in thin beds; they are shaly throughout and become more so upward. These argillaceous beds, characterized by lilac, purple, and yellow colors, contain ferruginous concretions in places. The upper third of the series is friable, yellowish-white to purple micaceous sandstone in thin beds. It contains intercalated varicolored shale in places but the sandstone tends to be considerably coarser in grain than the lower units. This unit has yielded most of the fossils reported from the series.

The author's random observations along the highway between Eusebio Ayala and San José confirm Harrington's three-fold division of the series in a general way, and add a few details as to parts of the section. The highway mentioned crosses the series diagonally from its base to its top, so that the following notes must be in approximately the correct stratigraphic order.

From a point 4.6 kilometers southeast of Eusebio Ayala to the broad valley of Arroyo Yhaguy, 5 kilometers west of Itacurubí de la Cordillera, the main highway traverses rolling grasslands marked by light-colored soils. Several road cuts present excellent exposures of a small part of the section traversed (see fig. 48). In these, the rocks are seen to consist of alternations of buff to light-reddish-brown soft shale and very shaly micaceous sandstone in beds 1 to 5 centimeters thick. A few of the beds, notably some of the micaceous sandstone, contain poorly preserved fossils.

Alluvial material masks the Devonian rocks in the valley of Arroyo Yhaguy where the main highway crosses it, but the beds are fairly well exposed a short distance south of the highway in the vicinity of the Minas-cué or "López" sulfur deposits. These deposits consist of widely scattered concretions of marcasite in shale. The enclosing rock, which doubtless corresponds to Harrington's shaly middle part of the Itacurubí series, consists of alternating beds of blue-gray shale and mudstone, with local splotches of red and pink. The shale is sparsely fossiliferous.

There are no good exposures along the highway near Itacurubí but walls, buildings, and piles of rock in various places suggest that there is a nearby source of

FIGURE 48.—Minor thrust fault in sandy micaceous shale of the Itacurubí series, Devonian age. View eastward on the highway 6 kilometers southeast of Eusebio Ayala. The beds at left have been pushed up and over the horizontal beds at right.

fine-grained olive-brown sandstone probably in the hills just south of town. This rock, which contains much clay-sized material, splits into solid but easily workable blocks from 12 to 30 centimeters thick.

At a point about 10 kilometers southeast of Itacurubí de la Cordillera, the surface is covered by 1 to 2 meters of lateritic iron ore, on thin-bedded alternations of micaceous sandstone and clay. The sandstone is purplish gray, very soft, and contains at least 50 percent fine-grained muscovite mica. The clay, no doubt a weathered shale, is reddish brown and is far less micaceous than the sandstone.

Two kilometers farther southeast, or 3 kilometers from San José, a shallow road cut exposes an extensive body of white, fine-grained micaceous sandstone that breaks along joints and horizontal bedding planes into smooth but relatively soft flagstones, from 2 to 6 centimeters thick. The vertical joints in this rock are seamed with brown limonite and many blocks of sandstone show diffusion banding that has worked away from the joints. Several poorly preserved fossils were found at this place.

The Itacurubí series rests on the Caacupé series of lower Silurian age and is overlain by the Tubarão series of Pennsylvanian age. Neither contact has actually been observed, but both evidently are marked by unconformities. There is, indeed, some evidence of a major erosional unconformity at the base of the Devonian beds. Harrington states that the Itacurubí series rests directly on the Piribebuy sandstone—the white saccharoidal member of the Caacupé series—and even considers the possibility that this sandstone should be grouped with the Devonian rocks. The relationship described by him is quite possibly true in the area directly west of Itacurubí and near Valenzuela. Farther north, however, the fossiliferous beds in the vicinity of Arroyos y Esteros, which are definitely part of the Caacupé series, are stratigraphically above the white sugary sandstone and beneath the Itacurubí beds. These relationships are discussed on pages 56–57. If the present author's concepts are correct, the relatively thick section of upper Caacupé beds that is present between Tobati and Arroyos y Esteros must be missing in the latitude of Itacurubí. This strongly suggests the presence of a major erosional unconformity between the Silurian and Devonian rocks.

Harrington (1950) lists the following fossils from a quarry at Cariy Loma, a few kilometers east of Itacurubí de la Cordillera. These fossils were found in sandstone near the top of the series.

Favosites sp. indet.
Schellwienella inca (d'Orb.)
Australostrophia conradii Harrington
Chonetes falklandicus Morris and Sharpe
Spiroaphe(?) sp. indet.
Tentaculites crotalinus Salter
Phacopina itacurubensis Harrington
Calymene sp. indet.

A small collection of fossils was made by the author and Ricardo Mazó U. from micaceous sandstone near the base of the series, 8 kilometers southeast of Eusebio Ayala. A. J. Boucot reports as follows:

> This collection contains an unidentified plicated brachiopod, probably a rhynchonellid, whose brachial valve bears a median septum. It resembles the genus *Camarotoechia*. Another finely plicated brachiopod is possibly an orthoid belonging to the Wattsellidae, Silurian or Devonian.

A. R. Palmer reports on trilobites from the same collection:

> *Hadrorachis*(?) sp., cranidium; *Homalonotus* sp., thoracic segment. Similar forms have been described from the Devonian of adjacent South American countries; however, neither genus is necessarily definitive of a Devonian age. On the basis of the trilobites, this collection cannot be more closely dated than Silurian-Devonian.

At the "López" sulfur workings, in the middle shaly member of the series, the author found one fossil, identified by R. J. Ross as follows:

> A single partial specimen of an orthoconic nautiloid possessing the ornamentation of the "form genus" *Spyroceras*. Similar forms are known in North America from mid-Ordovician to Devonian strata.

Boettner (1945) describes a single specimen of *Homalonotus* sp. from this same locality.

The white flaggy sandstone mentioned above as 3 kilometers west of San José yielded an unidentified smooth pelecypod and fragments of *Homalonotus* sp. and *Dalmanites*(?) sp. as identified by A. R. Palmer. Fossils that were found in the Santa Rosa and Picuiba exploratory wells in the Gran Chaco, and that are ascribed to the Devonian by Harrington are listed in the tables on pages 73 and 74.

These faunas, which contain species that are typical of the classic Devonian localities of Brazil, Uruguay, and Argentina, indicate the Early Devonian age of the Itacurubí series of Paraguay, as well as its general correlation with the Devonian sedimentary rocks of the surrounding countries.

GONDWANA (SANTA CATARINA) BEDS

The Paraguayan equivalent of the widely distributed Gondwana beds consists of a thick series of continental and epicontinental sedimentary rocks that overlie the marine Devonian beds unconformably (Du Toit, 1927; Oliveira and Leonardos, 1943; Harrington, 1950). The Gondwana of Paraguay is 1,000 meters (3,280 feet) or more thick, including its extensive cap of basalt. Because the name Gondwana is still widely used by geologists in Brazil and other parts of the world it is retained here. The name "Santa Catarina system" is, however, used parenthetically. It was applied by I. C. White (1906, p. 378) to the Gondwana beds of southern Brazil, and its use was extended to Paraguay by Harrington (1950).

In Paraguay, the following groups of Gondwana (Santa Catarina) rocks can be distinguished: the Tubarão series, of Pennsylvanian or Permian age and largely of glacial and fluvioglacial origin; the Independencia series, of Permian age and made up of sandstone with some shale; the Misiones sandstone of Triassic age; and the Serra Geral basaltic lavas of Triassic or possibly Jurassic age. The latter rocks are described above in the section on igneous rocks; the others are described in order below. So far as known, the carbonaceous and coal-bearing sediments that are present in the Gondwana beds elsewhere are not represented in Paraguay.

PENNSYLVANIAN OR PERMIAN SYSTEMS

TUBARÃO SERIES

The distribution of the Tubarão series, as shown on plate 1, is based almost entirely on Harrington's map (1950) with a few refinements by the author based on study of aerial photographs and maps. The series is shown as covering a northward-trending belt, of variable width, from the swampy basin of the Río Tebicuary as far north as the Río Apa boundary of Paraguay and Brazil, just west of Bella Vista. Actually, almost all this belt of "outcrop" is occupied by marshes and swamps and virtually the only exposures that have been studied are in the central region, in a belt that extends from near Caraguatay southeastward to the vicinity of Villarrica. Much farther north, and thus providing a good deal of justification for mapping the series over such a large area, Boettner (1947, p. 11) found undoubted glacial deposits between the Río Apa and Toldo-cué. He also found striated pebbles from the same series in the vicinity of Concepción.

Even in the central zone, where they are best known, the Tubarão rocks are poorly exposed, and it is impossible to study or measure a complete section. Harrington, who believes the entire series to be about 250 meters (820 feet) thick, found three distinct kinds of interstratified sediments in the series—glacial tillite, light-colored sandstone, and compact, laminated olive-green shale.

Tillite, according to Harrington, is exposed in a number of road cuts from the outskirts of Caraguatay to a point just north of the Río Tebicuary-mí between Coronel Oviedo and Villarrica. These beds were examined at only one part of this stretch—in the last 8 kilometers of the main highway between San José and Coronel Oviedo, or just west of the place where the highway forks lead to Coronel Oviedo and Villarrica. The grassy flats along the road are conspicuously covered with pebbles, mostly from 1 to 5 centimeters in diameter. A few of the pebbles are well rounded but nearly all are subangular with 2 or 3 flat sides characteristic; a few are typically scratched by ice. Most of the pebbles are of very hard, brown quartzite, but a considerable number are made up of varicolored agate or chert. One pebble of pink quartz porphyry, identical in appearance and microscopic character to the Precambrian porphyry near Caapucú, was found. The matrix that yields the pebbles is exposed in road cuts to a maximum depth of a little more than 1 meter. It is white to light-gray structureless clay, typical of tillite, in which the pebbles are randomly but sparsely distributed.

Toward the east end of the exposures, road cuts show several thin, lenticular beds of sandstone, some extremely fine-grained and dense, interbedded with layers of the tough clay.

In addition to pebble materials mentioned above, Harrington noted pebbles of granite and diabase. He also mentions pebbles as much as 50 centimeters in diameter and even a few much larger erratics.

Harrington (1950) also describes red fossiliferous sandstone that he believes to be either interstratified with the tillite, or to "represent part of the Bonito sandstones which according to many Brazilian geologists form a distinct group overlying the glacial beds." One such exposure is on top of a large hill immediately south of Villarrica, where it has been worked in several small quarries, now abandoned. The sandstone is thin bedded, red to gray, strongly arkosic, and fine to medium grained. Beder (1923) found well-preserved remains of *Mesosaurus*, probably *M. tumididus Cope*, in two of the quarries on this hill and also found similar remains at Jhovy, a town 2 kilometers northwest of Villarrica. Harrington found a few poorly preserved vertebrae in a quarry 1 kilometer west-southwest of the Villarrica railroad station.

Harrington found banded shale, which he believes to be at or near the top of the Tubarão series, exposed in a low hill on the north edge of Coronel Oviedo. This rock is hard, grayish-green, and typical of varved clay.

Harrington (1950, p. 31–32, 49–50) describes an exposure of hard olive-green varved shale in the vicinity of Paraguarí, far from the main belt of Tubarão rocks, that he believes represents this same series. It is this single exposure, plus considerations of the geologic structure, that led Harrington to map the entire Ypacaraí depression as underlain by Tubarão beds (pl. 1). The shale forms a small conical hill at the western edge of Cerro Jhu, an eminence that is 2 kilometers north of Paraguarí. The gap between the small hill and Cerro Jhu is traversed by the main road between Paraguarí and Piribebuy. The western foot of Cerro Jhu is made up of Paraguarí conglomerate, surmounted by arkosic sandstone typical of the Caacupé series. These beds strike about N. 30° E. and dip about 45° SE.; the varved shale of the smaller hill, on the other hand, strikes about N. 70° W. and dips about 45° SW. These relationships convince Harrington, as well as the present author, that the Tubarão beds to the west must have been downfaulted against the Caacupé beds to the east along a northeastward-trending fault that traverses the gap between the two hills.

The correlation of the tillite and related sandstone and shale with the Tubarão series of Brazil, as made by Harrington, seems to be entirely justified on the basis of lithologic and paleontologic evidence available. The age of these beds in South America, and of their probable or possible correlatives in South Africa and Australia is still in dispute. Many geologists believe them to be of Permian age, whereas others assign them to the Pennsylvanian. This question is left open here.

PERMIAN SYSTEM

INDEPENDENCIA SERIES

The Independencia series, named by Harrington (1950) for Independencia, 25 kilometers northeast of Villarrica, is about 400 meters (1,310 feet) or less thick and made up very largely of sandstone. It contains sparse fauna and flora of late Permian age.

The distribution of the series as mapped is based largely on Harrington's map; the rocks have only been studied in the central region, in the general vicinity of Villarrica, and Harrington himself expresses some doubts as to the extension of the belt of outcrop as far north as Bella Vista on the Río Apa. As shown on plate 1, the series is about 400 meters (1,310 feet) thick in the mountainous area east of Villarrica but elsewhere it is less than half this thickness in almost all places. How much of this apparent difference is real and how much is due to gross errors on the topographic or geologic maps is not known.

The best exposures known are in Sierra Ybyturuzú and its vicinity, but Harrington maps a number of known outcrops in the mountains north of Caaguazú. The series is described by Harrington, from his studies along the road between Mbocayaty and Independencia, as consisting of two thick sandstone units, separated by a thinner unit of alternating shale and sandstone. Only the lower sandstone was examined by the present author, and this only in one place, at the west base of Sierra Ybyturuzú, almost due east of Villarrica. There, the basal part of the sierra, which rises abruptly from the plains of Tubarão tillite, is massive sandstone, 60 to 90 meters (200–300 feet) thick, that forms steep to vertical cliffs (see figs. 49 and 50). The sandstone has siliceous cement and is light reddish brown, medium grained and moderately hard. Individual layers are less than 1 centimeter thick, but the bedding planes are tight so that the rock appears from a little distance to be made up of massive beds from 2 to 8 meters thick. Near the top of the unit the sandstone has characteristic deltaic crossbedding, with topset and foreset beds ranging from 1.5 to 5 meters thick.

Above the rock are about 60 meters (200 feet) of sandstone that is similar in most respects but somewhat redder in color and softer so that it forms gentler slopes and supports heavier vegetation. The rocks above this second unit are concealed, at least in that part of the mountain that was examined, by soils and dense forest growth. The slopes are moderate to steep and most of the upper part of the section is probably made up of sandstone similar to that lower down.

Harrington's description of the lower sandstone unit, which he found exposed 10 kilometers east of Mbocayaty, is substantially like that reported above except that he found the rock to be somewhat coarser grained, less well cemented and more arkosic than that seen by the author.

FIGURE 49.—Coarse-grained arkosic, crossbedded sandstone of the Independencia series of Permian age, 13 kilometers east of Villarrica. The dark slotlike ravine is in a deeply weathered dike of basic alkalic rock that contains much biotite. See figure 28.

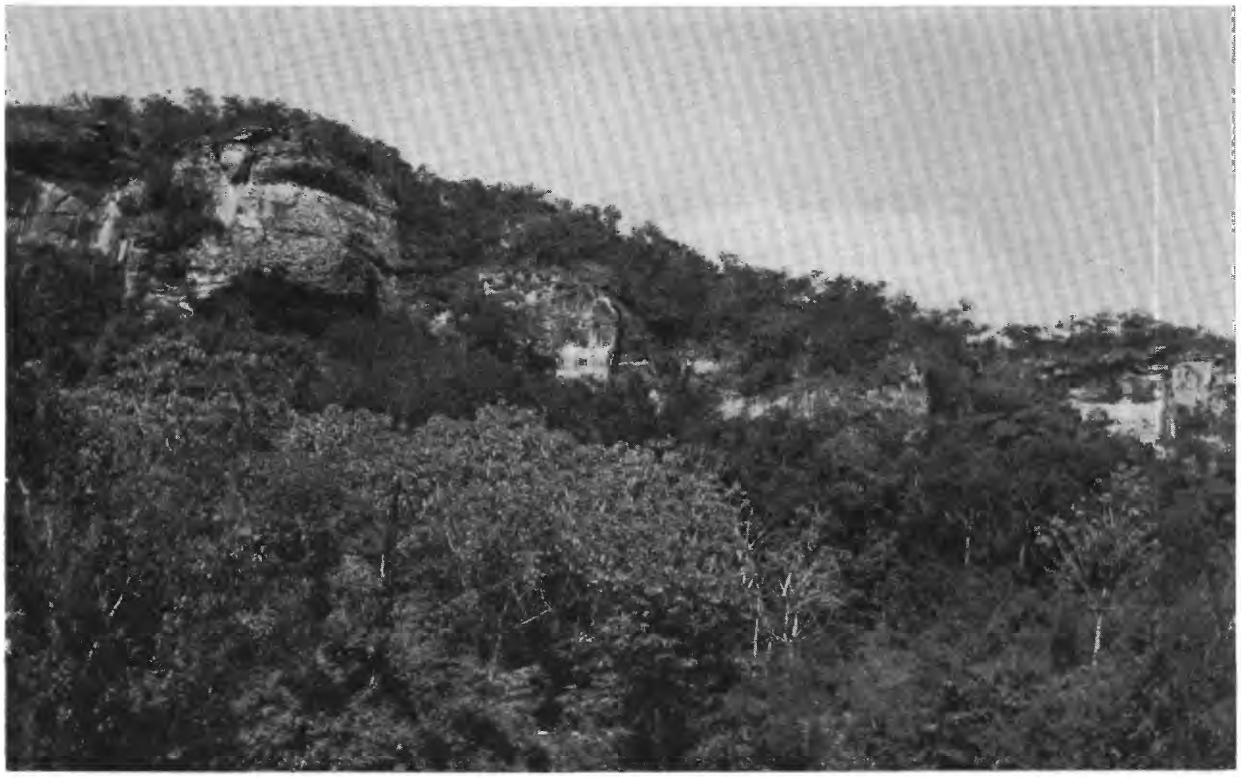

FIGURE 50.—Unusually good outcrop of crossbedded sandstone of the Independencia series of Permian age in the hills east of Villarrica. Vegetation is typical of the hilly parts of eastern Paraguay.

Above the lower sandstone Harrington found a unit, about 50 meters (165 feet) thick, of thinly alternating sandstone and shale. The sandstone is fine grained, feldspathic and shaly, generally light gray to yellow, and occurs in beds only a few centimeters thick. The units are interbedded with thin layers of cream, yellow, and gray shale.

The upper unit of the series, which contains little or no shale, is according to Harrington, fine to medium grained, strongly arkosic, crossbedded, and slightly cemented to friable. It ranges from light red to yellowish red and is mottled locally. About 200 meters (660 feet) thick, it has yielded most of the fossils reported from this series.

The Independencia series overlies the Tubarão and older rocks disconformably and is unconformably overlain by the Misiones sandstone of probable Triassic age. The angular disconformity at the base of the series is indicated in at least two places mentioned by Harrington. Just south of Villarrica the Tubarão beds dip southwest, whereas the Independencia beds, less than 2 kilometers east, dip eastward. Moreover, a small outlier of fossiliferous Independencia rocks, discovered by Windhausen in 1924 and first described by Reed (1935) is known about midway between Valenzuela and San José, where it rests directly on Itacurubí beds of Devonian age.

The first undoubted fossils of any kind to be discovered in Paraguay were found by Carnier (1911b) in what are here called the Independencia beds. The fern and conifer fossils, the latter said to be abundant, were found in two creeks crossed by the road from Villarrica to Mbuvevo. The location of the latter place is not known, but the fossil locality is near the foot of Sierra Ybyturuzú. It is quite possibly the same fossil-wood locality described by Harrington (1950, p. 35) as 6 kilometers west of Independencia; he places this locality as probably near the base of the upper sandstone unit of the Independencia series. Schuster (1911) describes and figures the fern materials collected by Carnier as *Osmundites carnieri* Schuster and the silicified conifer remains, some of them trunks 15 centimeters in diameter, as *Dadoxylon* sp. He felt that these plants indicated a Tertiary age, a mistake that was corrected by Beder (1923).

Carnier (1911b) also mentions fossil wood from near Maciel, southwest of Villarrica, and from near the Río Paraná at Villa Azara. Some existing maps show a town of this name in the general vicinity of Foz de Iguaçú. There is some doubt that this is indeed the locality noted by Carnier, for it is in an area mapped as Serra Geral lavas by all investigators whose work is known to the author.

Fresh-water invertebrate fossils have been found in at least three different localities in the Independencia beds—near Villarrica, in the small outlier between San José and Valenzuela, and near Independencia. The stratigraphic position of these fossils within the series is not known accurately, but those at Independencia and perhaps the others, are believed by Harrington to be in the upper sandstone unit, not far above the plant-bearing horizon.

Beder (1923) found lamellibranchs on the southeast edge of Villarrica at a point where the road is cut in reddish-gray sandstone. This is 2 kilometers east of the *Mesosaurus* locality mentioned above in the description of the Tubarão series. The fossils, which are poorly preserved, were identified by Beder as *Solenomorpha*, probably *S. similis* Holdhaus and *S. intermedia* Holdhaus. Gerth (1932, pt. 2, p. 209–210) says that Beder's *Solenomorpha* was later redescribed by Reed as *Myophoria*. *Solenomorpha similis* Holdhaus is now called *Leinzia similis* (Holdhaus) Camargo Mendes (1951). Leanza (1948) calls attention to the fact that Windhausen in 1931 added *Sanguinolites* to the list of fossils from Villarrica; it accompanies Beder's *Solenomorpha*.

Reed (1935, p. 41–42) describes and illustrates fossils collected in 1924 by Windhausen from an outlier of Independencia beds between San José and Valenzuela. The only description of the geology is of

> pinkish or buff-colored fine-grained sandstone containing numerous poor impressions and internal casts of one or more kinds of small lamellibranchs.

