REPUBLIC OF PARAGUAY
PRESIDENCIA DE LA REPUBLICA
SECRETARIA TECNICA DE PLANIFICACION

THE STUDY ON WATER POLLUTION CONTROL PLAN FOR THE LAKE YPACARAI AND ITS BASIN

VOLUME 3
SUPPORTING REPORT Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ

AUGUST 1989

JAPAN INTERNATIONAL COOPERATION AGENCY

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TOPOGRAPHY, GEOLOGY AND SOIL

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TOPOGRAPHY, GEOLOGY AND SOIL

CHAPTER 1

TOPOGRAPHY

1.1 Location of the Study Area

The study area, Lake Ypacarai and its related basins, is situated between 57°05' and 57°35'W longitude and between 25°05' and 25°35' S latitude. The area lies in a NW-SE direction, with a length of 65Km, the widest area at 30Km and an area of 1,084Km^2.

1.2 Study Methods

In this study, investigations on the general topography of the land basin as well as on the water basin were carried out. Land basin conditions and land use conditions were studied on the basis of existing topographic maps, new aerial photographs and on-site investigation.

Water basin topography was studied by conducting control point survey, depth survey and cross-section survey.

1.2.1 Aerial Photographs and Topographic Maps

The index map of the aerial phtographs newly taken in this project is shown in Fig. S1.1.1. The photo numbers, by origin and course, are shown in Table S1.1.1.

Table S1.1.1 Employed Aerial Photographs

Scale : 1:40,000 Photographic Altitude : 6,060mts
Date : Feb. 5, 1988 Photo. Company : Terra Foto, SAO PAULO, BRAZIL

COURSE No. LINEA	PHOTOGRAPH NOS. EXPOSICION	Number of PHOTOGRAPHS
01	1~23	23
02	1~22	22
03	1~24	24
04	1~19	19
05	1~13	13
		Total 101

Basically, in order to learn of the past land use conditions, the following materials were used for reference.

Aerial photo. MARCH 1984
SCALE 1/50,000 (approx.)
MMTAP-PT-84-3 R5 7941~7945
MMTAP-PT-84-3 R6 7985~7987
Total 8 pieces

Mosaic semi-controlled photo map
Prepared by the Army Map Service. U.S.A. 1965
Aerial photo JUN~AUG 1965
SCALE 1/100,000 (approx.)
ASUNCION STOCK No. H041×5370
LUQUE No. H041×5470

The base map used for the study was a map compiled from the 7 sheets indicated in Table S1.1.2 which were taken from the CARTA NACIONAL, PARAGUAY 1:50,000 of the DIRECCION DEL SERVICIO GEOGRAFICO MILITAR, PARAGUAY.

Table S1.1.2 Employed Topographic Maps

5370- I VILLA HAYES	5470-IV LIMPIO	
5370-II ASUNCION	5470-III YPACARAI	5470-II CAACUPE
	5469-IV ITA	5469- I PARAGUARI

The background of the above is the following

		FOTOGRAFIAS AEREAS TOMADAS	COMPILADO	IMPRESO
5370- I	VILLA HAYES	1965~1978	1973	1983
5370- II	ASUNCION	1965	1971	1987
5469- I	PARAGUARI	1965~1978	1969	1987
5469-IV	ITA	1978	1969	1985
5470- II	CAACUPE	1965~1978	1971	1987
5470-III	YPACARAI	1965~1979	1973	1986
5470-IV	LIMPIO	1965~1984	1970	1985

From the time of topographic mapping to that of taking the recent aerial photographs, changes that have occurred in the topography and in natural land features (lakeshore configuration, water courses and roads) were checked through airphoto interpretation and corresponding modifications were made as much as possible.

1.2.2 Survey of the Lake Area

A topographic survey of the lake and its immediate surroundings was carried out by local companies under Japanese supervision to obtain cross sections of the major inflowing and outflowing rivers and to prepare a bathymetric chart, which are necessary in estimating the volume of river water inflow and outflow, as well as the lake water volume.

The topographic survey consisted of control point survey, depth survey and cross-section survey.

The control point survey was carried out to determine the position of control points which are necessary for the depth survey and sampling work in the lake.
The positions of 50 control points were determined by a traverse survey and forward intersection method.

The depth survey was carried out by an echo-sounding method using a 12 KHz echo-sounder. Total length of the survey line amounted to about 150Km.

The cross-section survey was carried out by direct leveling, 14 sections of 4 rivers being surveyed.

1.3 Topographic Summary

The Lake Ypacarai and its basins lie between the following boundaries : at the SE, upstream side, Paraguari city; 65Kms from that point at the NW, downstream side, Rio Paraguay; at the NE side, Cordillera de Los Altos plateau at an elevation of 400-200m, and at the SW side, Cordillera de Yaguaron and the adjacent hilly land at an elevation of 300-100m.

The zone lying between these two mountains is a marsh which has an elevation of 150-100m and a width of 5-8Km. At the center of this is Lake Ypacarai (area 59.6Km^2, length 11Km, average width 5Km, water depth less than 3m). Upstream in the Lake is a grassy marsh and downstream is a swamp.

Principal inflowing rivers are the Pirayu, coming down through the SE plain, and the Yuquyry, coming down through the western hilly land. Others are parts of a group of small rivers on the east and west shores of the Lake. That outflowing river is the Salado, which meanders through the Lake's downstream expansive swamp before joining the Paraguay River.

In order to understand the general outline of the geomorphology of the study area, a relief map was made, which is shown in Fig. S.1.1.2.

At the SE side of the plain, the scarp at the front margin of the Cordillera de Los Altos plateau and the connecting pediment attain continuous elevation of 400~200m, and then at the downstream side, gradually turn to hills.

In the upstream area, some Inserbergs offering a spectacular sight of small mountains can be observed in places. They have been left behind, due to their hard lithology, by erosion and the consequent process of retreating and reduction of the front slope of the plateau. These are known as the Cerro Mbatovi, the Cerro Santo Tomas, the Cerro Jhu, the Cerro Pero and so on.

At the SW side, in the Pirayu basin, the Cordillera de Yaguaron exists, however in a dissected state of hilly mountains.

The Yuquyry basin is undulating hilly land at elevations ranging between 200-80m. In the NE area of the basin, Patiño-Aregua hill, adjacent to the Cord. de Yaguaron, extends in a SE-NW direction facing the Lake. The Yuquyry flows down, enclosing the west side of this same hill, passes through the swamp downstream of the Lake and enters the Lake. The course of the water within the swamp lacks a definite formation, becoming scattered downstream.

The main branch stream flows in a S-N~SW-NE direction on the left bank of the main course of the river and dissects the hill continuing until nearly the divide of the Yuquyry basin, forming a 1Km-wide flat river bed plain, revealing a large amount of past erosion.

The plain at the upstream side of the Lake shows similar configuration at its 80m, 100m and 120m elevation lines. Between the 80m and 200m lines there is a large distribution of small ponds.

Furthermore, considering geology and the nature of the soil, it is estimated that the plain was submerged up to 150-200m, forming at one time (the precise era unknown), a large lake.

The formation process of the central plain zone which includes the Lake isn't defined, but it could be considered due to the graben theory, the "erosion along the step fault - echelon fault" theory or the Cuesta theory. However, for any theory, geomorphically, the past occurrence of a tremendous spread of erosion and debris transportation throughout the entire basin is illustrated.

It is hard to believe that this large scale erosion and transportation could be related to the present scale of the Pirayu. It is possible that at a stage in the geological age, the Pirayu was a large river extending as far as south of city of Paraguari, that was however later cut upstream by river capture.

It is difficult to think that the present Yuquyry, even if considering the river channel gradient, contains a large erosive agent. However, if it is assumed that at one time the Lake water level was 120m above sea level, then it is possible that the Lake's water invaded the Yuquyry basin near the Cerro Patiño, between Ypacarai and Aregua, and thereby increased the erosive agent.

1.4 *Topographic Classification*

The main objective in investigating the characteristics of the basins concerning debris supply sources was to produce a basin landform classification map. This is shown in Fig. S1.1.3.

