The El Fraile Formation which is at least 2,250 meters thick, is mainly composed of tuffaceous shale and calcareous sandstone. The lower part of the formation grades northwestward into a contemporaneous series of volcanic tuffs and ignimbrites called the Tamarindo Group. This part consists of clayey to sandy sediments and conglomeratic sandstone with fossil tree trunks. These fossils indicate a change from shallow depth marine (Masachapa Formation) to deltaic or terrestrial conditions.

The above mentioned gently folded and faulted Miocene and older formations at the Pacific Coastal Plain are overlain with sharp angles of the flat-lying El Salto Formation. The sediments of the El Salto Formation are only locally preserved in erosional remnants capping the Masachapa and Brito Formations between the Sierras de Managua and the coast, and it is approximately more than 100 meters thick in the exposed area.

This formation is composed of typical shelf deposits such as dirty tuffaceous sandstone and siltstone, sandy shales, marly shale and marls, while cobble conglomerates occur locally at its base. Both sandy and shaley layers contain large quantity of shells, which are also concentrated in reef-like build-ups of large oysters forming coquinas of widespread mixed shell deposits. Some of them are mine fields of crude materials of cement production.

This El Salto Formation, along with the Brito Formation is widely uncomformably overlain by the Las Sierras Group in the Study area and they form hydrogeologically low permeable basal layers (Fig. 4.1.2).

2) Igneous and Related Rocks

Numerous dikes and sheets of diabase, and at least four stocks of hornblend diorite, intrude the sedimentary series of the Pacific Coast. The largest stock of diorite, about 30 kilometers in size, is located in the exposed area of the Brito Formation. This intrusion probably occurred during Late Miocene age.

3) Volcanic Rocks

The Tertiary Volcanics in the Interior Highland can be divided into three volcanic groups: the Matagalpa Group (Paleocene to Oligocene), the Coyol Group (Miocene to Pliocene) and the Plio-Pleistocene volcanics in ascending order (Fig. 4.1.1, 4.1.2).
These volcanic rocks is composed of lavas, dykes and pyroclastic materials of basalt-andesite-dacite.

In the Nicaraguan Depression and the Pacific Coastal area, many kinds of volcanic rocks and volcanic sediments of the Tamarindo Group (Miocene), the Las Sierras Group (Plio-pleistocene) and the Quaternary volcanics are widely exposed.

(2) The Study Area

The Study area is mainly composed of volcanic rocks and volcanic sediments ranging in age from the Pleiocene to the Recent. These volcanics are uncomformably underlain by the Brito Formation of the Paleocene to Ecocene and the El Salto Formation of the Pleiocence, regarded as a hydrogeologically low permeable basal layers. The geological age relation, distribution and geological structure of the principal rock units of the Study area are summarized in Table 4.1.2 and Figure 4.1.4 to 4.1.9.

1) Basal Sedimentary Rocks

The basal part of the Managua Groundwater Basin is composed of low, permeable sedimentary rocks of the Brito and El Salto Formations of the Tertiary. Resulting from electrical prospecting and test well drilling, a shape of top surface of the formations is estimated to be as shown in Figure 4.1.5 to 4.1.9 and 4.8.2.

2)Plio-Pleistocene Lavas

In the southeast wall of Masaya caldera and the south to west wall of Apoyo caldera, the older hard lavas are exposed. The older lava in Masaya caldera is olivineaugite basalt, and the older lava in Apoyo caldera is hypersthene-augite andesitic basalt. These older basaltic lavas are overlain by the Las Sierras Group.

3) Las Sierras Group

This group is mainly composed of basaltic to andesitic pyroclastic rocks of the Plio-Pleistocene. Based on the lithological features, the Las Sierras Group has been subdivided into 3 formations: the Lower, Middle, and Upper Las Sierras Group.

The Lower Las Sierras Group (TQps(I)) is mainly exposed in the vicinity of El Salto, unconformably overlying the El Salto Formation with a typical basal conglomerate. This formation consists of basal conglomerates with cobble and boulder of limestone of the El Salto Formation, fine conglomerate or conglomeratic sandstone, tuffaceous sandstone and siltstone, and basaltic tuff and tuffbreccia with brown fossil soil beds. TQps (I) is not exposed in the surface of the Study area, and it is estimated that distribution of this group is very limited in underground of the Sierras de Managua in the Study area (Fig. 4.1.6).

The typical outcrops of the Middle Las Sierras Group (TQps (M)) in the Study area are seen in the walls of Asososca, Nejapa and Tiscapa craters, and also in deep canyons on the southern flanks of the Sierras de Managua projecting into the Study area. Those outcrops consist of massive and compact basaltic to andesitic agglomerate with tuffbreccia (lapilli tuff) and tuff containing pisolite.