Reed classes these as *Pinzonella* cf. *illusa* Reed.

Harrington (1950, p. 35) describes pelecypods from a small abandoned quarry 800 meters south of Hotel Tilinsky in Independencia. The fossils are stratigraphically above the plant-bearing beds but still in the lower third of the upper sandstone unit. They were taken from a light-gray to reddish-gray layer of sandstone, only 20 centimeters thick, that lies between crossbedded sandstone units. There are many individual fossils, but Harrington found only two species—*Pinzonellopsis occidentalis* (Reed) Camargo Mendes and *pseudocorbula anceps* Reed.

The paleontologic evidence, though somewhat sparse, convinces Harrington (1950) that the Independencia beds of Paraguay are of late Permian age and stratigraphically equivalent to the Río do Rasto group and the Estrada Nova formation of the Brazilian Passa Dois series (Gordon, 1947).

TRIASSIC SYSTEM

MISIONES SANDSTONE

The Misiones sandstone was named by Harrington (1950, p. 37–40) for the Misiones region, between the Río Tebicuary and the Río Paraná, where it is particularly well exposed. It consists of homogenous red sandstone, and probably of red clay or shale, and overlaps all, or nearly all, of the older rocks in the country. It is overlain by the Serra Geral basalt, and is possibly interbedded with it in part.

One very large area of outcrop and several smaller ones are shown on plate 1. The main outcrop occupies a southward-trending band, 20 to 70 kilometers wide, that extends through the eastern part of Paraguay from the Río Apa to the Río Paraná. At the latitude of Caazapá the lower boundary of the belt trends abruptly westward and the belt is broader, covering most of the extreme southwestern part of eastern Paraguay. The distribution as mapped is based partly on Harrington's map, partly on sketch maps and descriptions by Carnier (1911c) and other earlier workers, and partly on observations, interpretations, and guesswork. The contact between the Triassic sandstone and the Serra Geral lava is believed to be one of the most accurate shown on the entire map (see p. 26 and pl. 1). The broad expanse of Triassic rocks shown in the southwestern corner of the country is almost pure guesswork, however, for nearly all of this area is marshland. Similarly, the northern half of the belt of outcrop is drawn as essentially conformable on the Independencia rocks; there are no maps or descriptions known to the author to help determine whether the Misiones beds there are conformable or whether they overlap the older beds as they do farther south.

A second fairly large area of outcrop lies in the area between Asunción and Ypacaraí, and extends as far south as Paraguarí (pl. 1). Exposures are poor in most of this area, and the soils are redder and thicker than in many parts of the country. Good outcrops of massive, thick-bedded, reddish-brown sandstone are known at Yaguarón, at Itapitapunta (a cliff on the Río Paraguay south of Asunción), in road cuts in and near Asunción itself, and at a few other places. Harrington describes a striking angular unconformity between the Misiones sandstone and the underlying Caacupé series. In a ravine almost midway between Itauguá and Ypacaraí, and about 200 meters north of the highway, he found the strike of the Misiones sandstone was almost due north and the dip 42° W. The actual contact is not exposed, but below the Misiones beds Harrington found typical Caacupé sandstone—light-colored, crossbedded, and strongly brecciated—that appeared to dip at 70° or higher angles toward the west.

A small inlier of sedimentary rocks along the Río Paraná near the colonies of Jesús and Trinidad (pl. 1) is referred to the Triassic with considerable hesitation. On the basis of several specimens of coal reported to have come from that area, Harrington (1950) mapped these rocks as above the Serra Geral lavas and as of possible Cretaceous age. Baker (1923) also mentions sedimentary rocks younger than the lava in the same area. Consideration of the structure, as well as observations by others, suggest that the rocks constitute a window of Triassic red beds as provisionally shown on plate 1. DeMersay (1860) and other writers describe the remarkable masonry churches and other early mission buildings as having been built of resistant fine-grained red sandstone that is abundant in the environs of Jesús and Trinidad. DeMersay also notes the presence of a white tough sandstone, suitable for whetstones, between the two missions and along the Argentine bank of the Río Paraná. These observations are substantiated by those of Robert M. Miller, who reported orally that the rocks in and near these colonies are largely red beds, capped by basalt on the higher ridges.

As described by Harrington (1950), and substantiated by the author's few direct observations, the Misiones sandstone is probably between 150 and 200 meters thick and is dark red, uniformly colored where fresh, but weathered to pink or gray in places. It is medium to coarse grained and made up almost entirely of quartz grains that are well rounded to spherical and have pitted or frosted surfaces. Generally the sand grains are poorly cemented by hematitic clay, but locally the rocks are silicified to form tough quartzite. Most of the beds are massive and thick, but here and there, as in the vicinity of San Juan Bautista, they are thin bedded or crossbedded. For example, at a point 9 kilometers west of San Juan Bautista and 1 kilometer north of the road, there are some small quarries that produce excellent red flagstone, almost quartzitic in character, from the lower beds of the Misiones sandstone (see fig. 51).

FIGURE 51.—Typical flagstone quarry, 3 kilometers west of San Juan Bautista. The rock is well-cemented coarse red sandstone of the Misiones series of Triassic age.

Occasional small pebbles of quartz and quartzite, ranging from well rounded to subelliptical, are scattered through some of the more massive beds. Though not abundant, there are some true conglomerate beds in a few places. At a point 3 kilometers west of San Juan Bautista, for example, a coarse conglomerate with rounded pebbles of quartzite and chert is exposed in road cuts.

Harrington describes a similar conglomerate, 1 meter thick, near San Juan Bautista, with a few pebbles as large as 15 centimeters in diameter, with fully 15 percent of the smaller pebbles of banded agate. He also describes the sandstone on the hill 7 kilometers east of Santa Rosa as containing abundant nodules of epigenetic agate. These nodules, as much as 20 centimeters in diameter, are very irregular in shape and show blue, light yellow and white in concentric bands. Their relation to the surrounding sandstone is such that they are certainly concretionary in nature and probably related to hydrothermal activity associated with the Serra Geral lavas.

Though clay or shale are not described in the literature as an important constituent of the Misiones section, there must be considerable quantities of such material, for a large part of the outcrop area between Carmen del Paraná and Yhú appears from the air to be underlain by red clay or shale. In the immediate vicinity of Yhú, moreover, workable deposits of white pottery clay and red clay suitable for brick manufacture, are well known (see fig. 52).

Because of its stratigraphic position between the Independencia series and the Serra Geral lavas, Harrington believes that the Misiones sandstone is of late Triassic age and is correlated directly with the Botucatú sandstone of southeastern Brazil.

TERTIARY AND QUATERNARY SYSTEMS

A very large part of eastern Paraguay is covered by alluvial deposits of clay, silt, and fine sand of Tertiary and Quaternary age. The deposits are probably as much as several hundred meters thick in places, as in the vicinity of Pilar in the extreme southwestern corner of eastern Paraguay where they are known to contain peat deposits, at least locally. Elsewhere their thickness probably ranges from 1 to 20 meters in most places. Virtually every swale in the country contains some alluvium but the larger deposits are, of course, along the broad, nearly level valleys of the major streams. There they are almost invariably marked by poor drainage conditions or by permanent or intermittent swamps. The boundaries of the alluvial materials

FIGURE 52.—White pottery clay interbedded with red shale and sandstone of the Misiones sandstone of Triassic age. Air view near Yhú.

shown on plate 1 are drawn almost entirely by connecting areas shown as "swamp" or "subject to flood" on existing base maps, particularly the U. S. Air Force preliminary charts.

A few fossil discoveries have been reported from the Tertiary deposits along or near the east bank of the Río Paraguay. Vellard (1934) says that many mammalian fossils, similar to those from the Gran Chaco that are noted on page 75, have been reported from the vicinity of Trinidad just northeast of Asunción, especially along the banks of Arroyo Teju-cuaré. None of these finds were seen by Vellard. He also says that many fragments of mammal bones have been found along Arroyo San Javahy, 6 kilometers west of Ypané, and 30 kilometers south of Asunción. Except for Trinidad, none of these features are shown by name on plate 1.

Mastodon andium, *Glyptodon*, *Toxodon*, *Macrauchenia*, and *Megatherium*, mammals of Tertiary age, were reported by A. de W. Bertoni (1939) as found in 1910 from "below" Asunción, quite possibly from the Arroyo San Javahy locality noted by Vellard.

A. de W. Bertoni (1939) also mentions the discovery of Tertiary invertebrate fossils in limy rocks at Villeta, 25 kilometers south of Asunción. He identified *Turritella*, probably *T. americana*, fragments of *Ostrea*, and a few remains of *nummulites*. He believes that these fossils record marine invasions during Oligocene and late Eocene times.

GRAN CHACO

GENERAL FEATURES

The Gran Chaco is a deep, elongate sedimentary (and probably structural) basin that lies between the Andes on the west and the much lower ranges along the Atlantic Ocean side of the continent.

The geology of the Gran Chaco, the part of Paraguay that lies west of the Río Paraguay, is even less well known than the eastern part. Except for a few comparatively small outcrops near its northern and eastern borders, the entire area is covered by unconsolidated alluvial materials. The only known facts about the subsurface character of these materials and the older beds that underlie them are those recorded by the logs of five deep drill holes, scattered through a very large area.

OUTCROPS OF CONSOLIDATED ROCKS

There are several large outcrops of sandstone in the extreme northern part of the Paraguayan Gran Chaco that are probably related to the Itacurubí series of Early Devonian age (pl. 1). There are also a few small outcrops of other rocks at various places along the

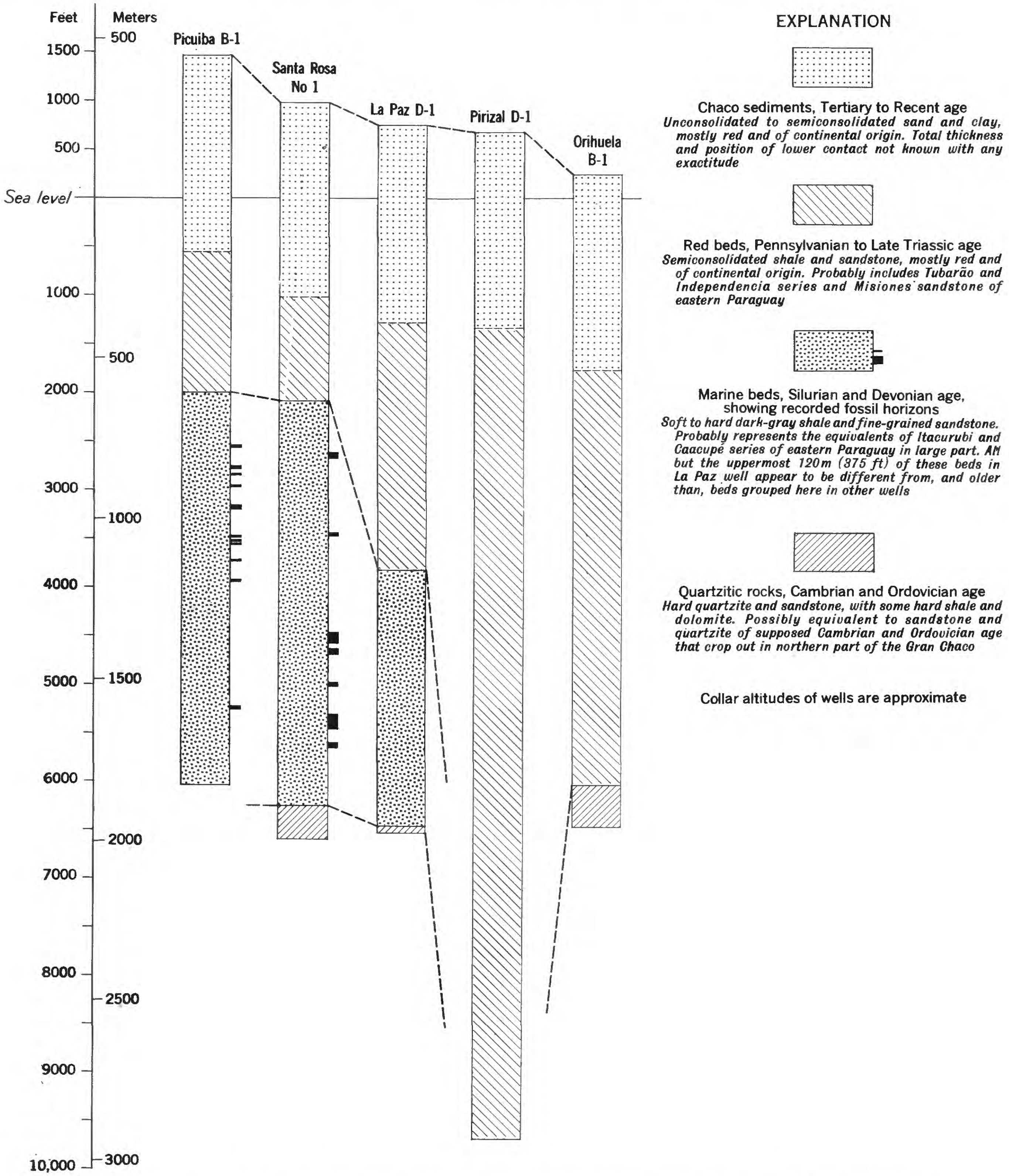

FIGURE 53.—Sketch showing the major rock units in exploratory wells drilled in the Paraguayan Gran Chaco. See plate 1 for location of wells.

west bank of the Río Paraguay. Some belong to the Precambrian basement complex that doubtless underlies the entire Gran Chaco basin; others belong to the Itapucumí series of probable Cambrian and Ordovician age. Those near Villa Hayes are reportedly of red sandstone and are mapped as belonging to the Misiones sandstone of Triassic age. The outcrop between Puerto Guaraní and Pôrto Murtinho is an extension of the supposedly late Tertiary syenitic body of the Pão d'Açúcar on the Brazilian side of the river.

There are several outcrops of sandstone and possibly of quartzite in the extreme northern part of the Gran Chaco, west of the Río Paraguay. None of them was seen by the author except in very distant air views and there are no known geologic maps that show them with any exactitude.

The largest outcrops make up Cerro Leon and Cerro Cristian (pl. 1). In addition to the several smaller bodies sketched on the map, there are a number of small hills on both sides of the Bolivian border that are reportedly made up of the same rock. Some of these hills have been used as triangulation points in boundary surveys.

In written communication to the author, Harrington reports that the rock of Cerro Leon is a medium-grained, reddish-brown ferruginous sandstone. From this rock the geologist for Union Oil Company collected a few well-preserved fossils that were identified by Dr. Harrington as *Leptocoelia flabellites*. This identification leaves no question as to the lower Devonian age of the rocks, which would appear to be about equivalent to the Itacurubí series; they are so mapped on plate 1.

The quartzite and sandstone beds of eastern Bolivia and extreme northern Paraguay are briefly described by F. Prieser (*in* Ahlfeld, 1946, p. 32–36). They are nearly horizontal in most places and form vast tablelands some distance north of the international border. Some of the hills in and near Paraguay may be erosional remnants of these tablelands, but Prieser thinks some of them may represent uplifted fault blocks, or horsts. In Bolivia, the sandstone beds are slightly ferruginous and yellow or orange to white. They are medium grained, crossbedded, and cemented with secondary quartz. Their total thickness is about 200 meters. Several thin conglomerate beds are known. The rocks are provisionally assigned to the Ordovician period by Prieser, but on admittedly thin evidence; Dr. Harrington believes that they, like the rocks of Cerro Leon in Paraguay, are probably of Early Devonian age.

The sandstone and quartzite deposits are overlain in Bolivia by shale and sandstone of possible Permian and Cretaceous age locally, but by the Chaco formation of Tertiary and Quaternary age in most places. In northern Paraguay these rocks are everywhere overlain or surrounded by the Chaco sediments.

SUBSURFACE ROCKS

WELL RECORDS

The well records that follow are translations and condensations of the logs furnished officially by the Union Oil Company to the Government of Paraguay at the close of the exploratory campaign for petroleum in the Gran Chaco; they were made available to the author by the Paraguayan Ministerio de Obras Publicas for use in this report. They have doubtless been changed in condensation, as well as in a series of translations from English to Spanish and again to English. Nevertheless, they contain some hitherto unavailable facts as to the subsurface character of the Gran Chaco. The logs are given below; the author's attempt at their interpretation and correlation is sketched in figure 53.

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive

[Translated and condensed by Ricardo Mazó U. from logs transmitted by the company to the Government of Paraguay.]

	Thickness (feet)	Depth (feet)
Picuiba well B–1:		
Sand, yellow, fine- to medium-grained, grades downward to darker sand with laminae of clay and pebbles cemented by red or gray clay	1, 008	1, 008
Sand and sandstone, dark-red, with clay-cemented angular to rounded pebbles of quartz and other materials	87	1, 095
Sand, light-green, uniform grain size with some pinkish-brown grains	125	1, 220
Sand and siliceous siltstone, bluish-gray, very fine grained, some incrustations of pyrite at 1,400 ft	300	1, 520
Quartz sand, fine- to medium-grained, with much pyrite	260	1, 780
Sand, pale-greenish-gray, medium-grained; contains pyrite and one 1-ft bed of well-stratified sandstone	487	2, 267
Sand, gray, medium-grained, with abundant small rounded pebbles	10	2, 277
Sand and sandstone, pale-greenish-gray, with some pebbles and siltstone	163	2, 440
Siltstone, olive-green, with streaks of sand and of pyrite	70	2, 510
Sand and sandstone, greenish-gray, fine- to medium-grained, with some pebbles and a little shale	363	2, 873
Sand, siltstone, and shale, brick-red, with pale-green nodules of shale	227	3, 100
Sandstone, fine-grained, silty, pale-red and green, with some grains of coarse sand	44	3, 144
Shale, lustrous, dark-purple-red, with partings of fine sandy shale	316	3, 460
Sand, gray, fine- to medium-grained	15	3, 475

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

	Thickness (feet)	Depth (feet)
Picuiba well B–1—Continued		
Siltstone, micaceous, pale bluish-gray to gray, with fine- to medium-grained pebbly sandstone, lime-cemented and micaceous; some pyrite	80	3, 555
Sandstone, very hard, crossbedded, light-gray, fine- to medium-grained; contains some pebbles, interbedded with micaceous shale and sandy siltstone; some pyrite	10	3, 565
Shale, hard, sandy, dark-brown, slightly micaceous	4	3, 569
Sandstone, gray, fine- to medium-grained, and brick-red siltstone with gray micaceous spots	11	3, 580
Sandstone, same as above, but containing hard marine shale, becoming more abundant downward	27	3, 607
Shale, hard, micaceous, gray, with laminae of firm very fine grained sandstone. Sandstone below 3,845 ft yields strong odor of petroleum and gives other positive tests for petroleum	248	3, 855
Shale, hard, dark-olive-gray, with a few laminae of hard, gray, fine-grained sandstone. No evidence of petroleum	135	3, 990
Shale, hard, dark, with dark stains of organic material; some gray very fine grained sandstone; yields slight odor of petroleum	30	4, 020
Shale, same as above but no odor of petroleum; highly micaceous in interval 4,060–4,070 ft	148	4, 168
Shale, same as above, with strong odor of petroleum in interval 4,168–4,175 ft and slight odor at interval 4,460–4,470 ft; contains one 2-in layer of limestone at 5,207 ft	1377	5, 545
Shale, dark-gray, hard, very little sandstone	630	6, 175
Sandstone, friable, gray, fine- to medium-grained; yields odor of petroleum	40	6, 215
Shale, micaceous, gray; with fine-grained silty light-gray sandstone	944	7, 159
Shale, soft micaceous dark-gray; slight odor of petroleum in one 1-ft zone near top	356	7, 515
Santa Rosa well 1:		
Clay, varicolored	810	810
Sand, gray, fine-grained, silty, with streaks of waxy-green and red clay near base	30	840
Clay, varicolored	20	860
Sand, gray, fine-grained	43	903
Clay, red and green	55	958
Sand, gray, fine-grained, with sandy clay between 974 and 980 ft	37	995
Clay, blue and red	10	1, 005
Sand, bluish-gray, firm; silty and very fine grained	10	1, 015
Clay, red and blue, firm, sandy; contains inclusions of hard limestone	10	1, 025

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

	Thickness (feet)	Depth (feet)
Santa Rosa well 1—Continued		
Sand, gray, friable, very fine grained and well-sorted	30	1, 055
Clay, blue and red, firm, sandy to very sandy	140	1, 195
Sand, gray, fine-grained, well-sorted and with well-rounded grains	10	1, 205
Clay, blue and red, mostly firm and sandy, with limy material in places	290	1, 495
Sand, blue-gray, firm, with a few small pebbles	10	1, 505
Clay, red and blue, mostly firm and sandy	120	1, 625
Sand, white, fine-grained, firm limy	30	1, 655
Clay, blue and red, sandy in lower 10 ft	20	1, 675
Conglomerate of well-rounded black and red pebbles in matrix of blue and red sandy clay	10	1, 685
Clay, blue and red; mostly firm and sandy; contains many small concretions of limy material and a few pebbles	645	2, 330
Sand, gray, fine-grained	50	2, 380
Clay, red and blue, mostly firm and sandy; contains limy concretions in places	175	2, 555
Sand, gray, fine-grained, soft	10	2, 565
Clay, blue and red; firm and very sandy, with medium- to coarse-grained sand; many limy concretions in places	30	2, 595
Sand, gray, coarse-grained	40	2, 635
Clay, blue and red; very firm, sandy	10	2, 645
Sand, bluish-gray, fine- to coarse-grained, friable to firm; clayey in many places; contains abundant small pebbles of various colors almost throughout; limy nodules abundant in places. One 1-ft core of hard sandy blue-green to purple limestone near bottom	90	2, 735
Limestone, firm, sandy, nodular, light-gray, with streaks of red; contains large angular red and light-gray pebbles of quartzite and smaller well-rounded pebbles; top 2 ft appears weathered; grades downward to massive white to light-gray limestone. Limestone contains 87.5 percent $CaCO_3$, 11.5 percent insoluble, and traces of MgO and Fe_2O_3	10	2, 745
Limestone, white to gray to red, hard, massive to nodular; sandy in places	10	2, 755
Sand, friable to firm, white to gray, fine- to medium-grained; mostly silty; contains nodules of hard massive limestone and a few large pebbles	80	2, 835
Clay, red, firm, sandy; alternates with gray firm coarse-grained sand; many pebbles of quartzite in lower 10 ft	130	2, 965
Sand, red and blue, firm, fine- to medium-grained; silty and clayey with small angular pebbles throughout	20	2, 985
Conglomerate, containing pebbles of sandstone, shale, and siliceous material in matrix of sandy clay, interbedded with reddish-white hard sandstone containing many small rounded pebbles	8	2, 993