(1) Plateau and its front scarp

This is the front margin zone of the Cord. de Los Altos, bordered by the basin's SE-NE edge. The plateau, at 400~200m elevation, possesses a scarp, comprising a zone which faces the central plain.

The plateau itself forms an extensive plateau of the Piribebuy basin dipping gently east-northeast wards.

This plateau has principally consisted of a nearly horizontal Paleozoic Age sandstone formation. It has shallow, wide, dissected streams and, in places, hard rock sections reflecting the geological structure as ridges or Inserberg are dispersed in a regular fashion.

As for the study area side, the original plateau slope, due to erosion and consequent recession, possesses an outer edge which is abundant in bends and, from the edge of the plateau, at the point of a scarp and steep slope, drops off suddenly.

As for the surface of the plateau, in general, the soil layer is undeveloped and the base rock has numerous outcroppings, but it is utilized for farming and urbanization. On the front scarp, the vegetation is comparatively well preserved.

Moving downstream, the scarp becomes less remarkable and changes gradually from a dissected mountain to a hilly formation.

At the near side of San Bernardino and downstream area of the Salado, many small scale quarries are distributed.

(2) Mountains

These refer to highlands extending from Cord. de Yaguaron to the Cerro Patiño, at elevations exceeding 200m. An appropriate name for this formation would be a "hilly mountain", rather than a mountain.

The vegetation is comparatively good, but it is diminishing due to the advance of farmland. Because the base rock is hard, outside the vegetated areas the soil is of low development and, in many places, the surface soil isn't settled.

Depending on the growth of the pediment path resulting from erosion and dissection, the narrow tall mountain body contracts into a sausage formation, gradually transforming into isolated hills.

(3) Pediment

At the lower parts of the front scarp of the plateau and the mountain, there is clearly a piedmont line and a continuous gradually sloping area. With the recession of the plateau slope arises an outer edge abundant in bends and also areas of dissected valley.

At one time, it is thought that the plateau was covered by forest, however, presently, it rests largely transformed into farmland, on which is grown Paraguay coconut and corn, and also into colony land.

The plateau consists of Paleozoic conglomerate - coarse sandstone along the Cord. de Los Altos as well as from Paleozoic sandstone and conglomerate from post-Cretaceous Era, along the Cord. de Yaguaron. The surface layer soil is of comparatively good distribution, however, due to rainfall, a zone has developed which suffers drastic sheet erosion. In vegetation-meager areas, the surface layer is washed out and the basic rock exhibits abundant outcroppings.

(4) Mantled pediment (partly Fan)

Continuing from the (2) pediment downstream border is a gently sloping zone and due to creeping and washing out of debris supplied from (1) and (2), there is transported sedimented matter. In the vicinity of Pirayu, a fan-like topography has been formed.

Basically, this is a half marsh / half grassland which, up until a comparatively recent geologic period, is thought to have been submerged and, grade into consequent alluvial deposit, in interfinger contacts. Due to flooding, this is an easily submerged zone.

On the Cord. de Los Altos, the dissection has progressed along the stream until the upper end of the slope. There have also been formed waste-filled valleys.

The east side is principally used as pasture, partly farmland and for housing. The west side, usage in the form of farmland and for housing is even greater.

(5) Hills

Hills are distributed widely throughout the entire Yuquyry basin and the western side of the Cord. de Yaguaron, achieving elevations of 200-100m. The hills are of the post-Cretaceous red sandstones. Due to progressed dissection, the surface is rounded and exhibits a gently sloping topography.

Within the study area, land use is highly advanced in the form of urban land, housing, industrial land, farmland and roads. In recent years urbanization has rapidly progressed and farmland has diminished. Essentially, geologic and topographic conditions for easy surface soil development exist, however because of sparse vegetation and progressed urbanization, soil erosion is strongly active under various forms.

(6) Marsh (Moor)

This is the Pirayu's low, flat marsh-like zone. The surface deposit is sandy soil at a thickness of 1m. The position of groundwater is also high.

Within the marsh, round ponds, with diameters up to 200m, are widely scattered.

The area is principally used as pasture.

Traces of former meandering river channels and tributaries and ponds can be interpreted from aerial photography, however theyare often buried by floods, therby giving the land an extremely flat, low surface.

(7) Natural Levee

This is the long, continuous micro-relief running along the main course of the Pirayu and its principal branch stream which often gives rise to river bank forests.

(8) Swamp

① is a zone found along the Pirayu's main course with a width of 1-2Km. ② is a zone found widely spread between the lower reaches of the Lake and the Paraguay River.

① is a marshy grassland formed of grayish black-brownish black clay deposits. At normal times, it is not full of water, however in torrential rains, it is easily submerged. Near the mouth of the river, the swamp is composed of hydrophyte and normally full of water.

This is used for large scale pasture.

② is extremely similar to ①, however is of a larger scale, has wide distribution of normally flooded areas and areas of luxuriant vegetation and also a tall tree forest.

The sedimentation process taking place over many years has produced a soft zone composed of sand, clay and humus from lake bottom alluvial deposits. North of Aregua 10Kms, the Nueva Asuncion area is relatively higher from the circumference and exhibits, on comparatively dry flatland, the beginnings of a housing development, however as there is an insufficiency of potable water, the project has been abandoned. The land, other than being used as pasture, is almost completely unused.

This zone is said to represent the former natural environment of the Lake, in a preserved state, and a treasury of aquatic plant, animal and bird species.

(9) Riverbed Plain

This is the riverbed of the main stream and main branches of the Yuquyry, with an elevation of 120m above sea level.

The riverbed has a dissected flat, dish-like profile, is covered by sand and clay deposits, has a normally low flow amount and is however, during torrential rains, easily submerged. Black-brownish black clay are distributed in various places and are mined to make bricks.

(10) Isolated small hills

On the plain at mid-point between Pirayu and Ypacarai, with a relative height of 100m are located ellipsoidal igneous rock hills of a major axis below 1Km which are quarried for road construction use.

Also upon the gently sloping hilly land of Cerro Coi and Cerro Chorori (both at 180m elevation), 1Km west of Aregua, there are protruding isolated hills.

At one time, unique rock of a columnar joint with a hexagonal profile developed, which is now used for road pavement material.

The same type of rock is processed also at the quarries of San Lorenzo and 2-3Km east of Luque.

(11) Lake

The Lake is situated at nearly the center of the central lowland zone, is swamp-like and has, at present, a surface area of approximately 60Km^2.

Through this study, the water depth and landform of the lake basin became clear.

The profile presented is entirely and extremely flat and dish-like and has a maximum depth of 3m. At a point 500m from the lakeshore, the lake floor gradually slopes, however at the bottom after the 500m point is almost completely flat.

Excluding the Pirayu river opening at the inflowing side of the Lake, the fairway is not identifiable at the lake bottom.

At the Lake bottom, black mud seems to be widely spread. On the east shore at San Bernardino and on the west shore at Aregua, a sandy quality is present and the land near the water is used as a resort area.

The thickness of the mud at the lake bottom could not be confirmed by a columnar bottom sampler.

1.5 Basin Division

According to airphoto interpretation, extraction was made as far as first order drainage and on a 1:50,000 topographic map, the boundary of drainage basins was established. This is shown in Figs. S1.1.4, S1.1.5.

Due to the distribution of flat marshlike - swampy plains throughout the study area, by rainfall and submerging, channel alterations and river captures frequently and easily occur, thus characteristics are traces of perplex drainage pattern and drainage divide.

The Lake's basin is divided into 4 basins : at the SE, Pirayu basin, at the W, Yuquyry basin, on the east shore, the east shore basin and on the west shore, the west shore basin.

The results from the order-analysis of the drainage system* state that the Pirayu and the Yuquyry are equivalent 4th order streams and on the east and west shores of the Lake, small 2nd - 1st order streams are present.