From the results of review and analysis of existing borehole records and test well drilling, it can be estimated that lithofacies of the Middle Las Sierras Group in the study area is composed not only of compact agglomerate with tuffbreccia and tuff but also porous pyroclastic fall deposits or pyroclastic flow of scoria with fossil soil beds as of good aquifers.

The main outcrops of the Upper Las Sierras Group (TQps(S)) are seen continously at the Mateare Fault Scarp, which is composed of an alternation of massive basaltic to andesitic agglomerate, tuffbreccia and tuff with thin layers of fossil soil, scoria and pumice. On the other hand, the group exposed in the northeastern slope of the Sierras de Managua is composed of a frequent alternation of agglomerate, tuffbreccia, tuff, pisolite-rich sandy-tuff, tuffaceous sandstone and fossil soil.

4) Masaya Group Volcanics (QvM)

Masaya volcano is a typical double volcano with big caldera of Glen Coe type.

As shown in Figure 4.1.4, there are many cones, collapse craters and collapse calderas influenced by the volcanic chain extended in the north-south direction in the surrounding area of the Masaya Central volcano. The volcanic sediments originating from these volcanoes are composed of basaltic lavas and pyroclastic materials (volcanic breccia, scoria and ash), and they categorized under "Masaya Group Volcanics" in this report.

In the northern area of the Masaya caldera, there is an old underground valley extending toward the Lake Managua with NS direction, which is estimated to be formed in the TQps(M) during the Middle Pleistocene and to be buried by the QvM.

According to existing borehole records and the results of test well drillings (JI-2,JI-3), the volcanics buried an old valley are composed of porous basaltic lava, and the layer of pyroclastic flows is one of those that can be developed as aquifer in the Study area. The thickness of the QvM is about 100-120 meters in the central zone of the valley.

5) Apoyo Volcanics (QvA)

The caldera of Apoyo, though only 10 kilometers from Masaya is a magnificient example of a Krakatau type of caldera formed from a collapse as a result of the eruption of great quantities of dacite pumice.

The pumice covers a wide area as shown in Figure 4.1.4.

Cuadro 4.1.2 Estratigrafia del área de estudio
Table 4.1.2 STRATIGRAPHY OF THE STUDY AREA

Edad Geológica GEOLOGIC AGE		Nombre de las Unidades Rocosas geólogicas NAME OF GEOLOGIC ROCK UNITS			Litologia LITHOLOGY
QUATERNARY Cuaternatio	Holoceno HOLOCENE		Aluvio ALLUVIUM	Qal	Sedimentos arena y arcilla con material piroclástico, depósitos de escombros. SAND AND CLAY SEDIMENTS WITH PYROCLASTIC MATERIAL, DEBRIS DEPOSITS
			Volcánicos Holocénicos HOLOCENE VOLCANICS	QvH	Lavas Basalticas-Andesiticas BASALTIC-ANDESITIC LAVAS Flujos piroclásticos y depósitos piroclásticos caidos. PYROCLASTIC FLOWS AND PYROCLASTIC FALL DEPOSITS.
	Pleistoceno PLEISTOCENE		Volcánicos Pleistocénicos PLEISTOCENE VOLCANICS	QvP	Depósitos piroclásticos caidos con flujos piroclásticos y lavas. PYROCLASTIC FALL DEPOSITS WITH PYROCLASTIC FLOWS AND LAVAS.
			Volcánicos Apoyo APOYO VOLCANICS	QvA	Depósitos piroclásticos caidos y flujos (pomez) con rava dacitica. PYROCLASTIC FALL DEPOSITS ANS FLOWS (PUMICE) WITH DACITIC LAVAS
			Grupo Volcánico Masaya MASAYA GROUP VOLCANICS	QvM	Lavas basálticas (dura y porosa-auto brechada) BASALTIC LAVAS (HARD AND POROUS-AUTO BRECCIATED) Flujos piroclásticos y depositos piroclásticos caidos PYROCLASTIC FLOWS AND PYROCLASTIC FALL DEPOSITS
Terciario TERTIARY	Plio-Pleistoceno PLIO-PLEISTOCENE	Grupo Las Sierras LAS SIERRAS GROUP	Grupo Superior Las Sierras UPPER LAS SIERRAS GROUP	TQps(S)	Aglomerado Básaltico-Andesitico, toba brecha, toba, suelo fósil, arena y limo tobácea BASALTIC-ANDESITC AGGLOMERATE, TUFFBRECCIA TUFF, FOSSIL SOIL, TUFFACEOUS SAND AND SILTE
			Grupo Medio Las Sierras MIDDLE LAS SIERRAS GROUP	TQps(M)	Aglomerado basáltico-andesitico, compacto brecha tobácea, toba, flujo piroclástico. BESALTIC-ANDESITIC COMPACT AGGLOMERATE, TUFFBRECCIA, TUFF, PYROCLASTIC FLOW.
			Volcánicos Plio-Pleistocénicos PLIO-PLEISTOCENE VOLCANICS	TQpl	lavas basálticas andesiticas en las proximidades de las Calderas Masaya y Apoyo. BASALTIC-ANDESITIC LAVAS IN NEAR MASAYA AND APOYO CALDERAS.
	Plioceno PLIOCENE-(EOCENE)		Formacion El Salto y Sedimentos Terciarios EL SALTO FORMATION & OTHER TERTIARY SEDIMENTARY ROCKS	TPS	TUFFACEOUS SANDSTONE & SILTSTONE WITH FOSSIL SHELLS. (BROWN TUFFACEOUS SHALES.)