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

	Thickness (feet)	*Depth (feet)*
Santa Rosa well 1—Continued		
Clay, red, yellow, and purple, firm	12	3, 005
Shale, red and lavender, laminated, micaceous, with irregular bedding planes	16	3, 021
Shale, light-greenish-gray, lavender, and yellow, soft to firm, with thin layers of red, harder shale. Pyrite clusters at 3,022 ft	12	3, 033
Shale, dark-gray, firm to hard; poorly laminated in large part but upper layers near top are well-laminated and locally crossbedded. One megascopic fossil at 3,058 ft (see p. 74 for list of fossils here and in lower part of well)	249	3, 282
Shale, hard, dark-gray, poorly to well-laminated, very micaceous; silty in part	1, 086	4, 368
Sandstone, hard, dark-gray, micaceous, very fine grained and poorly sorted	6	4, 374
Shale, hard, dark-gray, micaceous, poorly bedded to massive with a few thin layers of silt	98	4, 472
Recovered 2 ft of core: 1 ft of hard, very fine-grained sandstone and 1 ft of hard massive dark-gray shale	10	4, 482
Shale, hard, massive, dark-gray, interbedded in lower part with equal quantities of hard fine-grained silty sandstone	72	4, 554
Shale, hard, dark-gray, micaceous, interlayered with hard dark-gray micaceous siltstone	144	4, 698
Shale as above, interbedded with an equal quantity of hard gray very fine grained sandstone in layers as much as 1 in thick	10	4, 708
Sandstone, hard, gray, very fine grained and silty, with 10 to 20 percent of shale in thin layers	40	4, 748
Shale, hard, dark-gray, massive to well-bedded, with considerable quantities of light-gray micaceous crossbedded siltstone in upper half	639	5, 387
Shale as above, interbedded with hard, very fine grained silty and micaceous sandstone	18	5, 405
Shale, hard, dark-gray, micaceous; massive to poorly bedded, with silty and sandy material in places. Odorless gas bubbles from fresh core at 5,606 to 5,723 ft; no evidence of petroleum	500	5, 905
Sandstone, hard, gray, very fine grained, micaceous, crossbedded and silty, interbedded with equal quantity of hard gray micaceous shale. Sandstone shows gas in fresh cores but no evidence of petroleum	50	5, 955
Shale as above with fine-grained sandstone in lower few feet; gas shows when fresh	50	6, 005
Sandstone as above with a little shale; gas shows when fresh	10	6, 015
Shale, hard, dark-gray, micaceous, with a few thin layers of siltstone; and some clusters of pyrite crystals	1, 071	7, 086

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

	Thickness (feet)	*Depth (feet)*
Santa Rosa well 1—Continued		
Shale as above with a few layers as much as 0.4 ft thick of very hard massive gray limy and sandy "shell"	20	7, 106
Limestone, 0.2 ft, hard, massive, gray, and 2.3 ft of shale as above	14	7, 120
Shale, hard, dark-gray, micaceous, with a few thin layers of siltstone; much pyrite	37	7, 157
Shale, very hard, dense, gray, micaceous, and very sandy, with irregular layers of hard gray siltstone and sandstone	12	7, 169
Siltstone, very hard, gray, sandy, micaceous, crossbedded with irregular streaks of very hard dense shale, grading downward to shale with some siltstone	22	7, 191
Limestone 0.3 ft, hard, gray, massive; sandstone 0.4 ft; siltstone 0.2 ft; very hard, fine-grained and limy, micaceous, and crossbedded sandstone 1.5 ft; very hard micaceous siltstone 2.1 ft	5	7, 196
Sandstone, very hard, gray, silty, fine-grained, micaceous, with thin streaks of shale	10	7, 206
Shale, very hard, gray, sandy, and micaceous	7	7, 213
Sandstone, fine-grained, silty, and micaceous, approaching quartzite in hardness	20	7, 233
Shale, very hard, dark-gray, sandy, and micaceous, with irregular streaks of very hard fine- to medium-grained quartzitic sandstone, especially abundant in upper 25 ft	346	7, 579
La Paz well D–1:		
Silt, sandy, soft, reddish, and siltstone with some small pebbles	810	810
Silt and fine sand, green-blue; with red clay	80	890
Clay, red and greenish-blue	70	960
Sand, medium- to fine-grained, greenish-gray with some red clay	140	1, 100
Sand, fine to coarse, light-brown; contains fragments of limy material and some silt and clay	540	1, 640
Sand, white, quartz, clean	10	1, 650
Sand, white, quartz; mixed with red and greenish-blue sand	290	1, 940
Clay, dark red; with a little green-blue clay and some sand	240	2, 180
Silt, fine sandy, light-red, with white quartz sand; a little light-green clay	140	2, 320
Sand, fine, light-brown; some sandy blue clay	270	2, 590
Clay, dark-red; and sandy silt	450	3, 040
Clay, dark-red, sandy, with streaks of bluish-green clay	170	3, 210
Clay, dark-red; with sandy silt and some white lime	160	3, 370
Silt and clay with fine sand	800	4, 170
Silt and clay with gray lime	30	4, 200

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

	Thickness (feet)	Depth (feet)
La Paz well D–1—Continued		
Sand, silty, red and green; with some lime	381	4, 581
Shale, black to gray, hard, unstratified; with abundant mica	275	4, 856
Shale as above, with nodules of pyrite and calcite-filled fractures	144	5, 000
Sandstone, fine, hard, gray, micaceous; with some shale	343	5, 343
Shale, hard, and sandstone, both micaceous	682	6, 025
Shale, dark-gray to black, medium-hard, laminated, micaceous; some fine sandstone in lower part	1, 133	7, 158
Sandstone, coarse; interbedded with shale; some fragments of black dolomite	10	7, 168
Shale, dolomite, and fine sandstone with pyrite	29	7, 197
Shale, dark-gray, interbedded with light-gray sandstone	55	7, 252
(Hole ended in hard quartzite.)		
Pirizal well D–1:		
Clay, pale-red; with a few layers of fine sand; veinlets and crystals of gypsum locally	1, 710	1, 710
Clay, same as above, with green clayey siltstone and some gray sandy mudstone	1, 400	3, 110
Siltstone, red; with about 30 percent green, fine sandy siltstone	248	3, 358
Siltstone, green, red, and brown; some amorphous gypsum	922	4, 280
Siltstone, greenish-blue; alternating with brown siltstone that contains thin sandy layers	200	4, 480
Siltstone, clayey, red and green; with partings of sand	310	4, 790
Quartz sand, gray, fine- to medium-grained	30	4, 820
Siltstone, sandy, red; with a few green streaks and fragments of anhydrite	640	5, 460
Sandstone, dark-gray, fine-grained; upper part is hard and crossbedded, lower part very friable	5	5, 465
Sand, dark-gray, silty	10	5, 475
Shale, pebbly, conglomeratic sandstone and silty gray sand; small particles of carbonaceous material	10	5, 485
Sand, fine-grained, chestnut-brown	20	5, 505
Sand, friable, fine- to medium-grained, gray; with carbonaceous material along bedding planes	30	5, 535
Siltstone, sand and gypsum, gray, green, and dark-red	30	5, 565
Sandstone, dark-red, fine-grained, silty; contains some gypsum crystals; friable in part	20	5, 585
Siltstone, red; with sandy streaks	10	5, 595
Sand, dark-red, fine-grained; with silty streaks	29	5, 624
Siltstone and sandstone, dark-red	43	5, 667

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

	Thickness (feet)	Depth (feet)
Pirizal well D–1—Continued		
Siltstone, sandy, red to chestnut-brown; with intervals of fine red sand at 5,750, 5,770, and 5,800–5,840 ft; clean medium- to coarse-grained quartz sand at 5,710–5,740 and 5,870–5,910 ft	271	5, 938
Sand and siltstone, fine-grained, silty red	72	6, 010
Siltstone, sandy, red to chestnut-brown; with fine-grained red sand at 6,050–6,090 ft and 6,160–6,170 ft and clean medium- to coarse-grained quartz sand at 6,040–6,050, 6,100–6,120 and 6,180–6,220 ft	270	6, 280
Sandstone, fine-grained, silty, red; with red siltstone at 6,300–6,310, 6,350–6,370 and 6,470–6,490 ft and abundant quartz sand at 6,370–6,380 and 6,400–6,410 ft	260	6, 540
Siltstone, red to chestnut-brown; with fine-grained red sand in lower 20 ft	94	6, 634
Conglomerate of fine to coarse sand and well-rounded quartz pebbles	30	6, 664
Siltstone, sandy, red	20	6, 684
No recovery	16	6, 700
Siltstone, sandy, red; with thin layers of fine sand	500	7, 200
Siltstone, red and chestnut-brown; with a few fragments of anhydrite	1, 086	8, 286
Siltstone, sandy, pale, red	20	8, 306
Sandstone and siltstone, fine-grained, red to chestnut-brown; with some fragments of anhydrite	773	9, 079
Shale, hard, varicolored	21	9, 100
Siltstone, red to dark-red; with some sand	946	10, 046
Siltstone and hard shale, red to chestnut-brown; with some gray-green nodules	285	10, 331
Orihuela well B–1:		
Clay, yellowish- to greenish-blue; with fine- to medium-grained sand	1, 100	1, 100
Quartz sand, medium-grained; with some yellow clay	150	1, 250
Sand, muddy, fine- to medium-grained, yellow to dark-red	80	1, 330
Mud and clay, red to yellow; with a little quartz sand	1, 170	2, 500
Mud, sandy, soft, light-red	20	2, 520
Mud and clay, dark-red; with quartz sand	750	3, 270
Mud and clay, dark-red; with fine- to medium-grained quartz sand and streaks of white bentonite or ash	60	3, 330
Mud and clay; same as above, with layers of white calcareous sandstone and one 2-in layer of sandy conglomerate	190	3, 520
Mud, sandy, dark-red; with laminae of very soft dark-red clay	10	3, 530
Mud; same as above, with one 4-in layer of soft pebbly sand	20	3, 550
Sand, light red, muddy, fine-grained	30	3, 580
Sandstone, soft, friable, fine- to medium-grained reddish-gray, with pebbles	300	3, 880

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

Orihuela well B-1—Continued	Thickness (feet)	Depth (feet)
Sand, muddy, 1.5 ft, red, fine- to medium-grained; 1.5 ft red siltstone and shale, with some quartz pebbles	10	3, 890
Sand, fine-grained, silty, and sandy siltstone	10	3, 900
Sand, soft, micaceous, brilliant red, fine-grained	40	3, 940
Sand, soft, friable, red, fine-grained	110	4, 050
Shale, red	40	4, 090
Siltstone, sandy, light-red; fairly hard at top, grading downward to softer and sandier material	70	4, 160
Sand, soft, friable, silty, brilliant-red	60	4, 220
Siltstone, sandy, soft fine sand, and thin layers of clay, all bright red; a little hard limy sandstone 10 to 20 ft above base	240	4, 460
Sand, silty, bright-red, fine- to medium-grained	770	5, 230
Sandstone, hard, fine-grained, light-red	10	5, 240
Sand, soft, friable, silty, bright-red, micaceous near base	50	5, 290
Siltstone, sandy, hard, red; with black stains of an unknown mineral	10	5, 300
Sand, silty, bright-red	150	5, 450
Sandstone, hard, fine-grained, light-red	10	5, 460
Sand, silty, soft, red; with laminae of clay	50	5, 510
Siltstone, sandy, bright-red; with laminae of clay	10	5, 520
Sand, soft, friable, silty, fine-grained; with a few laminae of clay	170	5, 690
Shale, dark-red	10	5, 700
Sandstone, fine- to medium-grained, reddish-gray	10	5, 710
Sand, soft, friable, silty, fine-grained, light-red	46	5, 756
Siltstone and shale, bright-red	94	5, 850
Sand, soft, friable, red, fine- to medium-grained	180	6, 030
Siltstone, sandy, bright-red; with abundant anhydrite and pebbles of quartz	150	6, 180
Sand, soft, silty, fine-grained, red; with angular pebbles of quartz	60	6, 240
Siltstone, sandy; with laminae of red shale and abundant pebbles of quartz	46	6, 286

Records of wells drilled by Union Oil Company in the Gran Chaco, western Paraguay, 1944 to 1949, inclusive—Continued

Orihuela well B-1—Continued	Thickness (feet)	Depth (feet)
Quartz, white, and quartzitic sandstone, with fragments of red siltstone and of pale-green shale	255	6, 541
Sandstone, quartzitic, fine-grained; with stains of iron oxide	174	6, 715

FOSSILS

The following record of fossils recovered from the Picuiba well was given to the writer by Dr. Horacio J. Harrington and is published with his permission.

Fossils from Picuiba well

	Depths	
	Meters	Feet
Top of Devonian	1, 187	3, 893
Plant remains, indet	1, 207	3, 959
Calamitean stems and wormburrows	1, 273–1, 274	4, 175–4, 179
Cyclostigma sp	1, 290	4, 231
Palaeoneilo sp	1, 333	4, 372
Crinoid stems (very similar to those described by Steinmann from the lower Devonian of Bolivia)	1, 394–1, 398	4, 572–4, 585
Wormburrows and very small Cruziana-like trails	1, 490	4, 887
Brachiopod indet. and plant remains indet	1, 502	4, 926
Crinoid stems, like those of level 1,394	1, 509	4, 949
Hadrorhachus australis (Clarke)	1, 561	5, 120
Crinoid stems, like those of level 1,394	1, 628	5, 340
Tentaculites crotalinus Salter and *Australostrophia mesembria* (Clarke)	2, 020–2, 022	6, 625–6, 632

This record indicates that the Lower Devonian beds extend downward at least as deep as the 2,022-meter level and Harrington writes that he "would not be surprised to learn that the lowermost 500 meters of the well are also lower Devonian." The following table shows that there is also a very thick section of Lower Devonian beds in the Santa Rosa well. This record is taken from a report made to the Union Oil Company by Harrington and made available to the present author by the Paraguayan government.

Distribution of species of fossils in Union Oil Company's Santa Rosa No. 1 well

[Determinations by Dr. Horacio J. Harrington, Universidad de Buenos Aires, who states in a report to Union Oil Company that all fossils are marine and of Early Devonian age]

Species	Depth in feet																
	3,055–3,065	3,600–3,602	3,615–3,625	4,423–4,433	5,472–5,482	5,492–5,502	5,522–5,530	5,530–5,540	5,625	5,960	6,290	6,330	6,391–6,401	6,688–6,698	6,698–6,707	6,698–6,707	6,698–6,707
1. Ctenocrinus? sp															×		×
2. ?*Anoplotheca silvetti*																	×
3. *Australospirifer* cfr. *antarcticus*														×	×		×
4. *Acrospirifer* (?) sp. nov		×	×														
5. *Australostrophia arcei*														×	?	×	?
6. *A. mesembria*						×				×							
7. *Chonetes falklandicus*		×	×														
8. *Ch. skottsbergi*		×	×														
9. *Lyorhynchus* (?) sp														×			
10. *Derbyina whitiorum*		×															
11. *Leptaena* sp											×	?		×		×	
12. *Leptocoelia flabellities*				?									×		×	?	×
13. *Lingula lepta*					×			×									
14. *Rensselaeria relicta*														×		×	×
15. *Schellwienella agassizi*							?		×					×		×	×
16. *Spirifer* sp														×		×	
17. *Tentaculites crotalinus*																	×
18. *T. jaculus*	×																
19. Trilobite?													×				

INTERPRETATION OF WELL RECORDS

The following broad generalizations can be interpreted from the facts available in the well records above and from the few surface outcrops.

The entire Gran Chaco basin is doubtless underlain by Precambrian basement rocks, but their surface is probably everywhere at considerable depth except in the extreme northeastern part of the Gran Chaco; they are very deeply buried—more than 3,289 meters (10,331 feet)—in the southwestern part, near the Pirizal well.

The Itapucumí series of limestone and dolomite of Cambrian and Ordovician age probably overlies the Precambrian rocks directly in places; how far it extends west of the outcrops along the Río Paraguay is unknown, but it was not recognized in the drill holes nor does it reappear at the surface in the Andean foothills west of the Gran Chaco (Ahlfeld, 1946, fig. 23). On the other hand, quartzitic rocks, not known in eastern Paraguay, extend beneath the younger rocks at least as far south as the Santa Rosa, La Paz, and Orihuela wells.

A thick series of dark-colored marine shale and sandstone beds rests directly on the older quartzitic rocks. These beds, which are more than 1,200 meters (4,000 feet) thick in the Picuiba and Santa Rosa wells, thin to less than 800 meters (2,600 feet) in the La Paz well only 70 kilometers east of the Santa Rosa well; most of the rocks there appear to be older than those in the Picuiba and Santa Rosa wells. They appear to be entirely missing in the Orihuela well and, if there at all, are below the 3,289 meters (10,331 feet) bottom of the Pirizal well.

There can be little doubt that these marine beds are at least in part the equivalents of the Caacupé and Itacurubí series of eastern Paraguay and of the Los Monos and Iquirí groups of beds assigned to the Devonian in eastern Bolivia (Ahlfeld, 1946, p. 58–62, fig. 23), where they reappear at the surface in a series of anticlines that parallel the front of the Andes. The fossils identified by Harrington in cores from the Santa Rosa well are evidence for this correlation. It should be noted, however, that according to Union Oil Company reports to the Paraguayan Government, the Devonian beds in the La Paz well are only about 120 meters (400 feet) thick; these are underlain by a sequence of Paleozoic beds that were not in the Santa Rosa well and with very hard quartzite at the base.

The older Paleozoic beds are covered by a great thickness of unconsolidated and semiconsolidated beds of sand, clay, sandstone, shale, and conglomerate. They are largely red and, so far as can be told, represent all the Gondwana or Santa Catarina beds (except for the Serra Geral lavas) of eastern Paraguay, as well as a Tertiary to Recent series that is not known in the eastern half of the country. The total thickness of this accumulation is not known, but it is certainly more than 3,000 meters (10,000 feet), for in one well, the Pirizal, these beds were not penetrated at a depth of 10,331 feet. There is nothing in the well logs to show the break between the Gondwana beds and the younger Chaco sediments, although, on the basis of recorded changes of color and degree of consolidation, it appears likely that the Chaco beds are about 650 meters (2,000 feet) thick, underlain by beds that tend to be harder and redder than those above.

CHACO SEDIMENTS

The outcrops of igneous and sedimentary rocks described above make up only a tiny fraction of the surface of the Gran Chaco. The remainder of this vast plain, which rises gently from a minimum altitude of

55 meters along the Río Paraguay to a maximum of only about 400 meters along the western border of the country, is covered by unconsolidated alluvial materials here called the Chaco sediments. These materials, called the Chaquena formation in Bolivia (Ahlfeld, 1946, p. 52, and Oliveira and Leonardos, 1943, p. 780) and the Pampa formation in Argentina (Stappenbeck, 1926, p. 68–170) are little known even at the surface.

The Chaco sediments, that is, those above the Gondwana or Santa Catarina sediments, are probably similar to those of northern Argentina, described in considerable detail by Stappenbeck (1926, p. 68–170). There, they range from Miocene to Recent, are largely unconsolidated clay with some sand, and include both marine and continental deposits. The amount of material of eolian origin included in these beds is unknown. Sand dunes, some stabilized and some active, are known at the surface in the extreme northwestern corner of Paraguay. Kanter (1936) failed to confirm the presence of true loess in his travels through the Paraguayan Gran Chaco, but as Ahlfeld (1946, p. 53) points out it is possible that some of the material at the surface, as well as in the deeper beds, is loess, deposited by the strong winds that blow northward from the Argentine pampas at present and probably also in the past.

Four known occurrences of fossil mammals are reported from the Gran Chaco by Vellard (1934). One of these is near Reventon, on the lower Río Pilcomayo; the other three are along the upper Pilcomayo near the forts of General Bruguez, General Delgado, and Salto Palmares. Not all of these localities are shown on plate 1. Vellard also notes unconfirmed reports of similar fossils on the banks of the Río Negro.

None of these localities have been explored; the finds have been made by soldiers assigned to the military posts. The fossils are said to be exposed in the beds of rivers or along their banks; new exposures are made at frequent intervals by the constantly changing stream channels. Vellard says that bones from Reventon have been identified by A. de W. Bertoni as those of *Glyptodon clavipes*, *Mastodon andium*, and *Machranchenia boliviensis*.

STRUCTURAL GEOLOGY

GENERAL RELATIONS

Paraguay occupies parts of two great sedimentary and structural basins—the Paraná basin of southern Brazil to the east and the Gran Chaco basin of Paraguay, Bolivia, and Argentina to the west. In its gross aspects, the geologic structure amounts to a deep syncline beneath the Gran Chaco whose western limb rises gradually toward the Andes Mountains and whose eastern limb rises to a gentle northward-trending anticline that is parallel to and only a short distance east of the Río Paraguay. The easterly limb of this anticline dips at very low angles eastward toward the Brazilian center of the Paraná basin.