*1 The terminology for this stream order : stream class and / or stream order. It signifies a system of rating main water courses and tributaries of various degrees by assigning numerical values. As for A.N. Strahler's stream order, from the top to the point of confluence, from the point of confluence to a point of confluence with another water course of the same order. . . , orders are given in the so - called interval between points of confluence of same order water courses and the exit of the basin. There are many methods for assigning orders. In all the methods, affixing orders on the map from the contour line configuration over the valley topography, by extending the vertical line over the valley topography and according to the water system map.

1.6 Lower Stream Area of the Yuquyry

Topographically, the Yuquyry doesn't flow directly into the Lake, but into the Lake's downstream swamp, resulting in an indefinable flow path.

On the Paraguay side as well, water from the Yuquyry doesn't enter the Lake, but is thought to enter into the Salado. Land use in the Yuquyry basin is expansive and facilities discharging every type of pollutant are abundant. Thus, whether or not the Yuquyry's water enters the Lake will make a big difference in devising Lake pollution measures. Clarification of this matter was attempted.

On the Yuquyry, between the iron bridge 7Km NW of Aregua and 3-4Kms east of this, a water course with a width of 10m has clearly formed, however it gradually has become a swamp zone, losing its singular water course characteristics. Traversing the swamp, naturally, even in a small boat is difficult. Besides, among even the local people, there is not one who really is interested in where the Yuquyry water goes.

For this study, besides a detailed interpretation of the aerial photography (Fig. S1.1.6), on-site investigations along the water courses and from the air by use of the Navy's helicopter were carried out.

The results show that, in the past, it seems a water course existed along the southern edge of the micro-relief near Nueva Asuncion (thought to be a fan formed by the Old Yuquyry). That course ran in the direction of the Salado, however at present is indefinable and the land is partly used as pasture.

The present water course curves in an E - SE direction and, although the water courses regulated on the micro-relief within the swamp are scattered, the slow flow moves entirely in the direction of the Lake. These water courses, together with the Riacho Negro, near the lakeshore, and numerous other small ones all flow into the Lake.

In a sense, there is no recognition of a definite water course joining this river and the Salado. In the past, it is said there had been a human-built canal, in order to lead the water to the Salado, however at present, it is not used.

Furthermore, moving down the Salado in a boat until the wood bridge which crosses the swamp, there is no identification of any definite inflowing water course.

Considering the above, it is judged that the majority of the discharge of the Yuquyry either directly enters or indirectly oozes into the Lake and that a definite portion indirectly penetrates the swamp and then oozes into the Salado.

1.7 Lake Survey Results

Fig. S1.1.7 is the bathymetric chart of Lake Ypacarai (original scale is 1/25,000, contour interval is 10cm), and Fig. S1.1.8 is representative cross-sections of the lake.

The datum level of water depth is 120cm on the water gauge (mean water level of the last 22 years) of ADMINISTRACION NACIONAL DE NAVEGACION Y PUERTOS.

Fig. S1.1.9 shows the area of the lake by water depth. The area of the Lake at the datum level is about $59.1Km^2$, and the water volume below the datum level is about $1.15 \times 10^8 m^3$.

Above the datum level, the water volume increases by $6 \times 10^2 m^3$ as the water level rises 1cm.

The maximum depth at the debouchment of the Salado is 85cm below the datum level. Therefore, outflow from the Lake is impossible when the water level is under -85cm.

Fig. S1.1.10 shows the distribution of sub-bottom materials in the lake which were assumed from the echo-sounder records and grab-sampling.

Mud covers the majority of the Lake floor. On the other hand, sand distribution is limited in the eastern margin of the Lake.

Main rivers

Fig. S1.1.11 shows sites of the cross-section survey.

As the absolute height could not be obtained, the relative height above the temporary B.M. is shown except for that for the Yagua-Resa-u and the Y pucu.

CHAPTER 2

GEOLOGY

2.1 General Description of the Field Survey

The purpose of the geologic survey in this project is not to clarify academically the geologic problems such as geologic distribution, structure, history and so on, but to understand the characteristics of subsurface soil as closely related to distribution of vegetation, type of land-use, type of debris production and so on.

Surface geologic survey of the entire study area was carried out in order to clarify the characteristics of subsurface soil which is easily affected by the nature of bed rocks as parent material.

In the preliminary survey, an outline of the geologic distribution in the study area was observed by field survey and typical rock samples were collected. The preliminary geologic mapping was attempted in accordance with microscopic observation of rock samples and airphoto interpretation.

This preliminary geologic map was checked and corrected by the second field survey, sampling, additional microscopic observation, X-ray analysis and airphoto-interpretation, in order to draft the geologic map shown in Fig. S1.2.1. The number of rock samples is as follows.

	Microscopic observation	X-ray analysis
Feb. '88	27	6
Jul. '88	12	5

2.2 Geological Outline

The moorish plain, 65Km long, 5~8Km wide and 100~150m above sea-level, trends in a northwesterly to southeasterly direction in the central zone of the study area, with the Lake, at almost the center.

At the SE side of the plain, the Cordillera de Los Altos plateau ranges in elevation at 200~400m above sea-level. At the SW side, the Cor. de Yaguaron and its connecting hills are distributed at elevation of 100~300m above sea level.

The following bibliography describing the outline of geology of Paraguay was obtained.

GOBIERNO DE LA REPUBLICA DEL PARAGUAY

Comisión Nacional de Desarrollo Regional

Integrado del Chaco/Ministerio de Defensa Nacional

ORGANIZACION DE LAS NACIONES UNIDAS

Programa de las Naciones Unidas para el Desarrollo

Departmento de Cooperacion Técnica para el Desarrollo

PROYECTO PAR 83/005

MAPA GEOLOGICO DEL PARAGUAY

Texto Explicativo

1986

In this bibliography, stratigraphy and geologic age of the study area are summarized as follows :

「The basement of the area is composed of granite and sub-effusive porphyritic rock and a radioactive isotopic ages indicated them to be early Paleozoic in age.

The NE side of the area is composed of a sequence of conglomerate-sandstone-siltstone formation. The age given by the fossils indicates them to be later Ordovician to early Silurian in age.

This formation is comformable, intergradational, and arranged in a NW-SE direction.

At the SW side of the area, similar formation is narrowly arranged along the plain in a NW-SE direction, and is unconformably underlain by a conglomerate~sandstone formation, regarded as late Cretaceous ~early Tertiary in age, distributed widely in the area.

The area has even been intruded on small scale, by the Oligocene / Miocene igneous rocks.

Present geologic structure has been controlled by the Cretaceous~Tertiay igneous activity and a tectonic trend in the NW-SE direction is apparent in this area. The area had been divided in tectonic blocks by accompanied faults along this trend.

The mentioned geologic relationship is shown in Table. S1.2.1」

Table S.1.2.1 Compiled Stratigraphic Order of the Study Area

Cenozoic	Quaternary		SAN ANTONIO FORMATION
			ÑEMBY IGNEOUS ROCK
	Tertiary		PATIÑO FORMATION
Mesozoic		~~~ unconformity	
Paleozoic	Silurian	ITACURUBI Group	CARIY FORMATION
			VARGAS PEÑA F.
			EUSEBIO AYALA F.
	Ordovician	CAACUPE Group	TOBATI F.
			CERRO JHU F.
			PARAGUARI F.
	Cambrian	~~~ unconformity	
		CAAPUCU GRANITE	

The geologic map was prepared in this survey mainly on the basis of lithofacies classification, rather freely from comparison of geologic age and/or correlation of beds.

Microscopic observation and X-ray analysis of important rocks were carried out.

2.3 Stratigraphy

2.3.1 Basement Rocks

① Granite

This rock constitutes the basement of the study area but provides few outcrops.

This crops out

a) On the hill (80~100m above sea level), where CORPOSANA facilities are located in San Bernardino, and

b) At an abandoned quarry by the road (100~120m above sea level), 7Km east of Ypacarai, and

c) According to drilling data of SENASA, carried out at the foot of Cerro Palacios about 5Km northwest of Paraguari, existence of granite is reported at 55m below surface (110m above sea level), at PARAGUARI POZO(well)2, and at 80m (90m above sea level) at POZO 3.