The major structural features shown on the geological cross sections that accompany plate 1 are based more on the distribution of the major rock units and their relationship to the topography than on detailed observations or other knowledge of structural features themselves. In many places there are, however, bits of detailed evidence as to local geologic structures. They are all shown on the map and many of them are mentioned in the text. Thus, the local attitudes of both metamorphic and sedimentary rocks, as observed by the author or recorded in the literature, are known at many widely scattered localities throughout eastern Paraguay. A few faults are also shown on the map, though most of them are mapped on very scanty evidence. There is good evidence of minor thrust faulting in the Itacurubí beds south of Eusebio Ayala (see fig. 48); the importance of thrusting in the structural history of the region is quite unknown, however.

ANTICLINE BETWEEN RÍO APA AND SAN JUAN BAUTISTA

The anticlinal flexure that separates the two basins exposes the older Precambrian and Early Paleozoic rocks from the Río Apa as far south as San Juan Bautista, where it appears to die out or to plunge southward, for the southward-dipping Triassic rocks cover the older rocks south of that point. The sedimentary rocks and the overlying Serra Geral lavas on the east limb of the anticline dip generally at very low angles toward the east, but there are reversals of dip locally. Most of the rock units probably also thicken eastward for although there is little known local evidence of this, the entire sedimentary-volcanic section is thicker in southeastern Brazil than it is in eastern Paraguay. Available data indicate that the western limb of the anticline is much steeper than the eastern one, for the beds that occur at the surface along the anticlinal axis are more than 3,000 meters (10,000 feet) deep beneath the central part of the Gran Chaco basin. It is entirely possible that this drop, or part of it, is due to a major fault or faults that parallel the general course of the Río Paraguay, evidence being masked by the Chaco alluvial sediments. It seems more probable that folding has played a more important role than faulting in development of the structure but this statement is based on little evidence. Strong faults with downthrow to the west are known along the Rio Paraná in Argentina, south of Paraguay (Harrington, oral communication). Somewhat similar fault systems are also known north of Paraguay in the general vicinity of Corumbá, Brazil (Almeida, 1945, and Dorr, 1945). Possibly these fault systems also continue in Paraguay, roughly parallel to the Río Paraguay. If so, they must be somewhat west of the present stream and buried by the Chaco alluvial sediments. Only further subsurface data, geologic or geophysical, will solve the problem.

There is some evidence that the anticline has been in existence, though intermittently, since early in Paleozoic time. This would account for the sandy nature, as well as the relative thinness of most of the Paleozoic and Mesozoic sedimentary units along its axis as compared with their apparent correlatives in the Gran Chaco basin and as they are described in the Paraná basin of Brazil and in the Andes of Bolivia (Oliveira and Leonardos, 1943, and Ahlfeld, 1946).

The Río Apa and San Juan Bautista anticline is doubtless far more complex than described in the last paragraphs, as indicated by the several faults and the diversity in attitudes of the Precambrian and Itapucumí rocks near the Río Apa and by the absence of older rocks at the surface between Asunción and Concepción, suggesting a sag in the structure in that area. The complexity is also indicated by the interesting but incompletely understood structural and topographic feature called the Ypacaraí depression. As described by Harrington and shown on his map it is a rectilinear valley, 65 kilometers long and 6 to 8 kilometers wide, that trends northwestward from the vicinity of Paraguarí past the northern end of Lago Ypacaraí. It is characterized by a nearly flat floor, covered almost everywhere by swampy alluvium or by the shallow waters of the lake. It is flanked on both sides by relatively high abrupt hills whose faces suggest fault scarps or faultline scarps in many places.

Harrington believes that the depression is a long, very narrow graben bounded along its sides by major longitudinal faults and probably by a strong transverse fault at its southeast end. As evidence of the graben structure, Harrington cites the presence, 2 kilometers northeast of Paraguarí, of varved clay and of a granite erratic boulder—seemingly belonging to the Tubarão beds of Pennsylvanian age but in juxtaposition to beds of the Caacupé series of Silurian age. He also gives evidence of strong faulting along the western side of the depression, marked by fault breccia, locally as much as 300 meters wide, at a number of places from Paraguarí to some distance northwest of the Vargas Peña clay pit near Itauguá. In addition, he saw strong fractures along the eastern side of the depression.

In short, Harrington believes that the Ypacaraí depression represents a downfaulted block that has dropped the rocks several hundred meters, thus bringing the Tubarão beds within it down to the level of the lower Caacupé beds along its sides. There is little evidence of a transverse fault to close the southern end of the depression but there may be one. As mentioned by Harrington (1950, p. 51) such a fault, extending from Caballero northwestward past Paraguarí toward the Río Paraguay near Villeta, would explain the abrupt disappearance of the Misiones sandstone south of a line between Villeta and Yaguarón.

GRAN CHACO BASIN

Studies of the outcropping rocks of eastern Paraguay and of the records of the deep exploratory wells in the Gran Chaco indicate the presence of a very deep basin that centers in southeastern Paraguay, not far north of the Pirizal well. From this center the rocks rise northward toward the outcrops of Devonian sandstone and quartzite near the northern edge of the country. They also rise eastward, for some of the same rocks, or their close correlatives, appear at the surface along the Rio Paraguay and east thereof. Within a few tens of kilometers west of the Paraguayan border, in Bolivia, the rocks rise in a series of anticlines, some of them oil producing, along the eastern flank of the Andes.

Available evidence is far too scanty to determine the age of the Gran Chaco basin or how much of it is due to folding and how much to erosion and subsequent filling. Nor are there any available facts as to the presence or absence of older structures within the Paleozoic beds of the basin as distinct from the broad downfold indicated on section *A–A′*, plate 1, which, as drawn, involves the Mesozoic beds as well as the Paleozoic ones. It seems likely that the major folding took place in two stages—once after the Devonian marine sediments had been laid down but before the red beds of Pennsylvanian through Triassic age were formed, and once during the Tertiary. The latter folding, associated with the major uplift of the Andes, involved the continental red beds as well as the older rocks.

GEOLOGIC HISTORY

GENERALIZED ACCOUNT

With the exception of the paragraphs below on the Gran Chaco plains and on the Alto Paraná valley, most of the following summary of the geologic history of Paraguay is generalized from that given by Harrington (1950). During Precambrian time a series of clastic sediments of unknown thickness was folded and metamorphosed before being invaded by granite and other acid rocks. Most of the acidic rocks were deep-seated intrusives, but at some time during this period there were extensive surface flows and near-surface intrusions of porphyry. Between the formation of the granitic rocks and Late Cambrian or Ordovician time there must have been strong uplift and erosion followed by subsidence, permitting deposition of the Itapucumí limestone beds under marine conditions, on an erosional plane carved on the Precambrian rocks.

In late Ordovician time there was widespread uplift and regression of the sea, followed by an erosion period that permited removal of the limestone, and probably the quartzite, in southern Paraguay and quite possibly in parts of the area beneath the Gran Chaco. In Early Silurian time there was a general depression again, resulting in marine invasion of the Paraná basin and deposition of the Caacupé sediments. Whether the Gran Chaco basin was connected with the Paraná basin at that time is not known, but marine sediments that appear to be equivalent to the Caacupé series are known there. Quite possibly the two basins were only partly connected, with shoreline conditions, or at least shallower waters, between them in most places. Toward the close of the Silurian there was renewed uplift and erosion, followed in Early Devonian time by a new invasion by the sea, this time probably initiated in the Andean geosyncline so that deposition of the Itacurubí series proceded from west to east, or from the Gran Chaco toward the Paraná basin.

Middle Devonian time essentially marked the last of marine conditions in Paraguay. From that time to Late Pennsylvanian or Permian time there was apparently a period of extensive erosion and near-peneplanation. A glacial period followed, during which the tillites, varved clays, and other sediments of the Tubarão series were laid down over most of eastern Paraguay, possibly over the Gran Chaco as well. The glaciation was followed by renewed uplift and erosion until some time in the Permian, when the Independencia series was laid down under continental conditions. This period of deposition was again followed by erosion that led to complete removal of all the sedimentary rocks in places, notably in southern Paraguay. During Late Triassic time the Misiones series of red beds was laid down on the new erosion surface. The new red beds were soon covered by outpourings of Serra Geral basaltic lavas fed by fissures that centered in the Paraná basin. The lavas did not extend much farther west than is indicated by their present outcrop pattern. The lava flows were accompanied or closely followed by small intrusions of diabasic rocks in many places. At some time or times, from Late Triassic to late Tertiary, there were intrusions and volcanic eruptions of alkalic rocks. Some, like the caldera at Acahay and its nearby volanic cones still retain most of their original form, hence would seem to be very young, but other bodies of alkalic rock, such at that at Mbocayaty, are of quite indeterminate age.

The sparse evidence at hand suggests that there were no major periods of strong faulting or folding during the entire time from the close of the Precambrian until the Triassic. Instead, the entire region that is now Paraguay seems to have been the scene of a succession of gentle risings and lowerings of the crust, each marked respectively by periods of erosion and marine or continental deposition. The enormous thickness of continental red beds in the central Gran Chaco, however, strongly suggests that a major downwarp, perhaps accompanied by faulting, began at some time after the close of the Devonian. It probably reached its maximum during the Triassic, but may well have continued into the Tertiary, when it reacted to the major uplift of the Andes Mountains by renewed downwarping.

Except for the scattered volcanic rocks, and the swampy alluvium in many places, little or nothing is known of the geologic history of eastern Paraguay from the beginning of the Cretaceous to the present. The present upland topography is carved by subaerial weathering and erosion on rocks of Jurassic or older ages; the lowlands are largely filled, or at least thinly covered, by fine debris washed from the uplands or deposited by overflows of the Río Paraguay. The fact that Jurassic and younger sedimentary rocks are known in nearby Brazil suggests that similar rocks may have been deposited in eastern Paraguay; if so, they have since been removed completely.

In discussing the valley of the Alto Paraná, and particularly the Salto del Guairá and other waterfalls, Baker (1923) indicates convincingly that the Serra Geral lavas have been exposed at the surface ever since they formed in Late Triassic or Jurassic time. He feels that the upland surface of the Paraná basin, incised by the narrow gorges of the Río Paraná and its tributaries, represents one of the "oldest known youthful topographies in the world" and ascribes the cataracts to headward erosion along the axis of the synclinal basin which was followed by the Río Alto Paraná. Washburne (1930, p. 117–122), however, believes the valley of the Río Alto Paraná to be very late Pleistocene or, more probably, Recent in age. The narrow gorges in the Serra Geral lavas he ascribes to simultaneous erosion along great lengths by constricted rapids rushing down dip. The cataracts he believes to be due to downfaulting of the lavas toward the downstream side or to abrupt upstream dips of the flows.

GRAN CHACO PLAINS

The Gran Chaco, once a structural and sedimentary basin, is now an aggrading alluvial plain that is being built up with fine debris from the Andes to the west, distributed by the many meandering streams that wander across it toward the Río Paraguay. How long or how continuously the alluviation has been going on is unknown. It probably began at some time in the late Tertiary; certainly it is continuing today. The full answer must await further detailed studies of the Gran Chaco alluvial sediments themselves and of the geomorphologic history of the eastern Andes.

To the author's knowledge, Johnston (1876, p. 499) was the first to suggest that the Río Paraguay is in process of being shifted toward the east as a result of the uplift of the Andes. There is considerable evidence to support his belief that the river once flowed some distance west of its present course and it is being pushed eastward by the growing alluvial plains of the Gran Chaco. This evidence lies chiefly in the relations of the river to the outcrops of Itapucumí limestone from the Río Apa southward to San Salvador. On the east bank of the river the limestone forms almost continuous cliffs, 3 to 30 meters high, along this entire stretch; in addition there are a number of small but significant hills made up of Itapucumí limestone along the Gran Chaco side of the river from near Puerto Casado northward (pl. 1). As seen in the field in the vicinity of Vallemí, as well as by aerial observation and study of aerial photographs farther south, the river follows almost exactly the curves in the strike of the Itapucumí beds for the entire distance. The limestone cliffs along the river are almost everywhere steep; their surfaces are rough and pitted (see fig. 43).

A few of the stronger joints in the rock are marked by narrow, steep to vertical-walled ravines, most of them choked by large joint blocks that have slid into them. Most of the steeply dipping joints, however, are tight and almost unnoticeable on upper parts of the cliff faces. Yet within a few tens of centimeters of the river level many of these joints have been widened downward by solution into open caves, shaped like inverted V's. This feature was also described and sketched by Carnier (1911c).

In addition to the small tent-shaped caves along joints there is a striking series of longitudinal notchlike caves, that extend back beneath the cliffs from 60 centimeters to as much as 15 meters. As seen in April 1952, when the river was at a fairly high stage, these notches occurred at intervals from the water surface to a level about 5 meters above it; all were parallel to the water surface. The upper limit marks the highest river level in recent history. The solution notches are continuous across different beds, though they tend to cut deeper into the purer limestone beds than they do in the dolomitic ones.

The relationship of the river to the general structure of the rocks, as well as to the solution features, seems to mean that the river is pushing against the limestone outcrops laterally, rather than that it has cut its way down through them in more orthodox fashion. Had it cut downward, the limestone, which is extremely soluble in relatively lime-free, carbon dioxide-rich water such as that of this tropical stream, should have been dissolved almost completely. Outcrops, had they survived at all, should have been low and rounded, and joints should have been widened into broad valleys. It seems more reasonable to suppose that until comparatively recently the Río Paraguay flowed across the alluvium of the Gran Chaco, west of its present course, and that the Itapucumí rocks were subject only to subaerial erosion. Then, as the alluvium encroached eastward, it pushed the river sidewise against the higher lands of what is now eastern Paraguay, leaving "islands" of limestone protruding through the alluvium farther west, and allowing the river to begin to gnaw away at the main outcrops.

The only other explanation that occurs to the author is that the Gran Chaco plains were once higher and more extensive than they are at present and that the Gran Chaco basin was then dropped relative to the rocks of eastern Paraguay. This would, it is true, expose the limestone suddenly to solution by the river, but it fails to explain the outcrops of limestone on the Gran Chaco side of the river—nor does it account for the sinuous curves of the river that conform to the structure of the limestone.

MINERAL RESOURCES

SUMMARY

Paraguay possesses large quantities of certain nonmetallic mineral resources, notably clays suitable for brick, tile, and pottery; limestone and other raw materials for portland cement and for lime; common and ornamental building stones; glass sand; talc; and mineral pigments. Supplies of all these materials appear to be more than sufficient to meet all conceivable domestic requirements.

Except for iron ore, of which there are many small but rich deposits, the country appears to be very poorly endowed in most other mineral resources, metallic and nonmetallic. It has a little manganese, copper, mica, and beryl, but unless larger and richer deposits are found in the future than have been in the past, none of them seem to offer much promise. There is some slight chance that rumors of the existence of gold, tin, tungsten, lead and mercury, and gem stones may yet be substantiated by actual discoveries or rediscoveries, but the possibility of finding large or rich deposits of any of them is rather remote. There are, however, good geologic reasons for hoping that worthwhile deposits of salt, gypsum, and bauxite may yet be uncovered.

Even if rich mineral resources were to be discovered, the general lack of fuels and power would preclude the development of manufacturing industries on a large scale. Aside from wood—and water power that is both remote and totally undeveloped—the only known source of fuel or energy in the country lies in the peat deposits in the vicinity of Pilar. There is a fair chance that petroleum resources may exist beneath the Gran Chaco, but if so, their discovery and development will require the investment of many million dollars in the search for them.

Available facts on all the known and reported mineral resources are given in the following paragraphs; the section on "Future of the mineral industry" contains suggestions for making the most of the resources that the country is known to possess and for searching for others.

BARITE

A vein or veins of barite reportedly exists at or near Fuerte Olimpo, on the upper part of the Río Paraguay. The deposit is probably in one of the bodies of igneous rock ("porphyry") that are shown on most maps just south of the fort (pl. 1). It was reportedly examined by the Union Oil Company as a possible source of material for heavy drilling mud, but was not developed by them. Some studies have also been made by other groups, but high costs of transportation, tariff difficulties, and other economic factors have discouraged any active exploration.

BAUXITE

Bauxite, the ore of aluminum, is reported from San Juan Nepomuceno, Altos, Piribebuy, and Paraguarí, according to notes in the files of the Departamento de Geología, Ministerio de Obras Públicas. No bauxite was seen, but in view of the deep weathering and laterization of most of the rocks in eastern Paraguay, deposits of bauxite or of high-alumina clay are to be expected. The alkalic rocks, such as the shonkinite at Mbocayaty and the phonolite and nepheline syenite elsewhere, are of special interest in this regard. Weathering and laterization of similar rocks in Brazil and in other parts of the world have yielded large deposits of bauxite of commercial grade. The author knows of no places in Paraguay where these alkalic rocks are weathered to laterite, but it would be surprising if no such weathered zones exist. All the bodies of alkalic rocks shown on plate 1 are potential sources. Because of the lack of fuel and power locally, only large deposits that could form the basis of an export industry would be of interest. A determined search for such deposits appears to be worthwhile.

BERYL

Beryl is reported by Boettner (1947) in pegmatite dikes near Caracol, not far from the Río Apa. It is associated with mica and quartz. Occasional crystals of beryl are also reported by others from various parts of the Precambrian terrain in northeastern Paraguay, but no deposits that might be workable have come to the author's attention.

CEMENT

The country's one portland-cement plant, which first went into production early in 1952, is at Vallemí, on the east bank of the Río Paraguay, not far south of the Río Apa. The wet-grind, rotary-kiln process adopted is similar in all respects to modern practice in Europe and the United States except that pulverized charcoal is used for fuel. The plant itself is an old Belgian plant, reconstructed at Vallemí by native labor under the training and supervision of a German cement specialist. When visited in April 1952, only one kiln, with a daily capacity of 100 tons, was in operation, but parts and plans were available for more than doubling the capacity in future. Except for bags, gypsum, and balls for grinding, which must be imported, the plant should be self-sustaining, as raw materials and fuel are present in abundance and the company has plans for reforestation as the existing forests are used up. From the purely technical standpoint, therefore, there is every reason to believe that the operation could supply all of Paraguay's requirements for portland cement and could even produce some surplus for export. Whether it continues to do so will depend on the company's success in replacing worn plant parts and on economic or political factors. The Itapucumí series, of Cambrian and Ordovician age, provides part of the raw materials for the plant. The deposits consist of limestone and related rocks that crop out prominently along this part of the Río Paraguay. (See fig. 43.) Both argillaceous and calcareous rocks come from the same quarry, which is parallel to the river and immediately in back of the plant so that the quarried rock needs only be moved a few meters. The quarry face in early 1952 was about 20 meters high and between 100 and 200 meters long.

The lowest and oldest rock exposed in the quarry, at its extreme north end, is hard light-red silty limestone that contains much fine-grained mica. Although so impure that it resembles argillite in the field, in thin section it is seen to be a slightly siliceous dolomitic limestone. It is quarried separately from the limestone that overlies it and is used as the aluminous portion of the cement mix. It is thinly bedded, strikes nearly due east and dips south about 20°. It is regularly bedded but has been sufficiently metamorphosed to have a slaty cleavage which makes it difficult to break it along bedding planes, as the rock tends to fracture into elongate pencillike splinters. The uppermost 2 meters of this argillite unit is yellow instead of red and the top 30 centimeters consist of soft yellow clay that contains irregular masses of white to yellow, soft but coherent, granular calcium carbonate. This yellow clay zone may represent weathering along an unconformity between argillite and limestone, particularly since the overlying beds differ in attitude from those below. It is equally possible, however, that the discoloration and softening are due to weak hydrothermal alteration.

A series of limestones, some dolomitic, overlie the argillite. The entire series is about 50 meters thick, but only the lower 15 meters are exposed in the quarry face. The series has been sampled at the surface and is reported to be comparable in composition to the rocks exposed in the quarry. No drilling or sampling of the beds in depth has been attempted. The beds strike northeastward and dip southeast, or into the hill, at a rather regular angle of 15°. They are 30 centimeters to 1.30 meters thick. There are several continuous beds of dolomitic limestone that are characteristically flesh pink to white in color and streaked or mottled. They are called "bacon rock" locally. The remainder of the series is made up of alternations of dark-blue-gray crystalline limestone and greenish-gray limestone. The blue-gray rock, which is cut by veinlets of white calcite, is reported to contain an average of 95 percent $CaCO_3$. The greenish-gray rock, which has an average content of 80 to 85 percent $CaCO_3$, is made up of white to dark-gray crystalline limestone with many irregular slickensided streaks and nodules of dark-dull-green chloritic material. Much of this rock could be mistaken easily for serpentine marble. All the rocks in the series are partly to entirely recrystallized and many of them would form excellent ornamental marble.

A series of strong, nearly vertical joints that trend northeastward, 1 to 3 meters apart, cut all the beds. Some appear to be minor faults, with the beds dropped from a few centimeters to as much as 2 meters on the southeast sides. Many of the joints have been opened by solution, especially near the surface. The resultant openings, 4 to 75 centimeters wide, are filled with coarse-grained granular calcium carbonate (caliche) that cements a breccia of rock fragments. The caliche, which also coats the surface in places, is too high in magnesia and silica to be used for cement; it, and the dolomite in the quarry, must be removed by hand or avoided by selective quarrying.

The rocks are cut by many irregular veinlets of white calcite, with an opening here and there that is lined with crystals of calcite, dolomite, or mixed carbonate. One small grain of chalcopyrite was seen in one of these veinlets and one irregular mass of white quartz, about 12 centimeters in diameter, has been found. These facts indicate rather clearly that the rocks have been subjected to mild hydrothermal alteration.

On the assumptions that the present practice of sorting out the dolomite by hand continues to be successful, and that the higher beds, which will be reached soon in quarry operations, are no more dolomitic in depth than they are at the surface, the Vallemí operation seems to be assured of adequate raw materials far into the future. Even should these assumptions prove incorrect it is certain that sufficient limestone of usable grade can be found somewhere within the belt of outcrop of the Cambrian and Ordovician rocks.