Granite of a) is hard and compact two mica granite and reddish brown in color, and by its joint system in E-W and N-S directions, forms divided blocks of 2~3m in diameter.
This granite is unconformably underlain by the after mentioned arkose sandstone.

It is composed mainly of quartz (equigrained in 0.5mm±), potash feldspar, plagioclase, muscovite and biotite, with accessory zircon, apatite, tourmaline and opaque minerals.

In general, this rock is slightly altered, and potash feldspar and plagioclase show a slightly dirty brownish color, and plagioclase and biotite are converted partly into chlorite.

A part of quartz and potash feldspar show a myrmekitic texture.

Granite of b) is remarkably weathered, altered and decomposed coarse grained granite, and undergoes chloritization and very easily becomes coarse grained sand.

Granite of c) is briefly described only as "ROSADO Y MASIVO " and its details are unclear.

According to BITSCHENE AND LIPPOLT (c.f bibliography) the determined granite age of San Bernardino is within the interval of 573±14 Ma to 576±15Ma, indicating it being Precambrian in age.

② Granite porphyry and/or Hydrothermally altered acidic tuff

This is dark gray to gray black in color, compact and very hard porphyritic rock.

Out-crops are exposed on the low plain in four elliptical formed hills (diameters are less than 1Km in length and 20~60m in height), 4Km southeast of Ypacarai.

They are quarried for paving material.

However the petrographic name of this rock is hard to identify due to its changeable texture, at least it is the acidic rock rapidly cooled at surface or subsurface conditions.

According to the microscopic observation, it is composed mainly of quartz and plagioclase, with accessory zircon, apatite and some hydrothermally altered minerals such as biotite, ferro-hastingsite, chalcedony, sericite, chlorite and opaque minerals, and also some weathered limonite and vermiculite.
It contains sometimes xenolith of metasediments.

Fluidal texture, quartz of corroded on and crushed quart are generally common.
Microflaky biotite are visible in quartzo-feldspathic matrix.
Chalcedony fills up the existing openings.
Recrystallized textures are sometimes visible in quartz.

Two types of quartz phenocryst are recognizable. The first type is of a magmatic origin and the second type is of a hydrothermal alteration origin. The first type shows clear idiomorphic form and corroded form.
In the second type, micro-crystals of quartz are visible in gathered veins or pools and are commonly formed along the original fluidal texture.
Plagioclase shows an idiomorphic prism of less than 4mm in length.
Sometimes it is converted to sericite by hydrothermal alteration.
These textures suggest the occurrence of this rock as an intrusion in acidic tuff and as succeeded by hydrothermal alteration.

According to BITSCHENE AND LIPPOLT (1985), the determined age of this rock is 553±20Ma.

The activity of acidic magma, indicated by granite of San Bernardino and above porphyritic rocks, has been considered to play a part in the Brazilian orogenic cycle (750~450Ma, Precambrian age to Upper Ordovician age).

③ Quartzite and/or Quartz wacke

Small out-crops are observable along the 2Km road NEN of Paraguari, 1Km north of Cerro Cristo Redentor, at 130~140m above sea level.

The rock is light gray to grayish yellow in color, compact and very hard, and shows to silty lithofacies.

Drilling data from SENASA, PARAGUARI POZO 1, reported the existence of ROCA METAMORFICA (metamorphic rock), 70m below the surface (100m above sea level) as follows.

ROCA METAMORFICA, CON RECRISTALIZACIONES VARIAS, COLOR NEGRO PALIDO CON ABUNDANTES CRISTALES DE CUARCITAS Y MINERALES DE CARBONATOS (CALIZAS) DE COLORES CLAROS MUY COMPACTOS.

Lithofacies of these rocks are apparently different from those of granite and surrounding rocks. However the exact age can't be identified, these rocks are possibly Pre-Silurian in age and members of the basement of the study area.

2.3.2 Conglomerate-Sandstone Group

This group forms the plateau of Cor. de Los Altos, in the north-eastern margin of the study area, and is distributed widely in the eastern area of the plateau. This also is distributed in the higher area along the ridge of Cor. de Yaguaron, bordering the western margin.

The east group forms the steep slope of the western margin of the moderately undulating plateau which spreads more east-wards.

This group is classified in four formations in this survey.

This group is almost correlative with the CAACUPE group of the above mentioned bibiliography.

① (Quartzose pebble) Conglomerate Formation

This formation underlies the piedmont area of Cor. de Los Altos , north of Paraguari. This occupies the lower zone at 200m of elevation in the southern area, and the lower zone at 100m in the northern area (extending as far as the midpoint between San Bernardino and Emboscada). Type locality is at a road cut of the route passing eastward, through Itacurubi from Paraguari.

At this locality, subrounded-rounded gravel of quartz schist and metamorphosed chert, at 5~50mm in diameter, fairly swarm within a matrix of quartzose arkose sandstone.

Principal minerals of arkose sandstone are quartz and muscovite. Accessory minerals are zircon, apatite, limonite and hematite. Kaolinite and carbonate minerals are observable as altered minerals. Matrix is composed of micro quartz grains, chlorite and kaolinite (?). The grain size of the matrix is 0.1~1mm, is poorly sorted and subrounded to rounded.

This formation shows a clear conglomeratic litho-facies at the type locality but decreases in number and diameter of gravel, northernward, and grade into coarse sandstone, containing intercalated thin beds of pebble and gravel.

As for the near type locality, this conglomerate grades upward into cross-bedded arkose sandstone.

Abandoned open pits for gravels are observable everywhere because a matrix part of this formation easily decomposes.

This conglomerate~gravel bearing coarse sandstone formation is overlain by alluvial deposits at the eastern margin of the central plain, from Paraguari to San Bernardino, and seems to be distributed widely about 1m below the surface.

This overlain zone was affected by weathering, arosion, alterlation by ground water and/or gleyzation and resulted in a flat surface accompanied by hematite and limonite, and showing the texture of matrix-support with floating grain packing.

Sometimes this zone shows the complex color motling of white~yellow gray~reddish brown.

This conglomerate formation is the basal formation of the conglomerate-sandstone group 2) and rests unconformably upon the granite at San Bernardino.

This is almost correlative with the PARAGUARI formation described in the above mentioned bibliography.

② Subarkose Sandstone Formation

This formation conformably and intergradationally overlies the above mentioned conglomerate formation, and is traceable along the Cor. de Los Altos from Paraguari as far as Emboscada, in the northern part of the study area.

This occupies the higher zone at 200m of elevation in the southern area, and the lower zone at 100m in the northern area.

This forms the remarkable scarp extending from Paraguari to the

National Road No.2, and the rather dissected plateau or hilly landform as far as Emboscada via SanBernardino.

Type localities are observable at a quarry nearby a road cut similar to the case in ①, a road cut in the National road No. 2, at midpoint between Ypacarai and Caacupe, and quarries nearby San Bernardino.

This formation is composed mainly of subarkose sandstone and has considerable variation in color, such as light gray~pale yellow~light yellow orange.

This formation grades laterally and vertically from the above mentioned ① conglomerate and sometimes changes into coarse grained and/or contains scattered pebbles and granules of chert.

This sandstone is composed mainly of quartz grains with a minor amount of matrix.

Grain size varies from 0.1to2.0mm,almost all at 0.5mm and is subrounded to subangular.

Principal minerals of this sandstone are quartz, potash feldspar (±), plagioclase, muscovite and biotite (±).
Accessory minerals are zircon, tourmaline (±), rutile (±), and apatite (±).

Limonite, sericite and kaolinite, and other small amounts of chlorite, epidote and hematite are recognizable as altered mineral.

Lithic fragment such as quartz schist, chert and volcanic rock (rhyolite?) are sometimes recognizable.

This formation shows sometimes plated joints, crossed-bedding and banded structure, and can be frequently found showing lateritization processes. When there is no lateritization, they are friable and show saccharoidal aspects due to their quartzose composition and lack of matrix.