CLAY

Clay is one of the most widespread and abundant mineral resources of Paraguay, and the brick and tile industry is by far the most important mineral industry at the present time. In addition to the common clays, there are many deposits of clay of pottery grade; they form the basis of a moderate-sized industry that could be much expanded.

There are a few relatively modern plants that employ some machine methods. Good examples are the Vargas Peña plant near the town of Ypacaraí, which produces hollow structural tile, sanitary porcelain, sewer pipe, and other ware and the large plant at Areguá, which produces a large variety of cheap pottery. A great majority of the scores of brick and tile plants throughout the heavily populated regions, however, are tiny family affairs, producing only a few thousand brick per year. In these, the clay is dug by hand from shallow pits, and moved by wheelbarrow to a central point where it is thoroughly trodden by oxen attached to a long sweep. For some purposes, straw or grass is added to the clay at this stage. The clay is then further kneaded by hand in small quantities, and packed tightly into crude wooden or metal molds. After the rough tops are cut off by means of a wire the bricks are carried directly to an open grass-thatched drying shed; thin slabs for tiles are first bent over a wooden form to give them the proper shape. After several weeks of drying in the air the products are burned in a small wood-fired kiln. The final products vary considerably in quality, but most are at least fair to good, and have a pleasing buff to light red color. Considering the amount of hand labor that must be expended on each individual brick it is not surprising that bricks are roughly twice as large as the standard size used in the United States and in Europe.

REFRACTORY CLAY

Good refractory clay, suitable for firebrick and other high temperature uses, seems to be relatively scarce, but this may be due more to lack of adequate search and testing than to actual scarcity. Some of the known clay deposits have at least moderately good refractory properties. For example, the local clay near the old Quyquyó iron furnace is reported to have yielded as good refractory bricks as those imported from England. The glass plant at Eusebio Ayala uses local clay for its furnaces, though it has been found best to burn part of the clay first, regrind it, and then mix it with unburned clay to get the best results.

ALLUVIAL CLAY

Most of the small cottage-type clay plants depend on shallow accumulations of clay that characterize nearly all of the topographic swales in the country. Clay is naturally far more abundant in the areas underlain by shale, but nearly all the sandstone contains interstitial clay material that is released on weathering and concentrates in topographic depressions. These near-surface clay deposits are commonly gray to black because of a high content of carbonaceous material, but a few are colored red to brown with iron oxides.

WEATHERED SHALE

In contrast to the comparatively small and thin surface accumulations of clay, most of the larger and better-grade deposits represent beds of shale, usually interbedded with sandstone, that are more or less thoroughly weathered and bleached. More study of the geologic nature of the clay deposits is needed, but it appears that all the sedimentary formations yield workable clay in some places. The deposits along the west side of Lago Ypacaraí, between the towns of Areguá and Ypacaraí are perhaps typical.

There are a number of clay pits from 1 to 2 kilometers southeast of Areguá on a broad bench just west of the railroad. The pits expose white to light gray clay strongly mottled with brown and red to depths of 3 to 4 meters. The clay is very smooth to the touch and is strongly micaceous. Bricks made from it are a rich red brown and are of as good quality as any seen in Paraguay. The clay, which has the appearance of softened and weathered shale, is overlain by a series of massive, buff to red, fine-grained, micaceous sandstone and shaly sandstone beds. The lower beds contain a few fossils of Silurian age and the entire series of clay and sandstone is mapped as part of the Caacupé series on plate 1. The beds strike N. 65° W. and dip 32° SW. Even though the clay deposits thus dip beneath the surface, hasty examination indicates that a little exploration would prove the existence of enormous quantities of good clay within easy reach of the surface.

The Vargas Peña clay pit 2 kilometers northwest of Ypacaraí works beds that seem to be stratigraphically equivalent with those at Areguá. The beds strike N. 55° W. and dip 12° SW. Clay is exposed in two pits, one above the other. The lower one is 60 to 80 meters long, 10 meters deep, and 15 meters wide; the upper one is shorter but wider than the lower. The clay in each of the pits is white, very micaceous, contains little or no sand, and is richly fossiliferous in places. Locally it is stained brown and contains layers as much as 10 centimeters thick and a few narrow steeply dipping veins of light-gray iron carbonate, or siderite, largely altered to brown limonite. Massive, cross-bedded micaceous sandstone, about 25 meters thick, crops out between the upper and lower clay pits. The relations are not clear but it is believed that the sandstone lies between two separate layers of clay. It is possible, however, that the clay represents a single bed of altered shale that has been repeated by dropping along a steep northeastward-trending fault.

Samples of clay from the Vargas Peña pit were examined microscopically by Charles Milton. He found that they contained quartz and altered mica, with disseminated grains of rutile. The altered mica appears to be the major constituent of the rock, which possesses an obscure lamination, with some segregation into relatively mica-poor, quartz-rich areas. X-ray examination of the same samples by J. M. Axelrod showed that the material was made up of quartz, kaolinite, and muscovite; no montmorillonoid materials were found.

Other deposits of clay, some pure white and of excellent quality, are known to exist at a point 10 kilometers north of Tobatí and at Iturbe, Yegros, San Pedro del Paraná, Piribebuy, Yhú, in the Gran Chaco, and doubtless at many other places. The deposits at Yhú, which are reported to be very good for pottery, are interbedded with red sandstone of Triassic age (see fig. 52). The geologic setting of most of the others is not known, but their geographic distribution indicates a wide stratigraphic range.

A sample of washed pottery clay from Piribebuy proved, on X-ray examination by J. M. Axelrod, to consist of relatively large flakes of kaolinite with a little mica, quartz, and an unidentified mineral.

According to the report on Concurrencia del Banco Agrícola del Paraguay (Anon., 1911), tobacco pipes were made successfully from Paraguayan clays in 1903. The report contains the following chemical analyses of clays used for this purpose. Of these, the clay from Tobatí is said to have been the best.

Chemical analyses of Paraguayan clays

[Ovidio Rebaudi, analyst]

	Villeta No. 1	Villeta No. 2	Chaco	Tobatí
SiO_2	52.367	49.693	53.447	55.100
Al_2O_3	38.833	36.910	40.152	40.322
Fe_2O_3	2.800	4.120	.657	.210
CaO	.380	1.810	.410	.298
MgO	.120	.130	.198	Tr.
K_2O	.372	.298	.650	.310
Na_2O	.230	.196	.210	.200
Organic	.184	.120	Tr.	Tr.
H_2O	3.739	5.123	3.276	2.932
Loss	.975	1.600	1.000	.630
	100.00	100.00	100.00	100.00

COPPER

Of the several copper deposits that are more or less reliably reported, only one—the Paso Pindó deposit near Villa Florida—was seen by the author. Small amounts of malachite, azurite, and native copper are persistently and apparently reliably reported from the vicinity of Encarnación. Copper is also reported in and near Colonia Fram, 15 kilometers northeast of Carmen del Paraná, at a place 40 kilometers due east of San Pedro del Paraná, and from many other places where Serra Geral basalt covers the southeastern part of the country. The widespread popular belief that Paraguay is rich in copper is supported in part by reports such as these and in part by the legend that the early Jesuits produced bronze implements of many kinds.

Small amounts of copper are unquestionably present in some places, but most of the reported occurrences are unsubstantiated by specimens or assay results. It seems almost certain that many, if not most, reports are based on the fact that the cavity fillings of bright- to dull-green chlorite that are so widespread and so characteristic of the Serra Geral basalt has been mistaken for malachite or other green minerals of copper. It is reasonable to suppose that the reported production of bronze implements by the Jesuits represents remelted and recast Spanish bronze rather than that the alloy was made from local materials, particularly as even the legends fail to account for the tin that is an essential constituent of bronze.

The Paso Pindó deposit is 8 kilometers N. 18° E. of Villa Florida and 5 kilometers due east of kilometer post 157 on the Villa Florida-Caapucú highway. It can be reached from the highway by an unimproved secondary road. The country rock is largely a dense, fine-grained aplite that forms broad northeastward-trending dikes in coarse Precambrian granite. The deposit is on a weak nearly vertical shear zone, several meters wide, that trends N. 65° E. and extends at least as far southwest as the main highway, where it is well exposed in road cuts. It was not traced farther in either direction.

The deposit has been explored over an area of 50 to 100 square meters by 3 test pits, each 3 to 4 meters deep, and by several shallow opencuts. Copper occurs as malachite and other green oxidation products of copper sulfides, as films, and as veinlets along seams and joints of the slightly brecciated aplite. There is no well-defined vein and little or no evidence of strong alteration or of large openings that would have permitted the entrance of ore-bearing solutions in volume. A few pounds of high-grade carbonate ore has been mined and sorted by hand in the past. More may yet be found in depth or along the strike of the fracture zone, but the outlook for a large or rich deposit is distinctly unpromising.

FUEL RESOURCES

SOLID FUELS

As noted in the introduction, the chief known fuel resources are wood and charcoal. Comparatively small amounts of heat and energy are obtained from alcohol, hulls of cottonseed and palm nuts and by-products of the sugar and vegetable oil industries.

Inasmuch as the Gondwana beds contain coal in other parts of South America and elsewhere, it is entirely possible that some of those beds in Paraguay are also coal bearing. No authenticated occurrences have ever been reported, however.

Deposits of peat are known in some of the swampy areas along the Río Paraguay near Pilar. None were seen by the author, but they are reported to be large. During 1952 plans were being laid to develop and exploit these deposits. In view of the serious shortage of fuel in the country and of the bearing of this shortage on the total national economy, such plans seem to deserve continued and strong support. The extent, fuel value, and usability of the peat resources should be determined, and other deposits should be sought in similar geologic settings.

PETROLEUM AND NATURAL GAS

Except for one or two reported oil seeps in eastern Paraguay, and showings of oil and gas in one deep well in the Gran Chaco, Paraguay has no known deposits of petroleum or natural gas. There are some reasons for believing, however, that resources of these commodities may yet be discovered beneath the Gran Chaco plains.

From December 1944 through November 1949, the Union Oil Company carried out a rather costly and elaborate prospecting campaign in the Gran Chaco. Its work included a considerable amount of geologic mapping and very extensive geophysical studies that included almost the entire Gran Chaco. Five test wells, ranging in depth from 2,048 to 3,150 meters, were drilled. The approximate locations of these wells are shown on plate 1; partly condensed logs appear in the section on rocks of the Gran Chaco, and a generalized interpretation of the logs is given in figure 53.

The results of the drilling were almost more confusing than enlightening as to the subsurface geology of the Gran Chaco. In the two northwesternmost wells, Santa Rosa and Picuiba, great thicknesses of marine shale and sandstone of Devonian age beneath more than 1,000 meters (3,000 feet) of continental red beds were found. The La Paz well, only 70 kilometers east of the Santa Rosa well, showed that the Devonian shale had thinned from more than 1,200 meters to only 120 meters in that distance, but that it was underlain by a thick series of Paleozoic beds, reportedly very different in appearance from any of those in the Santa Rosa well. Conversely, the 3,149-meter Pirizal well, 130 kilometers south of the La Paz well failed to reach the marine sediments, demonstrating an enormous thickness of continental red beds there. In the Orihuela well, 210 kilometers east of the Pirizal, nearly 2,000 meters of red beds were penetrated and the drill passed directly into an old quartzite, probably Cambrian and Ordovician in age, thus proving the absence of Silurian and Devonian marine sediments in this area.

Evidence indicates a deep basin in the marine sediments, filled with continental red beds of Mesozoic and Cenozoic age that centers somewhere near the southwestern border of Paraguay, not far from the Pirizal well. Whether this depression is due to folding or to erosion and removal of the older marine sediments is unknown to the author; nor is the structure within the older beds known. It is clear, however, that these older beds rise to or above the surface eastward as well as toward a large domelike structure that has an apex near the extreme northwest part of the republic.

Despite the fact that only one well of the Union Oil Company—the Picuiba—found positive indications of the presence of oil and gas, the possibilities of eventual discovery of commercial petroleum or gas have not been exhausted. Very thick carbonaceous marine shale beds, possible sources for petroleum, are known in the area. An extensive structural basin filled with alternating layers of shale and porous sandstone, which could under favorable circumstances serve admirably as rereservoir rocks for accumulations of petroleum, is also known to exist in the area. Moreover, oil is produced in Bolivia in the anticlines on the western flank of this basin. The existence or location of minor folds, ancient shore lines, or other possible stratigraphic or structural traps within the basin is of course quite unknown, but it seems reasonable to suppose that such features may exist and may have been missed by the inadequate exploration that has taken place to date. Only further exploration can discover the unknown structural features. Such exploration would necessarily be both extensive and expensive; it would also require larger amounts of equipment and technical skills than were available in Paraguay when this report was written. The discovery of petroleum resources would mean so much to the national economy, however, that serious consideration should be given to developing the ways and means of making further search for them.

GEM STONES

There is a possibility, though only a remote one, that small quantities of precious or semiprecious gem stones may someday be found in Paraguay. The reported beryl in some of the pegmatites in the Río Apa region naturally indicates the possibility that, as in Brazil, some may be in the form of emerald or of aquamarine, though admittedly no reports of such occurrences have come to the author's attention.

Similarly, comparison of the general geologic relations in eastern Paraguay with some of the diamond-bearing areas farther north in Brazil, suggests that the basal conglomerate beds of the Lower Silurian Caacupé series, which locally mark the contact between these beds and the Precambrian granitic rocks, might yield stream-worn diamonds to thorough search. Such search, if attempted, should be done in the full realization that the chances of finding diamonds are extremely slim, particularly since there is little or no knowledge as to the sources of the Silurian conglomerate.

Many of the beautiful amethysts and agates that are produced in Brazil and Uruguay are derived from cavity fillings in the Serra Geral basalts that are apparently identical with those that cover a large part of southeastern Paraguay. Some beautifully colored agates and a few pale but otherwise gem-quality amethysts have indeed been collected from the Paraguayan rocks from time to time. Active search among the basalt outcrops themselves or among the pebbles along the Alto Paraná and other streams that drain the basalt area, would doubtless serve to discover additional material, though it is impossible to say in what quantity or quality.

Some of the younger volcanic rocks, such as those at Cerro Tacumbú in Asunción, contain crystals of clear green olivine, or "evening emerald" as much as 1 centimeter and more in diameter. It is probable that most, if not all, such crystals are so cracked or otherwise flawed as to be worthless for gem material, but it would seem worthwhile to check this conclusion by further examination of the rocks and of soils derived from them.

GLASS SAND

The local glass industry depends almost entirely on alluvial deposits of fine sand that accumulate as bars in some of the streams. These form an inexhaustible supply of fairly good material, though none of those seen are clean enough to yield high quality glass. The best apparent source of cleaner material known to the author is the white saccharoidal sandstone member of the Caacupé series. This sandstone, which could be very easily crushed, appears to be made up almost entirely of quartz grains in most places except for small specks of magnetite that could be easily removed by magnetic or gravity methods.

The best single source of pure silica for high-quality glass making now known is the large body of white vein quartz in the Precambrian rocks north of San Miguel. This body, described in the section on the older Precambrian rocks, would yield large quantities of quartz of extreme purity. Extraction and crushing would be very expensive as compared to the sandstones and alluvial sands. Quite possibly other sources of good quality siliceous material will be discovered as the geology of the country becomes better known.

GOLD AND SILVER

There are, almost inevitably, many legends to the effect that rich deposits of gold and silver were found by the early explorers and priests who settled Paraguay.

De Mersay (1860), for example, says that the early Jesuits are supposed to have taken fabulous quantities of gold from San Miguel. He notes the presence of deposits of white vein quartz there as supporting the possibility that at least small quantities of gold may actually have been found.

Though it is certain that these people sought the precious metals vigorously, and that they enlisted the original inhabitants to aid them in their search, there are no authentic records known to the author that they were successful. More important, there are no known evidences of old placer or other mine workings.

Reports of gold and silver discoveries are still made occasionally, but so far as known, none have been substantiated by samples or by assay results showing more than traces of either metal. The possibilities that precious metals exist in paying quantity cannot be denied, but in view of the record to date the outlook is distinctly unpromising.

GYPSUM

No commercially valuable sources of gypsum (calcium sulfate) are known to exist, yet the same reasoning applies here as to that for salt deposits (p. 91). Sporadic crystals of clear gypsum, or selenite, occur in some of the clay soils along the Río Paraguay near Concepción and south of Asunción. De Mersay (1860), for instance, notes the presence of blocks of gypsum, used to whitewash houses, in the banks and bed of the Río Paraguay at latitude 26°17′ S., not far from Alberdi; he mentions several other localities along the Río Paraguay and the Paraná. A little gypsum could doubtless be found elsewhere, though it is improbable that extraction from such sources could ever be made to pay. It seems entirely possible, however, that gypsum, like salt, might be found somewhere within the continental beds that underlie the Gran Chaco. In view of the comparatively small but continuing need for gypsum for plaster and for cement-making, cautious exploration by means of deep, carefully drilled wells may eventually be justified.

IRON

Many rich but comparatively small deposits of hematite and magnetite iron ore are known to exist in Paraguay. Most of them are in the Precambrian rocks that extend southward from Quiindy to near San Juan Bautista, but others are known in the Cordillera de Amambay and still others may exist in the body of Precambrian rocks just south of Río Apa.

So far as is known, there are no extensive deposits of bedded iron ore such as constitute resources of major importance in Brazil and in Venezuela. Nevertheless, the hematite-magnetite deposits of Paraguay do have considerable potential value, at least to the local economy. As described below, all the iron needed by Paraguay during the War of the Triple Alliance (1865–70) was successfully produced by a small charcoal-fired furnace that used locally produced ores. There is every reason to believe that similar but more modern furnaces would be as successful today and that the country could thus supply a part of its needs for iron (p. 96).

In addition to the veinlike deposits of hematite and magnetite, there are several other possible sources of iron. None are as promising as those just mentioned. A curious and little-known deposit of earthy lodestone occurs near Yuty (p. 86). Moreover, the lateritic material represents a very large reserve of low-grade iron ore whose chief constituent is hydrous iron oxide, or limonite. It ranges from a few centimeters to several meters in thickness and is widespread. Because of its availability and of the relative lack of gravel or other surfacing material it is used extensively for road metal. The laterite unquestionably contains an enormous amount of iron in the aggregate and a few schemes to use it as iron ore have been proposed from time to time. No analyses are available, but it appears almost certain that it contains too little iron—probably not more than 25 percent at best—and too much silica and alumina, to be usable as ore with present reduction methods.

EARLY IRON INDUSTRY

The following description of the early iron industry is taken largely from De Mersay (1860) and Du Graty (1865). The iron deposits in the general vicinity of Caapucú were discovered in 1847 but their existence was kept secret until 1854 when the Government established the iron industry as a monopoly. There are no records of the total production nor of the life of the enterprise, but it was continued at least through 1870, for it furnished most of the iron for cannon, cannon balls, and other weapons throughout the bitter War of the Triple Alliance (1865–70).

The furnace was established at Ybycuí, 15 kilometers northeast of Caapucú, apparently because there was a stream there, which, when dammed, could furnish adequate waterpower to operate the crushers and the blower. Clay for refractory bricks was found in the same valley in which the furnace was located. Experience showed that the bricks were better and longer lived than those that had been imported from England.

The iron ore first used came from Caapucú but after the mines there reached water level they were abandoned and most of the ore used in later years consisted of three parts specular hematite from near Quyquyó and one part magnetite from San Miguel. This latter ore was used because it was easily melted, even though it contained less iron than the hematite. The following analysis of San Miguel magnetite, quoted by Du Graty (1865), shows that it contained 31.91 percent of metallic iron compared with 40 to 50 percent in the ores from Caapucú and Quyquyó.

Analysis of magnetite from San Miguel

	Percent
SiO_2	50. 29
Al_2O_3	4. 57
MnO_2	1. 73
FeO	21. 28
Fe_2O_3	21. 95
Loss (ignition)	. 18
	100. 00

The furnace, at which 119 men were employed, had a capacity of 5,000 pounds of ore and flux and consumed an equal quantity of charcoal, producing 1,000–1,100 pounds of iron per 12-hour charge. The flux was a limy marl from near Paraguarí; because of its low lime content, it was used in the proportion of one part flux and two parts ore.

The iron produced was of very good quality, being low in silica and carbon and containing no sulfur or phosphorus. The following analyses of typical iron made from different ores, are given by Du Graty (1865).

Analyses of iron produced at Ybycuí

	Hematite from Caapucú and Quyquyó 100 percent	*Hematite from Caapucú and Quyquyó, 75 percent, and magnetite from San Miguel, 25 percent*
Fe	95. 78	96. 60
C	2. 76	2. 05
Si	1. 17	1. 00
S	None	None
P	None	None
Loss	. 29	. 35
	100. 00	100. 00

APICHAPÁ MINE

The Apichapá mine (also known locally as the López mine), one of the chief sources of iron ore for the War of the Triple Alliance, is about 4 kilometers northwest of Caapucú, 300 meters east of kilometer post 136 on the Quiindy-Caapucú highway. The country rock is massive pink to gray Precambrian quartz porphyry, with a strongly developed set of joints that trend N. 35° W. The ore occurs along a zone that is possibly 150–200 meters long and that trends N. 20° E.; it seems to be closely related, if not actually a part of, a strong northward-trending fracture zone that extends a distance of at least 20 kilometers (see fig. 2) and shows prominently in aerial photographs of the area. The main deposit was exploited by an opencut 50 to 75 meters long, 6 meters wide, and 3 meters deep that trends N. 20° E. Some streaks of ore and of altered rock are visible over a radius of 50 meters from the center of the cut, but apparently none were thought to justify exploration. The ore body has been almost completely worked out above the water table; its downward extension is not known, but early workers are supposed to have stopped work at a depth of 3 meters because of water rather than for lack of ore.

Small piles of ore left on the dumps consist of specular hematite and considerable quantities of magnetite, intergrown with much dense olive-green epidote and varying amounts of crystalline quartz. Hand specimens of this material, which range from 2 to 98 percent iron-oxide minerals, probably represent lower grade material than that sent to the furnaces at Quiindy.

The deposit is worked out above the water table and does not appear to be either large or very promising. Further exploration in depth and along the strike of the strong fracture zone would appear, however, to be justified.

DEL PUERTO DEPOSIT

The Del Puerto deposit is 3 kilometers northwest of Caapucú, 500 meters west of kilometer post 138 on the Quiindy-Caapucú highway. The country rock is largely dense pink to brown Precambrian quartz porphyry of the kind that is typical of this area, but there are considerable quantities of porphyritic rocks with somewhat different textures and possibly different compositions. The deposit is explored by two shafts, each 4 meters or more in depth, and each filled with water and debris to within 1 meter of the surface. They are 50 meters apart along a vertical vein, 1 to 2 meters wide. It trends N. 10° E. and, like the Apichapá (López) mine deposit, is closely related, if not actually a part of, a strong and continuous northward-trending fracture zone in the Precambrian rocks.

The vein material, which may have formed in part as a fracture filling and in part by replacement of the wall rocks, is an open boxwork of white to gray crystalline quartz with some gray, yellow, and red opal and considerable amounts of specular hematite and dense red hematite.

There is a little relict pyrite in places, and the shape and texture of the cavities in the boxwork indicates that most if not all of the material that has been dissolved to form them was pyrite. As shown by the chemical and spectrographic analyses on pages 23 and 24 (specimen P–31) the wall rock of the vein contains a little barium and zinc, which indicates that the vein matter may contain barite and sphalerite or other minerals of barium and zinc in places.

The vein shows evidence of alteration of the country rocks by mineral bearing solutions and seems to deserve further exploration in depth or along the strike. It seems probable that any iron minerals present would be too contaminated by sulfur to be desirable for iron ore. However, there is reason to hope that pyrite may exist in quantities sufficient to be a worthwhile source of sulfur—a commodity that is in much local demand.

DEPOSIT SOUTH OF CAAPUCÚ

About 6 kilometers southeast of Caapucú, 800 meters west of kilometer post 148 on the Caapucú-Villa Florida highway there is an iron deposit that was worked during the War of the Triple Alliance. It is in a saddle near the top of a small heavily forested hill. The country rock is dense fresh quartz porphyry like that at the Apichapá and Del Puerto deposits; the contact between the porphyry and a large body of coarse granite is only a few meters west of the deposit. There is one opencut about 40 meters long, and 3 to 6 meters wide that trends N. 10° W. Its original depth is not known, as the bottom is filled with water, but the part above water is about 8 meters deep. Only a few fragments of specular hematite were found on the dumps and the walls of the cut are fresh, unaltered porphyry. These facts suggest that the ore was rich, that there was a clean line of demarcation between ore and wall rock, and that the deposit was exhausted to or below the waterlevel.

DEPOSIT NEAR PASO PINDÓ

About half a kilometer northeast of the Paso Pindó copper deposit, which is 8 kilometers N. 18° E. of Villa Florida, there is a circular area about 50 meters in diameter that is very rich in iron ore. The country rock is coarse Precambrian granite and lies a little north of the belt of sheared aplite that contains copper at Paso Pindó. The surface material in this area is almost entirely iron ore, composed of an intergrowth of specular hematite and magnetite. Samples taken by R. M. Miller are reported to have yielded no sulfur and no phosphorus on analysis. The deposit is totally unexplored and the flat terrain precludes any guesses as to its shape or extent in depth. Unquestionably, however, it deserves investigation.

YTA-CUÉ MINE

Rich deposits of magnetite and specular hematite near San Miguel are reported by Du Graty (1865) to have been among the first worked during the War of the Triple Alliance. The deposits were not seen by the author, but are probably those worked by the Yta-cué mine, 3 kilometers north-northeast of San Miguel. According to unpublished notes by Ing. H. Almada Saprisa, circa 1950, the mine consisted of a series of pits that explored a body or bodies of magnetite along the northeasterly strike of a series of micaceous quartzite beds.

AGUIRRÉ-CUÉ MINE

According to the unpublished notes of Ing. H. Almada Saprisa, the Aguirré-cué mine is at the sharp bend of Arroyo Yguary, about 12 kilometers southeast of Quyquyó. His notes say that the deposit, in aplite and quartz diorite country rocks, was developed by a trench 50 meters long and 8 to 10 meters wide. No information on the amount or character of the iron ore is available.

DEPOSIT NEAR ROQUE GONZALEZ DE SANTA CRUZ

Small specimens of nearly pure specular hematite were seen that were reliably reported to have come from near Roque Gonzalez de Santa Cruz (also called Tabapy) between Carapegua and Quiindy. This is the farthest north that iron ore has been found in southern Paraguay. If the reported locality is correct, the deposit is doubtless in the granitic rocks that crop out in several stream valleys beneath the Paleozoic sandstone deposits in this vicinity.

DEPOSIT IN AMAMBAY REGION

A number of specimens of excellent specular hematite ore were seen from the "Amambay region, near Pedro Juan Caballero"; no closer locality description is available. The ore is identical in appearance to that from the various deposits farther south in the vicinity of Caapucú; associated rocks are crenulated mica schist, with granite and quartz porphyry that are very similar to those from Caapucú. Conradi (1935) mentions the presence of iron-bearing boulders of these rocks near Pedro Juan Caballero, but saw none of the material in place.

YUTY DEPOSIT

A deposit of lodestone is known to exist about 12 kilometers northwest of Yuty (Bertoni, 1940, p. 194). Several small samples of the material were dull brown, compact and earthy, and resemble the usual limonite, or mixture of hydrous iron oxides, except that the samples were strongly magnetic and attracted small pieces of iron. Elongate fragments, when balanced on a pivot, show sufficient polarity to act as compass "needles." Unfortunately, it was not possible to retain specimens for study, nor was it possible to visit the deposit.

According to Albert Morris, the deposit occurs as a near-surface bed that crops out along the banks of the Río Pirapó for a distance of 8 to 10 kilometers. Whether the bed is a part of the Triassic red beds shown on plate 1 to underlie this area, or is associated with younger alluvial materials along the river is unknown. The thickness, areal distribution, and origin of the deposit are also unknown, though from the above indications it seems worthy of examination. Small quantities of the lodestone should find a ready sale to mineral museums and it is conceivable that there is sufficient material available to be workable as iron ore.

LEAD

Lead "ore," probably in the form of galena, is quite reliably reported from Pedro Juan Caballero, from La Colmena—a farm colony midway between Acahay and Ybytymí—and from a few other places. Pottery made from the clays 60 kilometers north of Yhú are reported to "sweat out" globules of native lead when the pottery is fired. The only lead mineral seen was one small bleb of galena in the body of white quartz just north of San Miguel.

LIME AND LIMESTONE

The Cambrian and Ordovician limestone beds that crop out along the east bank of the Río Paraguay from San Salvador to the Río Apa constitute an inexhaustible supply of lime and limestone for all purposes. Some lime is imported from Argentina, but most of Paraguay's needs for the past 100 years have been met by a series of small quarries and charcoal-fired kilns at Puerto Fonciere, Itapucumí, and several other places. The lime is shipped by boat to Asunción in metal drums. Most of that seen contained large amounts of unburned limestone, but it would be a simple matter to improve the product greatly by better methods of calcination or merely by screening the burned lime.

Small but appreciable quantities of ground marble, presumably for use in the sugar industry, are imported regularly by Paraguay. With the raw materials and the crushing and grinding equipment currently available at the Vallemí cement plant, such requirements could be met locally. The same reasoning should apply to fragmental limestone, marble, and other rocks that are imported for use in terrazzo work.

The following paragraphs are condensed from a February 5, 1953, memorandum report by Dr. Klare S. Markley, vegetable oil specialist. The original is in the files of the Asunción office of the Institute of Inter-American Affairs.

Among the basic needs of Paraguayan agriculture are mineral fertilizers and agricultural limestone. Many of Paraguay's soils are highly acid and generally low in available phosphorus although they may be relatively high in total phosphorus. This high acidity limits the type of crops that can be grown, especially legume crops which are intolerant of high acidity. Innoculation of legume crops with nitrogen-fixing bacteria is often useless because the bacteria cannot establish themselves in highly acid soils. Proper liming of the soil will increase its fertility by releasing unavailable phosphorus, will make it possible to grow crops which are intolerant to acid soils, and to establish nitrogen-fixing bacteria in the soils which are now too acid to permit them to become established.

Pedro Tirado has shown that the Alto Paraná soils require 2.5 to 7.0 metric tons of lime in the form of limestone or dolomitic limestone to bring them to proper acidity (about pH 6.5).

The deposit of limestone which is now being worked at Vallemí for the production of cement is actually a mixture of limestone and dolomitic limestone. Only the former can be used for making cement, consequently the two minerals have to be separated which is done entirely by hand after partially cracking the quarried stone. This is the most costly operation carried out at Vallemí and the rejected dolomite or dolomitic limestone has no present use. This type of limestone is ideal for agricultural use and need only be crushed to pass a 10-mesh screen. For some special applications a finely ground limestone (50 to 200 mesh) might be preferable but is not absolutely essential.

I feel that the production and distribution of limestone in Paraguay could be one of the greatest contributions to agriculture that could be made short of the introduction of balanced chemical fertilizers.

MANGANESE

Manganese deposits are reported in many parts of the country, notably along the Rio Apa, in the vicinity of Villarrica, at Emboscada, at Yaguarón, and throughout the highland that extends from north of San Bernardino as far south as Paraguarí. Only the Yaguarón deposit, which is unpromising, was seen by the author.

It is, of course, conceivable that workable deposits of manganese exist in the country, particularly in the northeast, but no such deposits have yet been found, despite the fact that manganese oxide is resistant to weathering, hence should accumulate on the surface in easily visible and identifiable form.

EMBOSCADA DEPOSIT

The manganese deposit at Emboscada is generally considered to contain the richest ore now known in Paraguay. It was not visited but many small specimens of very rich manganese oxides from there were seen. Emboscada (Wright, 1940) is only 65 kilometers northwest of Asunción, but because of poor roads, it is most easily reached by boat to Puerto Minas, a small village not far above the mouth of the Río Piribebuy, thence via horseback about 5 kilometers to Emboscada. The country rocks are sandstone of the Caacupé series of Early Silurian age (pl. 1), which dip toward the northeast at low angles. A northwestward-trending zone of hard manganiferous sandstone can be traced for several kilometers. It has been explored by one pit 6 meters long, 4.5 meters wide, and 3.6 meters deep. This excavation exposes veinlets of pyrolusite 2 centimeters or more in thickness; locally there are masses 6 to 10 centimeters thick, but even the best specimens contain considerable amounts of silica. Results of chemical analysis of one specimen, doubtless carefully selected, were seen, which showed the material to contain 85.65 percent MnO_2 (equivalent to 54.90 percent Mn), 6.94 percent $BaSO_4$ and 0.23 percent SnO_2. The presence of tin in this material is surprising. There is no doubt that some manganese ore of commercial grade exists at Emboscada. However, the available evidence makes it seem very unlikely that any large quantities of ore will be found there.

YAGUARÓN DEPOSIT

The deposit, which is not believed to be of commercial size or grade, is in a prominent but relatively small hill just southwest of the town of Yaguarón (fig. 54). The steep slopes of the hill expose a total thickness of about 50 meters of brown, thick-bedded and cross-bedded, very fine grained arkose. This rock, shown on plate 1 as part of the Triassic Misiones sandstone is somewhat soft in places but elsewhere it is cemented by silica to a hard quartzite.

The manganiferous material forms an irregular pipe-like zone a few meters in diameter that extends almost vertically to near the top of the hill. Within this zone many joints are filled with narrow irregular veinlets of black oxides of manganese. The sandstone itself is also impregnated with small spherical bodies of similar oxides. There is no visible major fracture or fault; the manganese mineralization seems to have concentrated in the zone of joints.

"Mining" consists of the breaking off of pieces of outcropping rock and collection of loose fragmental material from the surface. The material so gathered is cobbed to pieces 4 to 10 centimeters in diameter and sorted by hand on the basis of color. None of the sorted material appeared to contain more than 10 percent MnO_2, and it is very doubtful that any quantity of better grade material could be produced.

MERCURY

De Mersay (1860) reported that mercury ore was found in 1779 at San Miguel. He stated further that samples that were sent to Spain for analysis gave unsatisfactory results and that no further development or exploration was attempted.

It is problematical whether the reported material consisted of the red sulfide mineral, cinnabar, or was some

FIGURE 54.—Coarse-grained, coarse-bedded, manganiferous arkose, believed to be part of the Misiones sandstone just west of Yaguaron. The beds dip 1° W.; the eastward slope of the hill is controlled by crossbedding. Just left of the central palm tree, joints and interstices in the sandstone are impregnated with manganese. Mandioca, a staple starch crop of Paraguay, in the foreground.

of the bright red iron hydroxide material that characterizes the weathered rocks in some parts of the country.

MICA

Mica is reported to occur in many pegmatitic bodies in the northeastern part of the country, between Concepción and the Río Apa. Several have been explored to some extent and have been examined by competent mining engineers, but no detailed descriptions or reports have become available. However, many selected specimens of mica were seen in sheets as much as 5 centimeters in diameter and there were many reports of sheets 2 to 3 times as large as this. All of those seen were so full of structural flaws or of dark inclusions of foreign ferruginous material that they would have little or no value as sheet mica.

Even though available evidence is scanty, it seems reasonable to assume that mica is widely, and perhaps abundantly, distributed in the Precambrian rocks in the northern part of the country. It seems probable that most of the material will be suitable only for scrap mica, which brings very low prices on the world market. It is possible, however, that good grades of sheet mica, which would bring much higher prices if competently extracted and graded, may exist in some places. Even if promising deposits should be found, questions of economics, of transportation, and of living conditions in this remote and largely unsettled region might play a larger part in the workability of the deposits than would the intrinsic value of the mica itself.

The most persistent and reliable reports of mica occurrences refer to the small area of Precambrian rocks 10 kilometers north of Concepción, and to the following places near the Río Apa: between "Reyes Cué" and Arroyo Seco, near Arroyo Caracol, at Puente Sinho, and close to Bella Vista. All but the last of these are sketched and described by Boettner (1947); he says that the pegmatite dikes at Arroyo Caracol contain large, badly flawed books of muscovite, associated with white and pink feldspar, quartz, beryl, and graphic granite.

In addition to the above localities, mica is also reported from Estancia Hermosa, from Potrero Bocayá, from Estancia Saty y San Blas—all localities in the Río Apa region—and from San Estanislao. This last report is the only evidence known that suggests the presence of Precambrian rocks in the vicinity of San Estanislao.

PIGMENTS

Many materials that could be used as pigments in the manufacture of paints are known in various parts of Paraguay. The only source known to have been worked in recent times is a deposit of ocher about 1,500 meters southwest of Tobatí. It is in the white sandstone described (p. 55) as the white saccharoidal member of the Caacupé series. Along several of the strong vertical, northeastward-trending fracture planes that characterize the sandstone there are irregular areas in which the sandstone grains are cemented with ocher instead of the more usual calcareous or siliceous cement. This ocher, which makes up approximately 2 to 7 percent of the rock, appears to be a finely divided clay that is impregnated and colored by secondary limonite. The largest deposit, and the one that was being worked in 1952, is about 30 meters long, 2 to 3 meters wide and 3 to 5 meters high. Part of it is shown in figure 47. The rock is soft and easily worked. Blocks are pried out with hand tools, hammered to small pieces, and then disintegrated by soaking in water (fig. 55). The heavier sand sinks to the bottom and is removed with shovels; the ocher is decanted off. The decantation process is repeated in 3 to 5 operations in small wooden troughs, and the resultant ocher, when dried in the sun,

FIGURE 55.—Quarry and paint factory near Tobatí. The sandstone at the right contains yellow ocherous clay interstitial to the sand grains. The yellow ocher is recovered by crushing the sandstone and washing it in shallow trays beneath the shed.

is an extremely fine ocher-yellow powder that has excellent covering and tinting properties. About 1,000 kilograms of finished product were on hand when the property was visited in April 1952.

Iron minerals are abundant in the rocks and soils in many places; by proper treatment they could doubtless yield pigments of all shades from ocher yellow through the reds to dark brown. The specular hematites in the general vicinity of Caapucú, the red-brown limonite that makes up much of the laterite soil in large parts of the country, and the gray, brown, and deep-red clay-ironstone, or partly altered siderite, that occurs as concretions and veinlets in many deposits of clay and shale would probably all be found usable. In addition to the iron-bearing minerals, the Paso Pindó copper deposit near Villa Florida and the reported deposit of barite at Fuerte Olimpo might yield small quantities of green and white pigment materials respectively.

PYROPHYLLITE

An extensive deposit of pyrophyllite is known about 12 kilometers northwest of Caapucú, about 7 kilometers west of the main Quiindy-Caapucú highway. The country rocks are brown quartz porphyry that makes up a large part of the upper Precambrian rocks in this vicinity. The pyrophyllite is exposed in places along a northeastward-trending zone that extends at least 2 kilometers and is possibly much longer. In the one shallow prospect pit that had been dug in 1952 (fig. 56) the pyrophyllite-bearing zone is 3 to 5 meters wide. The pyrophyllite ranges from pure white to dull red; much of it is mottled red, white, and gray. Large masses, a meter or more in diameter, of nearly pure pyrophyllite are abundant and have the texture and other properties of soapstone, but much of the material in the zone consists of porphyryitic rock that is only partially altered to pyrophyllite.

Three specimens of this material, each somewhat different from the others, were studied microscopically by Charles Milton. Two are grayish-white talclike rocks, very fine grained, with little visible impurity. An X-ray diffraction pattern made by J. M. Axelrod confirms the identity of the rock as pyrophyllite. The third is a red heterogeneous rock, and under the microscope is seen to be a pyrophyllitized volcanic tuff—as the others are, too.

The best grade material appears to consist of rhyolitic fragments, some with porphyritic texture, completely changed to an extremely fine-grained pyrophyllite mesh, with occasional small areas with sub-

FIGURE 56.—Test pit in a deposit of pyrophyllite, 5 kilometers north of Caapucú. Terrain is typical of Precambrian granitic rocks of south Paraguay.

rectangular outline showing coarser platy crystallization. Small opaque areas strewn through the section are leucoxene. One specimen (fig. 57) shows considerable amounts of fine-grained diaspore under the microscope.

The pyrophyllite appears to be derived by hydrothermal alteration of volcanic tuffs that are probably interlayered with the quartz porphyry.

In view of the very large indicated size of the deposit, continued search for material of good grade and color, would appear to be worthwhile. Studies should also be made of possible markets for the product, both as a substitute for talc and for other uses such as refractories.

QUARTZ CRYSTALS

Quartz crystals are reported to Robert M. Miller by local residents to occur on the ridge 6 kilometers northeast of Caapucú. Nothing is known of their size or optical quality. It seems probable that they are small doubly-terminated crystals similar to those that weather out of miarolitic cavities in Precambrian granite in many places. If so, they have little or no value.

SALT

No commercially valuable deposits of common salt (NaCl) are known to exist in the country, yet the universal need for this commodity (evidenced here by an annual importation of nearly $200,000 worth) plus known geologic conditions that should be favorable to salt accumulation, would seem to make a vigorous search worthwhile. Three possibilities are known to the author—recovery from surface efflorescences and from brine wells in central Paraguay and recovery from deep wells in the Gran Chaco.