The formation strikes N25° to 50° NE and dips 3° to 5° SE and is more than 150m in maximum thickness at Cerro Jhu, near Paraguari.

The conglomerate formation and the sandstone formation show characteristic landform due to the difference of each one's durability.

Overlying sandstone formation has relatively high durability due to lateritization and forms a front scarp of the plateau with dipping at

40°or so. Underlying conglomerate formation is easily decomposed due to its heterogeneous composition and forms a gentle slope with dipping at 15° or so.

This piedmont line is continuously traceable from a distance.

Geologic blocks divided by fault movement and broken by successive erosion sometimes remain as isolated Inserberg and present a singular sight such as CerroJhú, Cerro Santo Tomás and Cerro Mbatovi.

This formation is almost correlative with the CERRO JHU formation described in the bibliography.

③ Quartz Arenite (Orthoquartzite)Formation

This formation conformably and intergradationaly overlies the above mentioned subarkose sandstone formation, and is traceable in the northern area of Cor. de Los Altos as far as Emboscada. This occupies the zone higher than 100m in elevation .

Type localities are quarries located near Emboscada.

This formation is composed mainly of quartz arenite and has the characteristic platy joints, less than several centimeters thick, and is quarried in place for flooring and wall materials used in building.

In comparison with the above mentioned subarkose sandstone, this rock shows well sorted grain size, less laterization and fresher aspects.

In general, this rock is intensely silicified, sometimes friable and saccharoidal.

This arenite is composed mainly of clastic quartz grain and shows the texture of grain-support without matrix packing.

Grain size is 0.02 to 0.4mm which is mainly fine sand size of 0.1~0.3mm.

Grains are well sorted and well rounded.

According to the microscopic observation, the principal mineral is quartz, and as accessory minerals, tourmaline, zircon and sphane are recognizable. Muscovite, chlorite, kaolinite, rutile, hematite and limonite are also observable. Lithic fragments of quartz schist are sometimes included.

This formation is almost correlative with the TOBATI formation described in the bibliography.

④ Quartz Arenite Formation

This formation is distributed along the ridge of Cor. de Yaguaron forming the western margin of the study area. This occupies an area of about 10Km long, 1Km wide and higher than 200m in elevation, southeast ward from the Cor. Ybytypanema, west of Pirayu.

Type locality is a road cut, 1Km SW of Pirayu.

This formation is composed of light gray~pale yellow quartz arenite.

This arenite is composed mainly of quartz grain, and is massive and hard in general, but containing, however, saccharoidal friable parts. Some parts show scattering hematite patches.

The strike and dip of this formation is obscure.

Grain size is 0.1~2.5mm, mainly at 0.5m±, and subrounded ~ rounded.

The principal mineral is quartz and tourmaline, zircon,muscovite and biotite are recognizable as accessory minerals. Sericite, kaolinite, hematite and limonite are also observable as altered minerals.

Lithic fragments of quartz schist, meta-chert and volcanic rock (rhyolite?) are sometimes contained.

Texture shows grain-support packing~grain-support with interstitial matrix packing.

This quartz arenite is similar to the subarkose sandstone described in ②, in view of its lithofacies and accompanied accessory lithic fragments, but is different in that it contains almost none of the accompanied feldspar. This may be correlative with the ② group.

2.3.3 Alternating Group of Quartz Arenite and Siltstone

At the west side of the central plain, the alternating beds of quartz arenite and siltsone are distributed in the gently sloped mantled piedmont zone, from Pirayu northward as far as Aregua via Ypacarai, in a NW-SE direction, with an elevation less than 150~100m above sea level.

Near Pirayu, lithofacies show alternating beds of siltstones, in spite of detailed occurrences which are obscure due to poor out cropping, and are mined for ceramic raw materials in small scale.

At this spot, beds of ① micaceous siltstone, reddish brown to orange in color, and friable to powder and ② siltstone or quartz arenite, of light gray in color, and friable in plates, are observable.
The former has a sheared zone of a N-S direction and a small scaled folding structure and strikes N50°E and dips 40° to NW.

The latter strikes N to S and dips 60° to 70° W and has a well-developed bedded structure. The unit bed is soft siltstone containing thin hematite bed and has a thicknest of 3~15cm. These siltstone beds are objects for mining.

The principal mineral of the micaceous siltstone of ① is silt-sized quartz grain, accompanied by muscovite (illite?), tourmaline and zircon as accessory minerals.

Kaolinite, rutile, hematite and limonite are recognizable as altered minerals.

The grain size of the quartz varies from 0.02 to 0.08mm, and the quartz is relatively well sorted and subangular to angular.

Clastic grains are mainly composed of silt-sized quartz, and the preferred orientating muscovite with intersecting angles of 135° (45°) scattered throughout openings.

The soft siltstone beds of the same quality as ② are mined by the open pit method as "Caolin" for brick and tile making at Cantera Santa Teresa and Cantera Itaugua, northwest of Ypararai. Many abandoned small scale open pits for Kaolin are located between Ypacarai and Aregua.

At these open pits, the formation is on the whole composed of micaceous siltstone with the basal bed of quartz arenite, however there remains possibility of alternating relation.

Siltstones have considerable color variation: light gray ~yellow orange~grayish red and so on. The original color is light gray but varies to brown, due to plenty of limonite.

Frequent intercalations of thin beds of hematite-rich sandstone are observable.

The total thickness continuously exceeds 20 meters. The quartz arenite often strikes N30° to 40°W and dips 10°~20°S. The siltstone generally strikes N30° to 50°W and dips 5° to 30°SW.

The principal mineral of quartz arenite is quartz, accompanied with tourmaline and zircon as accessory.

Muscovite, sericite, hematite, limonite and kaolinite are recognizable as altered minerals.

The grain size varies from 0.2~0.5mm and the grains are well sorted and subrounded to rounded.

The principal minerals of siltstone are muscovite (illite) and some clay minerals. Accessory minerals are quartz, and limonite, hematite with kaolinite (?) as an altered mineral. Clastic particles are composed of muscovite, altered mineral such as limonite and a little quartz.

This siltstone, mixed with the grayish black~dark brownish silty clay sediments excavated from the swamp near Ypacarai, are utilized as ceramic raw materials.

According to the X-ray analysis, quartz, kaolinite and a small anount of illite have been detected even though their quantitative ratio is obscure.

In this survey, fossils of Eocoelia paraguayensis (HARRINGTON) and poorly preserved Orthocerotid indet. were obtained from the siltstone bed of an abandoned open pit 6Km northeast of Itaugua.

The former belongs to Brachiopoda and the age given by this fossil indicates the early Silurian (Llandoverian).

In the above mentioned bibliography, the correlative group with this alternating group of arenite and siltstone is reported to yield many kinds of fossils and is identified as the Itacurubi group of the early Silurian age, and is also subdivided into three formations.

In this survey, the mutual relationship between the three formations and the relationship with underlying formation have not been confirmed as they were made into one "alternating group".

This group is characterized by the presence of many fossils and its micaceous rock facies, and also is remarkably softer than the Paleozoic strata in Japan and similar to the siltstone bed of Neogene Tertiary age in Japan.

2.3.4 Conglomerate-Red Arenite Formation

This formation is widely distributed on the west side of the study area, mainly in the Yuquyry basin, the west shore of the Lake and south and west of the Cor. de Yaguaron. Furthermore, this seems to be widely distributed beneath the swamp zone, north of the Lake.

This formation is composed of conglomerate and arenite. On the whole, the underlying bed is conglomeratic and the overlying is quartz arenite with a characteristic color of reddish-brown. Arenite beds sometimes contain the intercalating gravel beds.

Type locality of conglomeratic lithofacies are observable at Cerro Peró of Paraguari, Cerro Patiño, SE of Aregua, and Compañía Salado, down stream of the Salado River and so on. (The zone of conglomeratic lithofacies is separately shown in the geologic map).

Gravel is composed of arkose sandstone, quartz schist and quartz-arenite, derived from the conglomerate-sandstone group of 2) and of siltstone, silicified sandstone and black igneous rocks. It varies from granule to boulder of 0.1~40cm in diameter and angular-subangular-subrounded in shape.