Pfotenhauer (1891) notes that the early Jesuits had a monopoly on extraction of salt from the salt playas (salinas) of San José and Santiago (now in Bolivia) in the northern part of the Gran Chaco and that they provided all the salt needed by Paraguay and neighboring provinces of Argentina and Brazil. Much later, De Mersay (1860) and Du Graty (1865) record the extraction of salt from salty earth, efflorescences, and dried ponds in the vicinities of Fuerte Olimpo, Concepción, the Río Piribebuy, the Río Salado (which drains Lago Ypacaraí), the Río Negro (in the Gran Chaco), and Lambaré (just south of Asunción). Du Graty

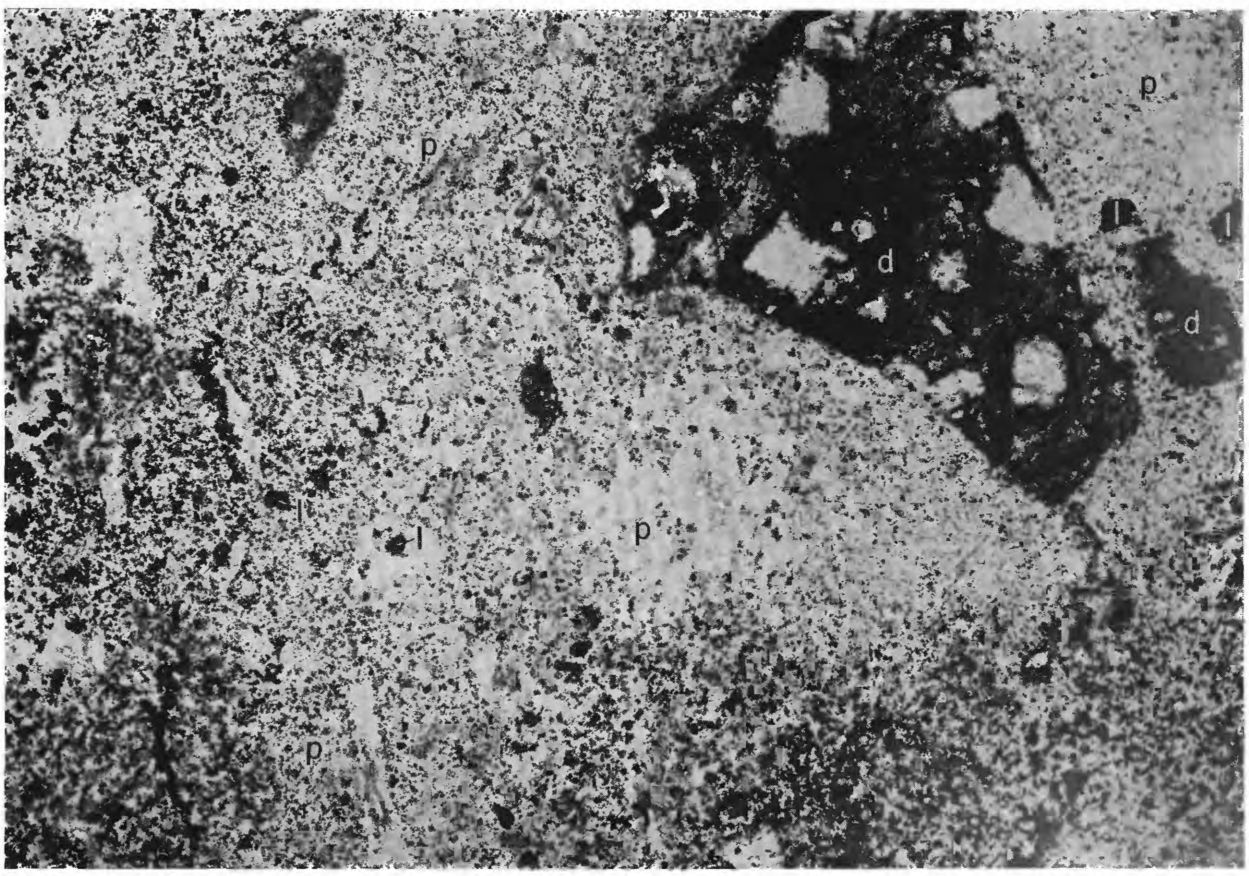

FIGURE 57.—Pyrophyllite with diaspore (specimen P-91) from 5 kilometers northwest of Caapucú. The light-colored groundmass, *p*, is pyrophyllite and the dark gray is diaspore, *d*. A few small dark areas are leucoxene, *l*. × 20.

states further that these sources furnished a part of the country's salt requirements and could have met them entirely if necessary. He quotes an analysis of the salt from Lambaré, by M. Parody, as follows:

	Percent
NaCl	91. 40
MgCl	2. 95
$MgSO_4$	. 90
$CaSO_4$	4. 23
Difference	. 52
	100. 00

There are persistent reports of the existence of relatively shallow wells in the area south of, and only a few kilometers from Asunción, that yield strong salt brines. None of these reports could be verified.

Nearly all the Gran Chaco is underlain by many hundreds of meters of sediments that were deposited under continental, and in part desert, conditions. It seems reasonable to suppose, therefore, that somewhere within this sequence of beds there may be beds or lenses that represent the evaporation of desert lakes that were high in sodium chloride. Whether this is so or not cannot be determined from present evidence. It is known that most of the streams in the Gran Chaco, as well as most of the near-surface ground water, are rich in dissolved mineral matter—though there appears to be more magnesium sulfate (epsom salts) than sodium chloride in most of them. The logs of the deep holes drilled by the Union Oil Company summarized above do not record the presence of salt beds. This is weak negative evidence, however, for discovery of soluble salts by the usual water-filled wells drilled in the search for petroleum are rare indeed.

SAND AND GRAVEL

Fine sand is extremely abundant in almost all parts of the country. Coarse sand and gravel, on the other hand, are almost equally rare. Some of the sandstone units, notably the white saccharoidal sandstone member of the Caacupé series and the red sandstone units in the Misiones and Independencia series might be easily quarried and crushed to yield medium- to coarse-grained sand suitable for concrete and other purposes. Unfortunately, few of these units occur in areas where there is the greatest demand. Gravel is even scarcer than coarse sand. A few stream beds contain some gravel but most do not. The basal conglomerate beds of the Silurian and Triassic rocks yield some excellent gravel locally, but these beds are too thin, too discontinuous and too poorly exposed in most places to yield large quantities either locally or in total. Most of the requirements for coarse aggregate for concrete are met by crushed igneous rocks. The basaltic rocks, such as those at Tacumbú and Lambaré on the outskirts of Asunción, are most widely used, but this is because they are close to the centers of population and of greatest demand. The Serra Geral eruptive rocks, the Cambrian and Ordovician limestone units, and many of the Precambrian rocks would be equally useful if there were local need for them, and some of them would be more easily quarried and crushed than the extremely tough volcanic rocks.

Limonite, in nodules or fragments from the laterite zones that make up the surface in many parts of the country, is very widely used, particularly in the central region, for gravel-size material for road surfaces. It is in large part responsible for the general impression, acquired by travelers who follow only the main roads, that Paraguay is characterized by red colors. The limonite has fairly good cementing properties, but is too soft and dusty to be particularly desirable if any better material were available.

STONE

Supplies of stone for either ornamental or rough construction purposes are more than adequate for any conceivable requirements.

Tough, durable rock for paving blocks, rubble masonry, and the like is produced in rather large quantities from a number of the volcanic deposits. Among those that were being worked in 1952 or had been recently worked are the deposits on Lambaré and several other hills close to Asunción, those just south of Ypacaraí that yielded most of the stone used on the paved highway, the flow rocks along the highway near Carapeguá, and the body of shonkinite at Mbocayaty. Almost any of the other igneous rocks shown on plate 1 would be suitable sources of good stone. The deposits of "pseudo-trachyte" near Luque and Areguá, which form nicely shaped polygonal columns from 4 to 15 centimeters in diameter, are used widely for walls and walks of many buildings in Asunción and its vicinity. The Serra Geral eruptive rocks of the Alto Paraná region provide attractive semidressed stone for buildings; the phases that contain green chloritic amygdules are particularly pleasing to the eye.

Several sandstone units are worked in places for flagstone and building stone. One of the most attractive comes from quarries near Emboscada from beds believed to belong to the Caacupé series. These rocks, which split easily to form good but somewhat soft flagstones, are nearly white in background color, but beautifully mottled with light tones of rose and brown. The lower beds of the Misiones sandstone are quarried in a number of small pits in the vicinity of San Juan Bautista (see fig. 51). They have a pleasing uniform red color, and are almost as hard and durable as quartzite. They consist of well-rounded frosted quartz grains, with interstitial cement made up of silica, sericitic mica, and other minerals.

Among the rocks that have not been worked commercially to any extent, but which offer considerable promise, are the marble, hard limestone, and dolomite of the Cambrian and Ordovician rocks, the Precambrian granite and quartz porphyry near Caapucú, and the shonkinite, or "black granite" of Mbocayaty. Any of these rocks would yield good decorative stone if properly worked; except for the Mbocayaty deposit the reserves of material are virtually unlimited.

SULFUR

At least two deposits of iron sulfide minerals, from which small amounts of sulfur might be recovered in case of extreme need, are known. No deposits of native sulfur have ever been reported.

One of the known deposits is the Del Puerto vein, near Caapucú (p. 85). The leached outcropping material of this vein contains a little pyrite, as well as evidence that pyrite once existed there in considerable quantity but has since been removed by solution. It seems possible that further and deeper exploration might uncover bodies of pyritic ore sufficiently large and rich to provide some sulfur. It is very unlikely, however, that any very large bodies of pyrite will be discovered.

The second known source of iron sulfide minerals is at the Minas-cué, or López, mine near Arroyo Yhaguy, about 5 kilometers southwest of Itacurubí. This deposit is reported to have furnished most, if not all, of the sulfur needed for gunpowder during the War of the Triple Alliance. It is possible that other deposits of the same kind may also have been worked during the war, but if so, there is no reliable record of them.

The Minas-cué deposit is on a nearly level plain that is cut by many small arroyos tributary to Arroyo Yhaguy. The "ore" consists of widely scattered concretions of marcasite in shale of the Itacurubí series of Early Devonian age. These shale beds underlie the entire grass-covered plain of Arroyo Yhaguy. Nearby hills consist of sandstone, also part of the Itacurubí series, that overlies the shale. The alternating beds of shale and mudstone are nearly or quite horizontal and are blue gray with local splotches of red and pink. They are strongly jointed along several sets of crisscrossing, nearly vertical joints that cause the beds to form vertical walls along the arroyos. The uppermost 1 to 2 meters are weathered to soft plastic clay, mottled in shades of yellow, white, and brown, surmounted by 20 to 60 centimeters of brown clay soil that contains sparse pebbles of quartz, quartzite, and agate.

Concretions of marcasite and siderite, or iron carbonate, are sparsely scattered throughout the shale. Some of the siderite occurs as oval concretions 1 to 7 centimeters in diameter but most of it forms small vertebralike cylinders that break easily into thin disks. In the weathered zone most of the siderite is altered to deep-purplish-red limonite but fresh material is dense and gray to buff in color.

The marcasite in the concretions occurs both as clusters of crystals and as irregularly oval masses. Some is pure iron sulfide, but some is earthy and probably contaminated with clay or with siderite. None of the masses seen was more than 7 centimeters in greatest dimension, and they are so widely scattered that none of the rock could possibly contain much more than 1 kilogram of marcasite to the cubic meter.

The main López workings appear to have consisted of a shallow opencut along one of the arroyos, about 2 to 3 meters in depth, 10 to 15 meters wide, and 150 meters long. One shaft in the bed of the arroyo, long since filled with water and debris, is said by local inhabitants to have been 20 meters deep and to have the richest concentration of marcasite in the entire workings.

About 1,000 laborers, mostly women, are reported to have worked the deposit during the war period of 1865–70. Apparently they dug vast amounts of the shale, sorting out the sparse marcasite concretions by hand. The material was roasted at the mine in a small brick furnace.

There is no question that very large amounts of marcasite are present in the shale in this place and quite possibly elsewhere in the shale units of the Itacurubí series. The marcasite is so widely scattered, however, and would require moving and treatment of such enormous amounts of barren shale to yield even small amounts of marcasite, that it cannot be regarded as a resource except under the most extreme conditions of economic or military emergency. If any such needs should develop, it is suggested that the shale be investigated over wide areas and to depths of 10 to 20 meters by means of earth augers or other drills. Such exploration might possibly serve to discover zones where the marcasite concretions are relatively abundant.

TALC

Known talc deposits are confined to a small part of the belt of lower Precambrian rocks that are exposed along the highway from the center of San Miguel to a point 5 kilometers north of that town. As described above, this belt comprises alternating bands of a wide variety of rocks, ranging from quartz veins through granite and aplite to mica schist and altered ultrabasic rocks. All are strongly crushed, and component minerals are strung out and flattened parallel to the banding, which trends N. 40° E. and dips 30°–60° NW.

Talc occurs in three distinct zones in this series, from 30 to 50 meters apart and each 2 to 3 meters thick. The talc is well exposed in the roadside ditch at kilometer post 176 (see fig. 5) and in a prospect shaft about 15 meters deep that is a few meters southwest of that point (see fig. 58), or along the strike of one of the talc-bearing zones. The material ranges from white to greenish gray and from very smooth or soapy to gritty. Here and there it contains a few veinlets of white quartz, and microscopic grains of chromite are widely but sparsely disseminated through it. Veinlets of cross-fiber talc that has the megascopic appearance of asbestos, from 5 to 15 millimeters in thickness, characterize some of the talc taken from the prospect shaft.

The texture, as well as the presence of chromite, strongly indicate derivation from serpentine or other basic rock, but no other evidence of its origin was seen.

The talc near the surface is somewhat iron-stained and is variable in texture and composition. It seems to be fairly extensive laterally, however, and to be almost certainly due to extensive hydrothermal alteration. In view of the potential local market for commercial grades of ground talc, further exploration with the hope of finding better grade material in depth seems warranted.

TIN

Tin, possibly in the form of cassiterite, is reported to have been found in the white pottery clay from near Tobatí, in the manganese ore from Emboscada and from near Panambí, a village in the vicinity of Caaguazú that is not shown on available maps. None of these reports appear to be very reliable.

TUNGSTEN

Wolframite, or some other ore minerals of tungsten, are persistently reported to occur on the Estancia San Luis near Concepción and elsewhere. Even though export licenses for tungsten have been granted and some purported tungsten ore has been actually shipped, there is considerable evidence that these actions were taken in error or chicanery and that no material containing appreciable quantities of tungsten has ever been produced in Paraguay.

MISCELLANEOUS MINERALS, LOCALITY UNKNOWN

Specimens of the following minerals, said to be from Paraguay but with no localities given, were displayed at the Buenos Aires exposition in 1910 (Anon., Concurrencia del Banco Agrícola del Paraguay, 1911): stilpnosiderite, native iron, millerite, sphalerite, pyrite, galena, magnesite, serpentine, sulfarsenate

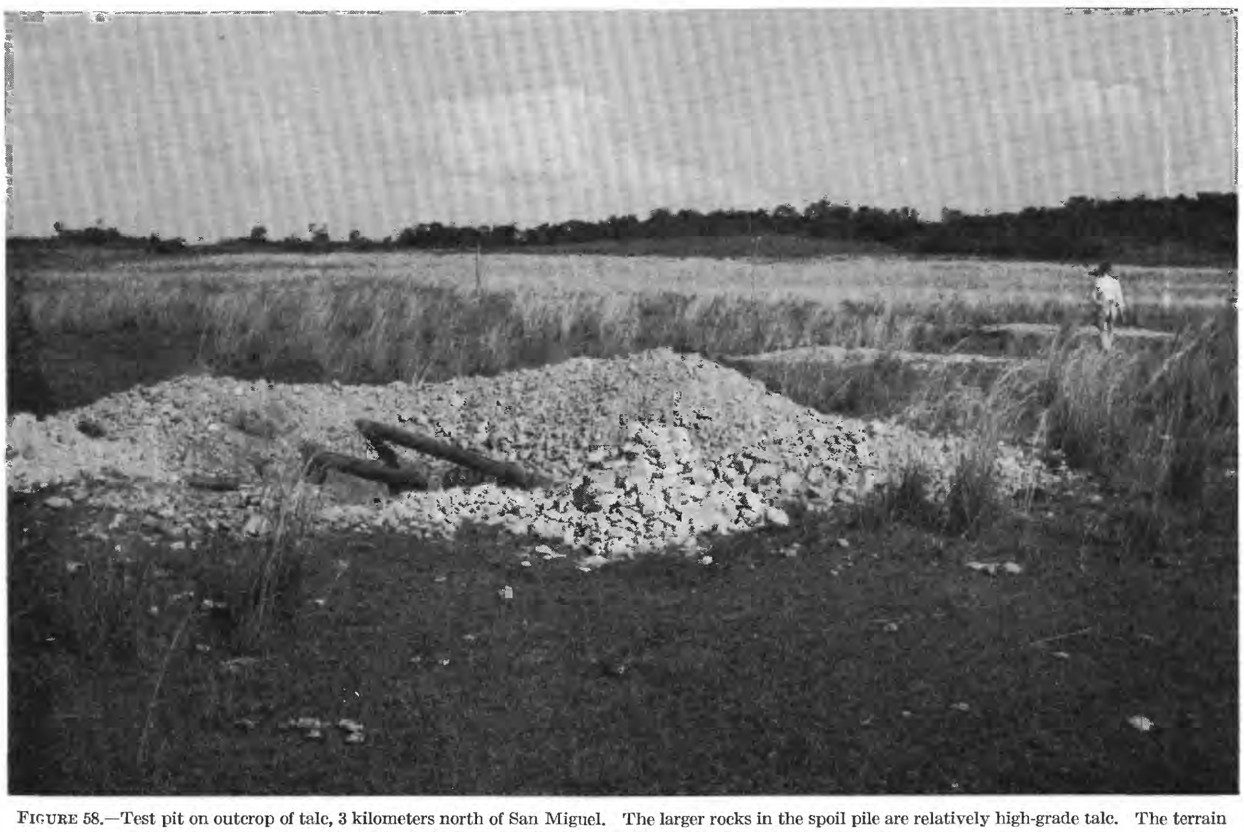

FIGURE 58.—Test pit on outcrop of talc, 3 kilometers north of San Miguel. The larger rocks in the spoil pile are relatively high-grade talc. The terrain and vegetation are typical of Precambrian areas of southern Paraguay.

of lead and silver, patrinite, antimonite, and six unidentified copper minerals. Some of these mineral names suggest the possibility that they represent specimens that originated in Bolivia or Peru rather than Paraguay.

FUTURE OF THE MINERAL INDUSTRY

GENERAL STATEMENT

Available facts indicate that Paraguay is very poor in mineral resources except for certain nonmetallic materials, such as clay, limestone, talc, sand, and various kinds of building and ornamental stones. It is possible that further exploration will serve to uncover other resources. Even if such hopes should prove to be ill-founded, however, there is every reason to believe that profitable local industries could be established that would provide some or all of the nation's requirements for certain commodities and would conserve some of its foreign exchange.

The author's pessimistic conclusion as to Paraguay's relative poverty in minerals is not reached lightly nor without reluctance. Nor is it based entirely on the results of the present 6-month reconnaissance that was inadequate to examine more than a small fraction of the mineral possibilities. Instead, it is based in part on history and in part on generalized knowledge of the geology of the country.

For nearly four and a half centuries, many men, some highly skilled in their profession, have sought mineral wealth in Paraguay. It is easy to believe that all of them may have missed the obscure or the deeply covered deposit, but almost inconceivable that all would have failed to discover obvious deposits that would be most easily found and developed. The fact that they have not done so is in itself strong presumptive evidence that easily discovered deposits do not exist.

So far as the geology is now known, the Precambrian rocks offer the best chances of discovering deposits of metallic minerals. Unfortunately, these rocks are covered in most places by barren sedimentary rocks, or by swamps and many of the exposures that do exist are remotely situated and difficult to explore. None of the younger igneous rocks appear to be of the kinds with which ore-bearing solutions are usually associated. As a result, neither they nor the surrounding sedimentary rocks, none having been fractured or metamorphosed enough to make them promising receptacles for ore deposits, seem to be of much promise.

These conclusions are at variance with widespread popular beliefs within the country that are based in part on the inevitable enlargement of legends with time, and in part on failure to distinguish between mineral occurrences and mineral resources. The belief in existence of gold and silver resources, for example, seems to be based entirely on stories that the early Jesuits found and produced fabulous quantities of these metals. Actually, there are no authentic records of such production and no assay reports or other proof that paying quantities of gold have been found since the time of the Jesuits. Again, the almost universally held belief that Paraguay is rich in iron is based on the well-known fact that local mines and furnaces produced all the iron needed in Paraguay's epic struggle against three powerful adversaries—Argentina, Brazil, and Uruguay—during the War of the Triple Alliance. As a matter of fact, Paraguay does possess rich iron deposits, but there are many reasons, geologic and otherwise, for believing that they are far too small, individually and collectively, to form the basis of an export business. Too, many beliefs in mineral riches are based on small specimens, with little or no proof that they represent workable quantities of ore. Thus, though manganese and copper are undeniably present in several places, there is no evidence known to the author that bodies of commercially workable size and grade have ever been discovered or developed. Similarly, though specimens of sheet mica can be seen in many private and public collections, none of those seen were of much more than scrap quality; moreover there is little more than hearsay evidence that large deposits of mica, regardless of grade, have been discovered. Part of the author's pessimism is based on the mere fact that most specimens of metallic and other minerals or ores seen are far below commercial standards. It is only human nature to select better-than-average material for specimens; if all specimens of such easily recognized materials as gold, mica, manganese, and copper ore are mediocre in quality, it is difficult to believe that the deposits from which they came are much, if any, better. This reasoning does not apply, of course, to the less-easily recognized minerals, such as the ores of tin and tungsten, nor to such things as petroleum that can only be discovered by extensive underground exploration.

SUGGESTIONS FOR PROSPECTING

Present knowledge strongly indicates that Paraguay is relatively poor in mineral resources. Details of the geology are but imperfectly known, however, and many parts of the country are so inaccessible as to have escaped very careful search for minerals. Further exploration, therefore, seems justified.

Many suggestions for prospecting are offered on preceding pages in descriptions of individual commodities. These suggestions are only summarized here.

In searching for deposits of the metallic minerals, and many of the nonmetallic ones, it is always well to proceed from the known to the unknown. The best chances of discovering more iron ore, for example, will lie in further exploration, in depth or laterally, of known deposits. This should be the first rule; the second should be to confine the search to favorable geologic settings. So far as is now known, nearly all the metallic deposits, as well as all the talc, pyrophyllite, beryl, and mica, are associated with Precambrian rocks in the Río Apa and Amambay regions and in the general vicinities of Caapucú and San Miguel. This fact alone should limit the search to a very small part of the country's area. In this connection, however, the geologic map should be only a guide (pl. 1), for it is entirely possible that fairly large areas of Precambrian rocks may exist that are not shown on it. Conventional methods of prospecting should be followed in most cases; in the search for iron ores, it is probable that geophysical methods that take advantage of their magnetic properties might serve to discover ore bodies that are not exposed at the surface.

Few, if any, guides can be given for hunting new deposits of clays, building stones, or bauxite. Only detailed geologic mapping of large areas would provide such guides. It is suggested, however, that serious prospectors take account of the deep weathering that characterizes most of the rocks, and prepare to expose unweathered material by trenches, pit, or soil augers. Mazó (1952) outlines procedures for exploring common clay deposits that might be applied to other materials.

The shortages of fuel and power in Paraguay are so acute that serious efforts to alleviate them seem justified. There is a good possibility that commercial quantities of petroleum exist in places beneath the Gran Chaco. In view of its potential importance to the national economy, serious efforts to search for it should be encouraged. Present efforts to develop the peat deposits near Pilar deserve strong support. There is little reason to expect authentic discoveries of coal, but every reported discovery should be followed up, as should reports of salt and sulfur deposits.