The type , diameter and swarming tendencies of gravel are variable, in accordance with the location.

At Cerro Peró, however, conglomeratic lithofacies is observable at elevations exceeding 50 meters. At the lower horizon, boulders (in many cases they are altered to decayed gravel) swarm and decrease upward in diameter and swarming. The matrix is composed of fine~coarse quartz sand and clay minerals.

Red Arenite is composed of clastic particles of quartz and shows a fair variation in the degree of sorting, grain size and contamination by laterite. Only the general situation was shown in geologic map due to difficulty of detailed strict classification.

This bed generally presents a light~dark reddish brown color and varies lithologically from hard to compact to saccharoidal and friable.

Weathered parts show characteristic reddish-brown by laterization and present a color symbolic of the Yuquyry basin.

Its strikes are hard to measure due to major massive lithofacies, though its dips are nearly horizontal.

Topographically, this bed widely occupies the gently undulating hilly area, thus the highest degree of land use in the study area is as urban-and cultivated area.

The area for this group seems to have suffered drastic washing out of surface soils due to meager vegetation cover. The thickness of soil and weathered horizon show very irregular variation from several meters to zero, exposing base rocks in places.
Open pits for gravel collection are observable in places.

The results of microscopic observation are compiled as follows.

The principal mineral of this quartz arenite is quartz. Accessory minerals are commonly apatite, zircon and tourmaline, and also biotite, muscovite and some opaque minerals are recognizable. Altered minerals are in general limonite accompanied frequently by hematite, kaolinite and muscovite. Quartz schist is common as a lithic fragment.

The grain size varies from 0.2 to 0.8mm, the grain has a degree of sorting change from "poor" to "well", with a subangular-subrounded shape.

This rock is generally poor in matrix and shows texture of the grain-support type, and also has very dirty appearance due to scattered limonite. In the downstream of the study area, its matrix parts increase, to some extent, to quartz wacke-like facies.

Drilling data at SENASA reports as follows:

At Pirayu POZO (well)1	:	Arenite continued until 68m below ground surface
At Pirayu POZO 2	:	Arenite continued until 65m below ground surface and then converted to "ROCA IGNEA (Lamprotido) COLOR OSCURO (Supposed to be a member of granite porphyry of basement rock)
At Laurelty, Capiata	:	Arenite up to 145m
Itaugua POZO2	:	Arenite up to 135m

Itaugua POZO 3	:	Arenite up to 135m
Aregua POZO 2	:	Arenite up to 50m
Caacupemi POZO 1	:	Arenite up to 90m

In any case existence of arenite is reported.

According to the above mentioned bibliography, this formotion is correlative with the Patiño formation, though unsolved problems still remain.

2.3.5 Igneous Rocks

Igneous rocks are found at places in small scale in the study area. The conglomerate-sandstone group of (2.3.2) has been intruded by a mass of gabbro at Cerro Santo Tomas, east of Paraguari. This gabbro body is black and very hard and is quarried for materials for road paving.

This rock is composed mainly of clinopyroxne, biotite, plagioclase and olivine, and is accompanied with apatite and opaque minerals.

The time of intrusion has been estimated as between the Jurassic and Cretaceous ages.

Very unique small rock bodies are found at Cerro Coi and Cerro Chorori, 1Km west of Aregua. In these places, very excellent and well developed columnar joints of pentagonal or hexagonal profile of several centimeters, are formed in the quartz arenite bed of (2.3.4), and suggest an apparent dyke intrusion. But according to microscopic observation, this rock is composed of fine~medium sized sandy materials which are , in turn composed of well-sorted quartz grain with sawteeth-like rims.

Occurrence and genesis of such a material is very hard to understand according to geologic common sense. In this report, this rock is only discribed as "very abnormal sandy materials".

Similar rocks of hexagonal columnar joints also are found at the quarry in San Lorenzo and 3Km east of Luque, and to be in close relation to quartz arenite.

According to the microscopic observation, the principal mineral of this material is quartz, with accessory minerals as zircon and tourmaline. Hematite, limonite and kaolinite as altered minerals, and quartz schist as lithic fragment are recognizable.

Quartz grains are 0.1~1.5mm in size, moderately sorted, poorly altered and subrounded. Characteristic is that the secondary growth of dirty sawteeth-like quartz or zeolite (?) is observable around the quartz grain and that alteration of quartz grain is recognizable to some extent.

This phenomena is considered the recrystallization of acquatically solved S_iO_2.

Plently of limonite or kaolinite (?) are also observable in the matrix matter.

The columnar joints of this material are clearly cooling joints and are not formed by consolidation or stress.

Existence of round and clastic zircon and tourmaline denies that silicification process converted the colummar joints of volcanic rock to such materials.

Petrologically, it is very interesting but its genesis is unknown at present.

At cerro Coi and Cerro Chorori, this material seems to be preserved as the natural monument, however at other quarries, is mined for road paving material.

2.3.6 Unconsolidated Sand, Silt and Clay Sediments

This group is extensively distributed in the central plain zone, including the Lake, which is 65Km long, 5~8Km wide and of a flat 5° grade.

In the Pirayu basin, upstream of the Lake, the plain is composed of sandy~silty unconsolidated sediment which is constituted mainly of quartz grains, is wet and is covered by grass. Outside of partial land use as farmland and coconut forests, most of it is used as pasture.

Many round-shaped ponds, less than 200m in diameter are scattered on this plain. Even though their genesis is obscure, some of them are linked by small channels and suggest the existence of former channel traces.

Many micro-geomorphic surface and remnant streams are recognizable on the plain by airphoto-interpretation and are supposed to have been smoothed and buried by repeated flood submersion.

The estimated thickness is 1m and so on and, in many cases, underlying weathered, altered and flat pan derived from the conglomerate formation forms aquiclude.

At the piedmont area of the Cor. de Los Altos, dissected waste-filled valleys have been formed by many tributaries of the Pirayu. They slope to some extent and form talus or small scaled fans. Many of these tributaries have no surface run-off and little debris supply at ordinary times.

The piedmont zone of Cor. de Yaguaron, in western margin of the study area, has undergone sheet erosion and gulley erosion owing to meager vegetation cover, the front-marginal gently-sloped, mantled pediment form an interfingered complex micro topography with little relative height to the plain.

Along the main stream of Pirayu, a zone of sediment abounds grayish black~dark brownish silt~clay conpositions and is distributed slenderly and thickly, though details are obscure.

The shore of Lake, both on the east and west side, is composed of sand, which is in turn mainly composed of well-sorted quartz grains.

In the large part of the swamp zone in the Salado basin, downstream of the Lake, the detailed character of sediment has been obscure, though mostly is estimated to be composed of grayish black~dark brownish silt~clay-rich planosol.

The river beds of the Yuquyry and its main branches show dissected flat dish-like shaped profiles. River bed deposits abound in grayish black~dark brownish silt-clay composition and are mined for making bricks.

According to X-ray analysis, this silt~clay material contains silt-sized quartz grain, kaoline minerals, illite and montomorillonite groups and shows a character similar to that in the Pirayu basin.
These components show effect of red arenite formation, besides the siltstone formation mentioned in (2.2.3).

The present drainage pattern, elevation and distribution of siltstone beds in the Yuquyry basin make it difficult to consider that large amounts of component of siltstone are able to be transported directly into this basin. As the genesis of this black silt-clay seems to have a close connection to the genesis of lake bottom deposits, a future study concerning this is desirable.

The unconsolidated sediment mentioned above is Holocene sediment, produced and accumulated through the repeated process of erosion, dissection, transportation, sedimentation and re-dissection of geologic beds and debris.

Referring to the bibliography, the above mentioned results are compiled and shown in Table S1.2.2 as the stratigraphic order of the study area.