DEVELOPMENT OF LOCAL INDUSTRIES

There is an excellent possibility of establishing several small new industries, or of modernizing existing ones, using local mineral resources and producing goods for local consumption. Such industries, whether fostered by the Government or by private enterprise, would result in freeing Paraguay from dependence on imports for some of its requirements and would, of course, conserve corresponding amounts of the nation's foreign exchange. They would also have long-range advantages in encouraging the search for mineral resources and in developing skills on the part of Paraguayan workers in mining and treating mineral products.

IRON

Because the known reserves of iron ore appear to be small, both as to total and as to individual deposits, and because of the lack of fuel, the possibilities of developing an export trade in iron ore or of developing a large local iron and steel industry are definitely not encouraging. On the other hand, there does seem to be an excellent chance of developing a small local industry, capable of supplying at least a few hundred tons per year of wrought iron and related forms of iron and even of steel. This iron could be made locally into such things as plowshares, crowbars, chains, machetes, anchors, ornamental grillwork, and many other items that are normally imported. Moreover, all such items have enormously higher value than the raw iron ore from which they are derived, so that the country's economy would benefit by the difference between the money that would be received from exporting raw ore and that which would be spent on importation of finished products.

The kind of iron works envisioned would be small modern blast furnaces or perhaps small Bessemer converters, both fired with charcoal, and similar to those that are in successful use in Brazil. Such furnaces are the modern descendants of the primitive furnaces or forges that were used in Paraguay during the War of the Triple Alliance and in Texas and Alabama during the War Between the States. Small modern furnaces could be constructed cheaply and quickly, largely from native materials, so that capital outlay and imports of materials would be small. Charcoal for fuel and limestone for flux are available in Paraguay in unlimited quantity, hence no imported materials would be needed after the furnaces were in operation.

If it is not already available in Paraguay, the requisite technical knowledge to build and operate the furnaces might come from Brazil. That country produces at least 500,000 tons of iron and steel per year from small charcoal furnaces; it has done and is doing a great deal of research on the technology and economics of such furnaces.

BUILDING AND ORNAMENTAL STONES

Paraguay possesses a great variety of rocks that could easily supply all local needs for ornamental stone and that could even be developed into an export trade if regular production of superior material could be assured. Even if production of finished ornamental stone were undesirable or impossible for any reason, there is no apparent reason why a single kilogram of crushed marble for terrazzo floor tiling and the like, of powdered marble, or of lime or limestone in any form should ever be imported by Paraguay.

Many types of sandstone are already being produced.

These range from white to red in color and many of them form very attractive stone for flagstone walks, walls, and exterior facing for buildings. Large quantities of broken stone, mostly basalt or other dark-colored igneous rocks, are used for street paving, for rough wall construction, and for foundations of all kinds. All these materials are quarried by very simple methods and little or no attempt is made to improve their natural appearance by cutting, polishing, or other dressing.

In addition to the rough building stones mentioned above, it should be possible to produce many kinds of marble from the large deposits that outcrop along the Río Paraguay from the mouth of the Río Apa southward to San Salvador. These rocks range from uniform white or gray through mottled and striped rocks of various shades to what should be an excellent verd antique serpentine marble. Crushed and powdered marble of a high degree of chemical purity could be produced as a natural byproduct of a small marble industry, or could be easily produced by the Vallemí cement plant, which already has all the requisite crushing and grinding equipment. The possibility of using the waste products from the Vallemí plant for agricultural limestone is discussed on page 87.

Several distinct types of light-colored granite with very attractive texture, all durable and suitable for ornamental stones, exist in the general vicinity of Caapucú and Quyquyó, and probably elsewhere. There is also some strikingly beautiful and extremely tough black "granite" (alkalic shonkinite) at Mbocayaty.

The establishment of an ornamental stone industry would require, in addition to technical knowledge that is probably not now available in the country, a considerable investment in equipment for quarrying, cutting, and polishing the stone, Once the industry were established, however, about the only continuous import requirements would be small amounts of explosives for quarrying and abrasives and acids for cutting and polishing.

GLASSWARE

Except for three plants that produce common bottles and jugs, virtually all of Paraguay's requirements for glass are imported. This is a particularly unfortunate situation because, with such a fragile and bulky commodity, transportation charges necessarily form a high proportion of the final costs. Paraguay could probably not compete successfully at this time with foreign producers of plate glass or the finer grades of domestic glassware, but there is no reason why it could not produce most of its requirements of the common grades of glass for commercial and domestic use, such as heavy water glasses, bottles, jars, and other containers. A cheap local source of glass jars would remove one of the chief obstacles in the way of preserving more fruits and other foods for domestic use and even for export, than is done at present. It would also provide a constant source of supply for the local bottling industry, which is now forced to shut down from time to time because of a lack of containers.

Silica sand is the main ingredient of all glass. Sand and sandstone are abundant in most parts of Paraguay. Much of it is of excellent quality and purity for glassmaking, although most of the sand contains enough iron to tint the glass green or yellow. This difficulty can be avoided by careful selection of iron-free sand or by the addition of small quantities of manganese oxide, also available locally. Most of the white or nearly white sandstone, such as that near Tobatí and Piribebuy, contains iron in the form of distinct particles of magnetite (iron oxide); it should be easy to produce iron-free sand from such material by crushing and washing, thus separating the iron particles by means of gravity. In places where electricity is available magnetic methods of separating the iron-oxide minerals could be employed.

In addition to silica sand, the chief ingredients of glass are feldspar and soda ash. Adequate supplies of feldspar can almost certainly be found in the pegmatites between Concepción and the Río Apa. If not, or if transportation costs from that region are excessive, feldspar is a far cheaper commodity than finished glass and the requisite amounts could be imported. The same reasoning applies to soda ash, which is used in relatively large amounts in glassmaking. There are no known deposits of sodium carbonate in Paraguay, but this is a cheap commodity and it would certainly be cheaper to import soda ash than glassware.

Glass factories require comparatively small capital investments for machinery, and either wood or charcoal are adequate as fuels. Existing plants would require modernization, particularly in improved chemical control of the raw materials and in control of temperatures if any serious attempt is made to supplant imports. It is probable that the necessary technical skills are already in the country, either among Paraguayans who have learned glassmaking techniques in the existing factories or among some of the immigrants from Germany and other European countries.

MINERAL PAINTS

Paraguay uses comparatively large quantities of paint for both exterior and interior decoration. Virtually all the paint needed is imported, either as pigment or as prepared paints, yet there is abundant material locally to supply all the requirements for yellow, orange, pink, red, and brown colors that are used. This material exists in the form of the rich iron ores near Caapucú, in the low-grade lateritic iron ores that cover the surface in much of central Paraguay, as concretions of iron carbonate in some of the clay deposits, and in various other forms. The only treatment needed to produce excellent mineral pigments from such materials consists of washing, roasting under carefully controlled conditions, grinding, and grading as to color. The resultant pigments should be equal in most respects to imported products.

The suggestion that Paraguay could produce much of its own paint is not original; DeMersay (1860) in his description of the red soils of the Misiones, near Encarnación, Trinidad, and other towns along the Alto Paraná, says that the early Jesuits used local materials in decorating their churches and colleges. He says that "clay veins" in the soils yielded red ochre, which was calcined, ground, washed, and mixed with a mucilage made from the juice of a local cactus (*Cactus peruvianus*). He adds that yellow and white paints were made in the same way as the red ones.

A small pigment industry would require only a few hundred dollars worth of washing, grinding, and roasting equipment. Technical knowledge can be easily gained by experiment and from the literature, or, perhaps better, by sending a technician to Brazil where there is a well-developed though primitive pigment industry. Except for the initial machinery, no raw materials would need to be imported in order to produce pigments regularly.

Production of pigments alone would save many dollars of foreign exchange annually. The saving could be increased several fold if finished paints, instead of pigment, were produced. Locally produced tung, linseed, and castor oils could be easily and economically treated to produce excellent vehicles for paints. If these oils were used, a fair share of the country's paint requirements could be met with no imports other than turpentine, small amounts of dryer, and containers for the final product. High-grade modern paints would, of couse, also require the importation of white lead, lithopone, and other ingredients. As noted above, glass containers could be produced locally, saving additional amounts of foreign exchange.

PORTLAND CEMENT

The portland cement plant at Vallemí has already demonstrated that it is technologically possible to produce good portland cement in Paraguay. Large reserves of raw material and fuel are available locally. Except for machinery parts and balls for grinding, the only materials that must be imported are a few tons of gypsum per year and paper bags for sacking the finished product. Paper bags could be replaced by locally made cotton bags or wooden kegs if that should seem desirable to conserve a little additional foreign exchange.

As this is the only large-scale mineral industry now in Paraguay, except for brick and tile, and as it is capable of producing all of the vitally needed cement, it would appear advisable for the Government to use all possible means to encourage and maintain regular production and to place the venture on a sound financial footing. This is even more desirable if the Vallemí plant is capable of producing an exportable surplus of cement over Paraguay's requirements.

POTTERY AND CLAY PRODUCTS

Paraguay contains abundant deposits of clay suitable for most grades of pottery, earthenware, and many other products, yet it still imports a large proportion of its needs of finished goods. Many of these needs could be produced locally with adequate modern machinery and careful technical control throughout the manufacturing process. Probably the initial investment would be relatively large, but continuing imports of raw materials would be small and would be confined essentially to coloring materials and to ground feldspar for glazes. As suggested in the paragraph on glass-making, there is a strong probability that requirements of feldspar can be met locally when more is known about the bodies of granitic rock near the Río Apa and elsewhere in the country.

TALC AND PYROPHYLLITE

Talc, which is used as a filler in insecticides, soaps, paints, and many other products, is imported in comparatively small, but nevertheless important, quantity. One deposit of talc is known near San Miguel and was being actively explored in 1952; other deposits will doubtless be found. As described above, there is also at least one very large deposit of pyrophyllite, which is adaptable to most of the same uses as talc, north of Caapucú.

It is doubtful that the local material is of sufficiently high grade to be used in preparation of toiletries, but it should certainly be able to compete successfully with imported talc for most commercial purposes. Moreover, if a cheap local source of talc were available, the demand for it would probably increase.

WATER RESOURCES

Water is unquestionably the most valuable single resource in Paraguay. There are possibilities of developing hydroelectric power at the Salto del Guairá on the Río Paraná and at smaller falls on several major tributaries of that stream. Were it not that all the potential sources of water power are so remote from centers of population, such possibilities doubtless would have been realized long ago. In addition to this potential use, water provides dependable transportation routes through most of the country, and is essential for the farming and livestock industries on which the livelihood of the country depends.

EASTERN PARAGUAY

Because of the heavy annual rainfall (see fig. 3) and the numerous perennial streams (pl. 1), virtually all of eastern Paraguay is abundantly supplied with water for all agricultural and stockraising pursuits. Even so, some crops suffer from drought damage at times, and in parts of the area it is necessary to build small earthen storage dams to provide water for cattle through droughts that may last 6 months or even more. In many areas, however, the problem is one of too much water, rather than too little. A glance at plate 1 reveals enormous areas that are swampy or marshy during at least parts of every year. Some of this marshy ground is well adapted to rice culture. Most of it, however, is suitable only for grazing land and is not even very desirable for that purpose because the grass it supports is inferior in nutritive value and there is danger of miring of stock. Recent experiments at the stock ranch of the Institute of Inter-American Affairs at Barrerito, 12 kilometers east of Caapucú, have shown that the swampland there can be easily converted to excellent grazing land, and at comparatively low cost, by means of drainage ditches. Similar experiments in drainage appear to be justified elsewhere in eastern Paraguay. It is to be expected, though, that some of the poorly drained soils that are derived from shale and similar rocks may not be as easily drained as the soils at Barrerito, which are derived from granite.

Virtually all the water needed for domestic and industrial use in eastern Paraguay comes from wells or, to much less extent, from stored rainwater. It is difficult to understand why surface water is not used more widely. Nearly all the larger communities are on the banks of the Paraguay or Paraná rivers, or on their major tributaries. All these streams carry a superabundance of water that could be recovered at little cost. All doubtless are bacterially contaminated and would require treatment, but it is certain that none can possibly be as contaminated as are many of the raw surface-water supplies in, for example, the United States.

In Asunción, much of the water for domestic use comes from shallow dug wells that depend on near-surface seepage for their supply. There are also a few deep wells, drilled to depths of 60 to 100 meters, which yield adequate supplies of good water from what appears to be the principal zone of saturation in this vicinity. A few deep wells in Asunción have been failures because they were drilled into sills of basaltic rock similar to that exposed on Cerro Tacumbú, but apparently most of the wells that are more than 60 meters deep are successful in finding water. Both dug and drilled wells are, of course, subject to contamination from surface wash unless they are properly protected.

Ground water conditions in most other communities are believed to be similar to those in Asunción. Generally speaking, moderate to large supplies of fresh ground water will be found in all the alluvial materials and sandy rock formations throughout eastern Paraguay. Formations that are made up principally of shale or clay will yield little, if any, water. The same statement is probably true of some of the volcanic rocks and of the rocks in parts or all of the Precambrian areas. The only known exception in the latter category is at the Barrerito ranch east of Caacupé. There, a well at the ranch headquarters tapped a good supply of water after almost 70 meters of solid granite had been penetrated. It is believed that the water occurred along one of the major northeastward-trending fault zones shown on plate 1 in that vicinity.

GRAN CHACO

Despite the innumerable streams that meander over the surface of the Gran Chaco (see pl. 1), water, and lack of water, are the chief obstacles in the development of its vast lands for agriculture, stockraising, or other uses. This paradox is caused by the fact that in this arid tropical climate the surface waters tend to alternate between states of flood and of drought, when most streams and waterholes become dry. A closely related and no less important factor is that most of the water, both surface and underground, is reportedly so highly mineralized as to be unfit for most uses. Bad water, as well as the periodic lack of water of any kind, is generally supposed to have caused more casualties to both sides during the Bolivian-Paraguayan Chaco War of the 1930's than did enemy action. Similarly, scarcity of water for both drilling and for camp use was one of the greatest problems met by the Union Oil Company in its exploration for petroleum during the midforties.

There are a few relatively deep water wells in the Gran Chaco, both in the Mennonite colonies in the interior and in several of the settlements along the west bank of the Río Paraguay. Except for these, most of the scattered army posts and ranches depend on shallow dug wells, on natural waterholes, or on small earth-dammed reservoirs for domestic supplies and for cattle. Such supplies are unsatisfactory at best and are of course unreliable during prolonged droughts.

The few facts available suggest that the water-supply problems of the Gran Chaco are not necessarily insurmountable. A vigorous but careful effort to solve them might well result in development of sufficient water to make the Gran Chaco outstanding in meat production and possibly agricultural food products.

The ideas presented here are nebulous in the extreme, because of lack of specific local knowledge. They are supported, however, by many facts from the Argentine Pampa, which is the southerly extension of the Chaco Boreal of Paraguay and where the geologic conditions are similar. Stappenbeck (1926) gives many details of the geologic and ground water conditions in the much more highly developed and more thickly populated Pampa. His work includes many well logs and chemical analyses, as well as a small-scale map showing the distribution of artesian conditions not far south of the Paraguayan Gran Chaco.

In any attempt to develop water supplies in the Gran Chaco, ground water must be used rather than the more obvious surface supplies. Even though the surface waters are abundant and of good chemical quality during wet seasons, the topography is such that no large or deep reservoirs are feasible. It thus seems impracticable to count on storage of fresh flood waters for use during droughts when the streams dry up or become too salty even for cattle. Instead, it would seem that the principal problem offered by the surface waters is one of drainage and of flood-protection. Such works, desirable though they may appear, are doubtless beyond the ability of the Paraguayan economy in the forseeable future.

Too little is known of the geology of the Gran Chaco to permit pinpointing of the area or areas that might yield usable supplies of ground water or formulation of any detailed suggestions as to the best methods for developing it. Two possible geologic sources of water are apparent, however, and both include very large geographic areas.

One source is the great sedimentary basin that occupies all but the northern part and the easternmost fringe of the Gran Chaco. The subsurface geology of this basin is known in a most general way from the records of the few deep exploratory wells put down by the Union Oil Company. No records are available to the author as to the quantity or chemical quality of any water that may have been in these wells. Any such information would be of doubtful value, for wells drilled in search of petroleum are notably prone to miss evidence that bears on water supplies.

It is known that the Gran Chaco basin contains a thick series of unconsolidated sediments and sedimentary rocks, that many of the rocks must be permeable to water, and that some crop out at the surface and, hence, provide catchment areas in Bolivia and northern Paraguay. Owing to the basinal structure, artesian conditions probably are widespread, though whether flowing wells can be obtained even on low ground is not known. Both the quantity and quality of the water in these sediments are of course conjectural, but by analogy with other sedimentary basins throughout the world it is reasonable to suppose that they contain fresh water in places, which might be recoverable by pumping or artesian flow from deep wells. Any more definite knowledge as to the availability of water at depth must await much more detailed knowledge of the subsurface geology of the Gran Chaco than is presently available. Considering the number of aquifers that must be present, it is entirely possible that wildcat wells might strike fresh water. The knowledge gained by means of such wells could be made the basis of a deep-well drilling program, backed by thorough geologic and geophysical studies.

The chances of developing fresh-water supplies from shallow aquifers in the Gran Chaco are somewhat more promising and easier of accomplishment than are the chances from deeper parts of the basin.

In a few parts of the Gran Chaco, the permanent water table is relatively near the surface and yields fresh water readily to pumped wells. In some places the lower part of the fresh-water zone grades downward within a few tens of centimeters to water that is so highly mineralized as to be unfit for use; elsewhere the fresh water is separated from underlying mineralized water by impermeable layers of clay. The few available analyses of "salt" waters in the Gran Chaco indicate that the principal constituents are of sulfates and chlorides of sodium and magnesium. No information is available as to whether any fresh-water zones exist beneath the "salt" waters.

The near-surface stratigraphy of the Gran Chaco is, of course, no better known than is the stratigraphy of the deeper and older beds. Because of the continental-alluvial conditions under which the younger beds were deposited, it is likely that most if not all of the younger beds are decidedly discontinuous, and, hence, that conditions found in any one well could not be extrapolated more than a few kilometers at most from the point of discovery.

If any serious attempt is made to develop near-surface supplies of fresh ground water in the Gran Chaco, the first necessary step would be to make an inventory of available information on all existing wells. On the basis of the data so derived, a series of exploratory wells 30 to 100 meters deep could then be drilled, with provision for offsetting any successful wells so as to delimit the areas that yield fresh water at reasonable depths. Any such program should be under the direct supervision of a geologist experienced in ground-water investigations, for, in the absence of surface exposures, useful information as to existence or distribution of fresh water can be gained only from close observation and control of the drilling operations and from study of the records so obtained. Once some guides are established by the suggested exploratory wells, geophysical methods might be used to trace out fresh-water-bearing horizons. Careful attention to and experimentation with methods of drilling, casing, and screening are at least as important as is geologic control, for there is always grave danger of missing fresh-water aquifers entirely, or drilling through them and contaminating the fresh water with underlying salt waters.

This suggested program of exploration has the virtue of flexibility as to scope; it could easily be restricted to small areas where the need for water is the greatest. Moreover, whatever its scope, it bears promise of possible reward far beyond its cost.

SOILS OF PARAGUAY

By Pedro Tirado Sulsona

About 70 percent of eastern Paraguay is covered by relatively deep residual soils that range from loamy sand to sandy clay in texture. They are classified in seven major soil series, the differences between them more closely related to the parent materials from which they were derived than to any other single factor. The remainder of eastern Paraguay is covered by transported soils, divided into four series; like the residual soils, all are sandy. As would be expected from its geologic history, virtually all of the Gran Chaco is covered by transported soils ranging from sandy loam to clay that are classed in six major soil series, with distinctions based more on drainage and topographic position than on parent materials or other features. The soils of Paraguay are described briefly in the accompanying table; their general distribution is shown in plate 3.

The soils of eastern Paraguay provide favorable to adequate conditions for root penetration, aeration, and water absorption and retention. The areas of transported soils, however, are generally characterized by a water table near or at the surface.

The residual soils are low in exchangeable calcium and phosphorus, and low to adequate in organic material and in nitrogen. They are commonly acceptable to high in exchangeable magnesium and potassium. Most are acid, the pH ranging from 5.8 to 6.8. The alluvial soils are higher in all nutrients than are the residual ones and can generally be considered as adequate for agricultural purposes if proper drainage can be attained.

All the eastern soils, transported and residual, tend to be very low in the minor elements, such as copper, zinc, manganese, and cobalt, which are known to be essential to healthy plant or animal growth. This shortcoming is doubtless a dominant factor in the slow growth and maturity of cattle, and perhaps it even contributes to the comparatively small stature of most of the people.

The absence of minor elements, as well as the low content of such elements as calcium and phosphorus, is a direct result of the geologic and soil-forming history of the region. As most of the soils are derived from sandstone, whose constituents represent long periods of weathering and of rather thorough sorting, it is only to be expected that they contain much smaller amounts of many essential elements than would soils formed from the weathering of rocks or mineralized zones that were richer in such materials. Moreover, all the eastern soils have evolved under tropical conditions, with heavy precipitation, so that much of the nutrient material they may have had originally has long since been removed by leaching.

The Gran Chaco soils are, as would be expected, richer in all the essential chemical elements than are those of eastern Paraguay. They represent alluvial material that, geologically speaking, has been freshly washed down from a great variety of rocks in the Andes and that has had little opportunity to lose these elements by leaching. Were it not for the high water table and the abundance of magnesium sulfate and other salts, there is little doubt that the Gran Chaco soils would be far more amenable to agriculture and to stockraising than are those east of the Río Paraguay.

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