Table S1.2.2 Stratigraphic Order of the Study Area

Era	Period	Formation / Rock	M.a
Cenozoic	Quaternary	Sand, Silt & clay	2
	Tertiary		65
Mesozoic	Cretaceous	Conglomerate-Red Arenite; Gabbro	141
	Jurassic	?	195
	Triassic	(Sandstone)	225
Paleozoic	Permian		280
	Carboniferous		345
	Devonian		395
	Silurian	Alternation of Quartz Arenite & Siltstone	435
	Ordovician	Quartz Arenite; Conglomerate; Sub-Arkose Sandstone; Quartz Arenite	500
	Cambrian		600
Proterozoic		Granite Porphyry; Granite; Quartzite	

2.4 Geologic Structure

As a general description of the topography and geology of the study area, the alluvial moorly flat plain, which is 65Km long and 5~8Km wide, is elongated in the direction of NW-SE as the central zone.

Along the NE side of the plain, the conforming successive, Paleozoic conglomerate~sandstone strata, which are older than early Silurian in age, are distributed in the same direction and unconformably overlie the base rocks of Cambrian~early Paleozoic granite and quartzose metamorphic rock.

The strata strike NE-SW and dip SE or NW gently.

Topographically, this area is of Paleozoic strata which constitute the dissected front margin of the Cor. de Los Altos, and also shows some characteristic Inserberg.

At the southern area, the Paleozoic strata are observed successively from the underlying bed to the overlying, and the former is overlain northward by the alluvial sediments of the plain.

Along the NW side of the plain, the relatively upper zone of Paleozoic group is elongated in the direction of NW-SE as the marginal zone, however the majority of the bed is overlain with the red arenite group of post-Cretaceous in age, presenting a hilly landform.

The Paleozoic group strikes N-S to NW-SE and dips 10°to 60° southwestward.

The red arenite beds are estimated to be almost horizontal flat.

In the NW side area, near Paraguarí, the base rocks are considered to be granite and metamorphic rock, and the same on the NE side by the drilling records. However, for the most part, the base rock is obscure due to overlaying by the red arenite group, which ranges up to 130 meters in thickness.

Near Ypacaraí, the porphyritic rock of almost the same age as the granite has been recorded by drilling, though its distributing range could be limited.

According to the airphoto-interpretation, in the area of Paleozoic group, on NE side of the study area, many lineaments of WNW-ESE, NE-SW, E-W, and N-S directions are recognizable, and each tributary shows the same tendency.

These patterns, on the whole, are assumed to be due to the echelon fault system though most of them are unconfirmable.

The large scaled fault controlling this echelon system is not tracable on the ground, but may be elongate under the plain, if it does exist.

In the area of Paleozoic group of the NW side, the fault system is difficult to assume due to its narrow width. However, the Cor. de

Yaguaron seems to be *divided into* some blocks by minor faults in NW-SE and E-W *directions*.

The red *arenite* formation is however generally massive, and shows scarce photo lineaments.

The drainage pattern of the Yuquyry, the arrangement of a unique rock of hexagonal columnar joint, suggests the existence of fault system of NW-SE and N-S directions.

Furthermore, the main channel of Pirayu is elongated in a straight line in the direction of SW-NE, from Paraguari to the Lake and along this is a grayish-black clayey zone.

Considering the topographic and geological characteristics mentioned above, *which* are *summarized* as

- Large scale *trend* in *the* direction of NW-SE
- Depression of the central plain
- Difference between the horizon and dip of the Paleozoic group in the NE side and that of the NW side of the study area
- Posibility of the existence of an echelon fault system.

It can be considered that the genesis of geological structure of the study area is ① *graben and/or* ② *echelon fault system followed by* selective erosion.

However, the interpretation of ① is easy to be accepted topographically, but large scale subsidence or graben is hard to be considered geologically, as the *elevation of top horizons of the base rocks* show almost the same level of 100m above sea level at the out-crops and from the drilling data in both east and west side, and as the conglomerate bed is distributed under the central plain and the big fault bounding the plain zone and the mountainous zone is difficult to be considered.

However owing to a lack of evidence of existence of the base rock in and *under the plain*, the bottom of lake and the downstream area, a definite conclustion must be reserved.

From the view point of ②, it is possible to suppose a fairly large-scale fault zone at the central part of present plain because of the *distribution of* Inserbergs near Paraguari, the elongation of clayey zone along the Pirayu, the existence *of intruded* rocks at south of Ypacarai and the records of Pirayu Drilling 3 and so on.

It is considered that the fault zone was formed, and resulted in an echelon fault system and the progressing of the erosion process along the branch fault.

Namely, the main stream of original Pirayu was deepened and widened gradually, and erosion proceeded along the branch faults and the joints to upper area, resulting in slope retreatment and the falling out of divided fault-blocks. After the repetition of such a process, plateaus which must have dominated the land were worn away until a nearly level plain resulted.

Profiles of the slope of NE side and existence of Inserberg may support the above mentioned idea of ②.

A steeper dip of the western Paleozoic strata than that of the eastern may suggest a stronger fault movement on western side of the main fault than that on the eastern.

Distribution of the upper zone of the Paleozoic group on the western side may show that the main fault was a hinge fault. Namely, though the top horizons of base rocks are on the same level at the upper stream area, deepening possibility at the down stream on the west side still remains.

At any rate, no conclusive results regarding the subsurface geological structure have been reached in this survey. It is desired to confirm this by the test drilling.

When the aftermentioned ground water survey is put into effect, the genesis and process of formation of the Lake will be revealed, especially by identifying of the depth of the base rock in the northern area of Pirayu and Ypacarai, the Lake bottom and the swamp downstream.

2.5 Problems Remaining Unsolved

Some questions still remain unsolved in this survey and are as follows. Future solutions are desired.

(1) On the problem of the formation process of the central plain, even though one of the abovementioned theories could be acceptable, the fact is a huge quantity of eroded debris must have been transported by streams, but considering the catchment area and the scale of streams of the present Pirayu, it is hard to suppose so strong an erosion agent present in the original Pirayu.

It may be considered that the original Pirayu was a big river elongated southward of Paraguari.

(2) During the formation process of the central plain, a large quantity of gravel (quartzose rounded gravels derived from the conglomerate formation) must have been transported, but almost no gravel is observable at present time on the plain, the lake bottom and the swamp.

This is one remaining question.

(3) The reason remains undiscovered why the red arenite group, which is distributed widely at the west side of the study area, is not observable on the central plain and in the east side of the study area. That is to say, the sedimentary environment and the arenite province are unknown.

This is important when considering the mechanism and period of the formation of Lake.

The red arenite group shows indistinct stratigraphy due to its massive lithofacies, and as it has a possibility to overlie the Triassic~Jurassic MISIONES sandstone formation (after the bibliography), careful observation and judgement of core samples are desired from future drilling.

(4) The origin and the genesis of the blackish clay, which is observable at points in the riverbed of the Yuquyry, are also unknown.

Under the present topographic conditions, inflow of these materials from the catchment of Pirayu is unconsiderable but the topographic condition in relation to the past on a geologic time scale are obscure.

The Yuquyry basin is supposed to have been formed from the inlets under the stagnant environment during the high water level stage of the old lake.

The clay materials, as well as the lake bottom deposits should be further studied in detail.

(5) The genesis of the "very abnormal sandy materials", characterized by their columnar joints with hexagonal profile, which are found at Cerro Coi and Cerro Chorori, is also petrographically unsolved.

CHAPTER 3

SOIL

3.1 General Description of the Field Survey

The field survey was performed at locations selected based on the preliminary survey of landform, geology, vegetation, land use type and the preliminary airphoto interpretation.

In the second field survey, both the test pit (a trench of about 1m in depth was excavated for observation of soil profiles) and the auger boring (the subsoil of approximately 1m in depth was studied by the use of a hand auger) methods were employed.

Soil samples collected from each sampling point were analyzed in Japan.

In accordance with the results of analysis and second airphoto-interpretation, the soil map was prepared.

The number of survey points for soil is listed in Table S1.3.1

Table S1.3.1 Number of survey points for soil

	Test pit	Auger boring	Analyzed sample
1988	62	18	57

The items studied at each test pit in the field are as follows.

(1) Horizon

Soil horizons were classified by the difference in soil color and texture, etc, and the depth of each horizon was indicated.

(2) Soil texture

The soil texture was estimated by a finger-analysis and the estimation was checked by the grain size analysis.

(3) Soil color

The standard soil color chart was used and the soil color was expressed according to the Munsell notation system.

(4) Mottles

The pattern was observed and the percentage of mottles was indicated.

(5) Gley

It was determined by the soil color (chroma) and the location was indicated.

(6) Humus

It was examined mainly by the soil color.

(7) Moisture (seepage surface)

Moisture was judged by the hand-felt OF mesh of soil cluster. The depth of the seepage surface was also recorded.

(8) Stickiness

It was classified into three classes, (none, moderate, high), based on a hand-felt analysis.

(9) Compactness

It was measured by use of the Yamanaka-type soil hardness equipment and expressed in mm.

(10) Other

Other remarks, if any, were recorded.

Results of the grain size analysis and the triangular diagram of soil texture are shown in Fig. S1.3.1, S1.3.2.

3.2 Soil Classification

Sampled soil was classified according to the classification system by the FAO/UNESCO*. Soils in the study area were classified into four major groups as listed in Table S1.3.2

Table S1.3.2 Soil classification of the study area

Major Group *	Subdivision of Major Group
1 Lithosol 2 Acrisol (red-yellow podzolic soil) 3 Regosol 4 Planosol	sub-type 1, sub-type 2

* Definitions of soil units after FAO-UNESCO Soil map of the World volume 1 Legend UNESCO 1974

Lithosols (L) : Soils which are limited in depth by continuous, coherent, hard rock within 10cm of the surface.

Acrisols (A) : Soils having an argillic B horizon with a base saturation of less than 50 percent (by NH, OAc) at least in the lower part of the B horizon within 125cm of the surface ; lacking a mollic A horizon ; lacking an albic E horizon overlying a slowly permeable horizon, the distribution pattern of the clay and the tonguling which are diagnostic for Planosols, Nitosols and Podzoluvisols respectively ; lacking an aridic moisture regime.

Regosols (R) : Soils from unconsolidated materials exclusive of recent alluvial deposits, having no diagnostic horizons (unless buried by 50cm or more new material) other than an ochric A horizon ; lacking hydromorphic properties within 50cm of the surface ; lacking the characteristics which are diagnostic for Vertisols and Andosols ; lacking high salinity ; when coarse textured, lacking lamellae of clay accumulation, features of cambic or oxic B horizons or albic material which are characteristic of Arenosols.

Planosols (W) : Soils having an albic E horizon overlying a slowly permeable horizon within 125cm of the surface (for example, an argillic or natric B horizon showing an abrupt textural change, a heavy clay, a fragipan), exclusive of a spodic B horizon ; showing hydromorphic properties at least in a part of the E horizon.

3.3 Distribution and Characteristics of Soil Types

The distribution and characteristics of soil in the study area are explained below. The soil map is presented in Fig. S1.3.5.

3.3.1 Lithosol-subtype 1

This is present in the study area's relatively highly elevated places and steep slopes, in discontinuous distribution.

The distribution is between Paraguari and the east side of the study area on the steep slope of the front margin of the plateau exceeding a 200m elevation in the Cord. de Los Altos and the west side of the study area, on the steep slopes exceeding 200m in elevation, in the Cord. de Yaguaron and the hills centering around Cerro Patiño. Generally, the vegetation is well-preserved. Much of it originates from Paleozoic conglomerate, sandstone and newer conglomerate. The soil layer is shallower then 50cm and often there are outcroppings of base rock.

There are steep slopes, however because of hard base rock and vegetation covering, erosion is comparatively difficult. Henceforth, the scope of consideration will be for vegetation protection.

3.3.2 Lithosol-subtype 2

This is distributed in an area which lies from the plateau~-hilly area on the east shore of the Lake, with San Bernardino as center, until the hill extending to Emboscada.

The San Bernardino area was originally covered with vegetation, however housing development and its ensuing road network have lead to remarkably progressed felling.

This type consists of Paleozoic age coarse sandstone, however surface erosion is strongly active. The soil layer is shallow and in many areas there are outcroppings of base rock. In torrential rains, there is extrusion and it is thought that the amount directly entering the Lake is large.

There is quite a bit of shrubbery within the dissected plateau - hilly land between San Bernardino and downstream at Emboscada.

In the sub-type 2 area, small quarries, where base rock shows well developed bedding, is excavated for building materials in numerous places. The resulting area, where vegetation has been cleared, is expansive.

As regards the 6 samples of Lithosol type, the pH is 4.04-6.82, with the average at 4.93, showing a strong acid characteristic.

Based on the grain size analysis, the various soil texture percentages are sand at 70-95%, silt at 5-25% and clay at 0-10% and sandy, with most of the concentration being in L-LS-SL range (Fig. S1.3.1, Fig. S1.3.2)

3.3.3 Acrisol (red-yellow podzolic soil)

This is usually widely distributed on generally gentle slopes, in the west of the study area, over the better part of the Yuquyry basin hills and over the Cord. de Yaguaron pediment and in the east of the study area, over the Cord. de Los Altos pediment. A unique reddish-brown soil color is presented.

In the west, the soil is constituted of Post-Cretaceous age conglomerate bearing red sandstone and, in the east, of Paleozoic age conglo.-sandstone.

Recently in the Yuquyry basin, urban and industrial building have progressed, taking the place of conventional farmland. This zone, having long been used as farmland, originally is of meager vegetation covering, however has reached a state now where soil erosion can easily occur.

In the pediment zone between Pirayu and Paraguari, vegetation clearing has progressed and the zone has been transformed into farmland. Topographically, the front margin of the pediment shows strongly active surface and gully erosion.

From Pirayu to Ypacarai and Aregua, the base rock is partially formed of weak and soft silt stone and there are many places where "Kaolin" is or was produced. It is strongly suspected that from this strata, in the past, the Lake was supplied with fine particles of silt-clay.

Extending from downstream of the Yuquyry to downstream of the Salado, areas of gravel collection and those showing traces of it, are highly abundant. The collection is from the gravel bed in the base rock and is, for the most part, never followed by vegetation restoration. The Lithosol as well as the base rock are left in an exposed state and surface soil extrusion is also intense.

The pediment zone in the Cord. de Los Altos also lies deeply within a wide, dissected valley, which is thought to have been supplied by a large amount of the debris, resulting from the former pediment erosion recession processes.

This Acrisol layer thickness is extremely irregular. From a 3m fertile section, almost all the surface soil has been washed away, resulting in abundant base rock outcroppings.

The 13 samples of Acrisol type has a pH of 4.46-6.32 with an average at 5.10. The soil texture percentages are sand at 60-90%, silt at 10-40%, clay at 0-15%, lying within the wide scope of S-LS-SL-SiL with the silt clay portion richer than the Lithosol (Fig. S1.3.1).

3.3.4 Regosol

This is in wide distribution in the Pirayu basin in the upper reaches of the Lake and also distributed in the lowland along the western shore of the Lake and in the marginal zone of the swamp at the downstream side of the Lake.

In the Pirayu basin, generally the base conglomerate bed and coarse sandstone bed lie as an altered impermeable layer which results from weathering and gleyzation. Above this, a 1m thick layer is mostly horizontal deposits of sandy, immature soil.

The thickness of deposit in the lower reaches of the Lake is unknown.

This Regosol has high moisture retention, which results in 10-200m diameter ponds existing throughout lowland zones.

Upon the micro-relief~natural levee along the lowland tributary courses, continuous river-bank forests are abundant. Also upon micro-relief is isolated forest cover, however this results in natural wet grassland covered by grass-like plants throughout most of the lowland. This mostly used as pasture.

On the Lake's west side, recently summer house and resort facility development has progressed.

The area where Regosol is distributed is flat lowland, thus there is no drastic erosion. However, as tributary beds are fairly hard aquiclude,