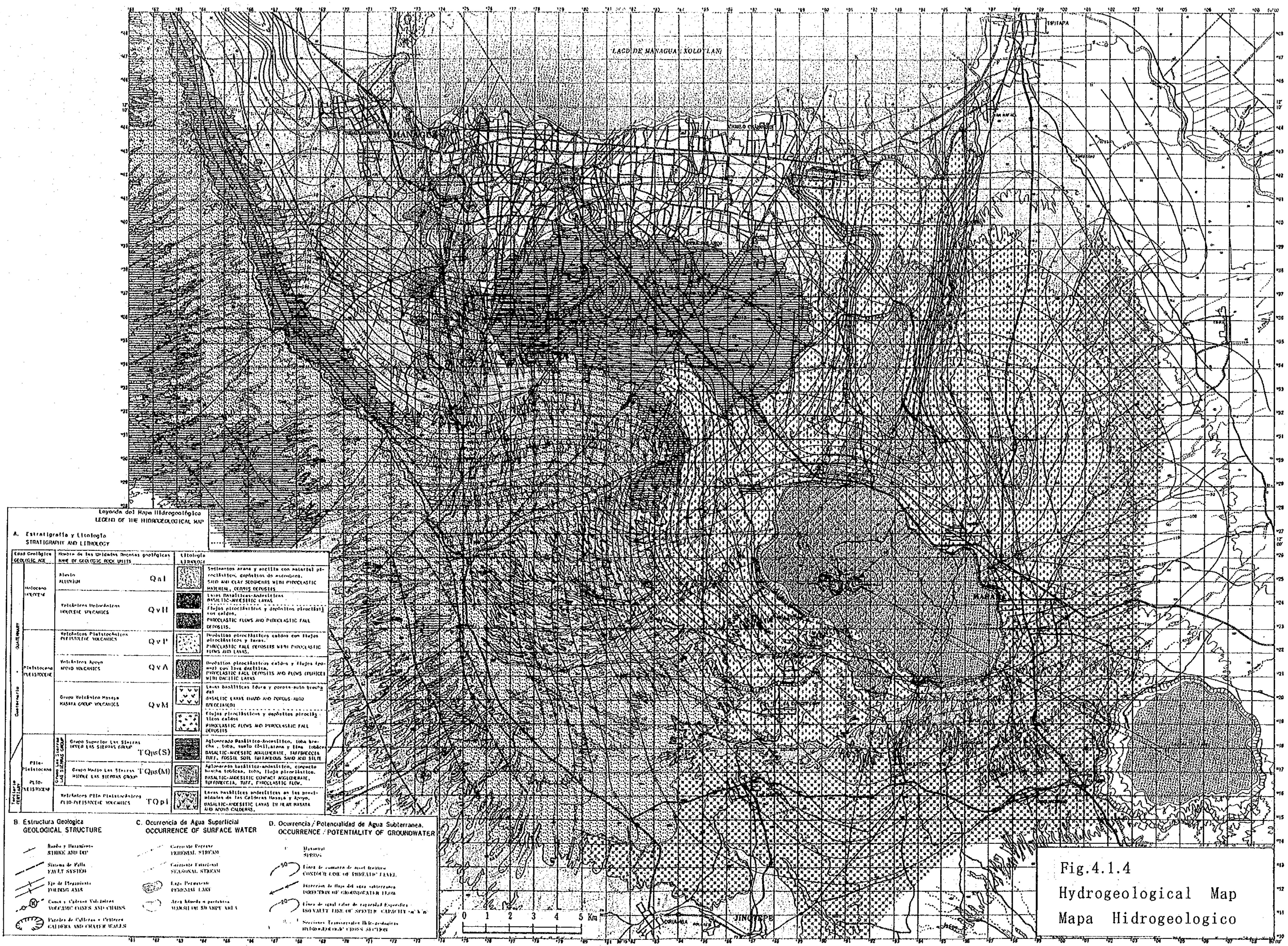


Fig.4.1.4
Hydrogeological Map
Mapa Hidrogeologico

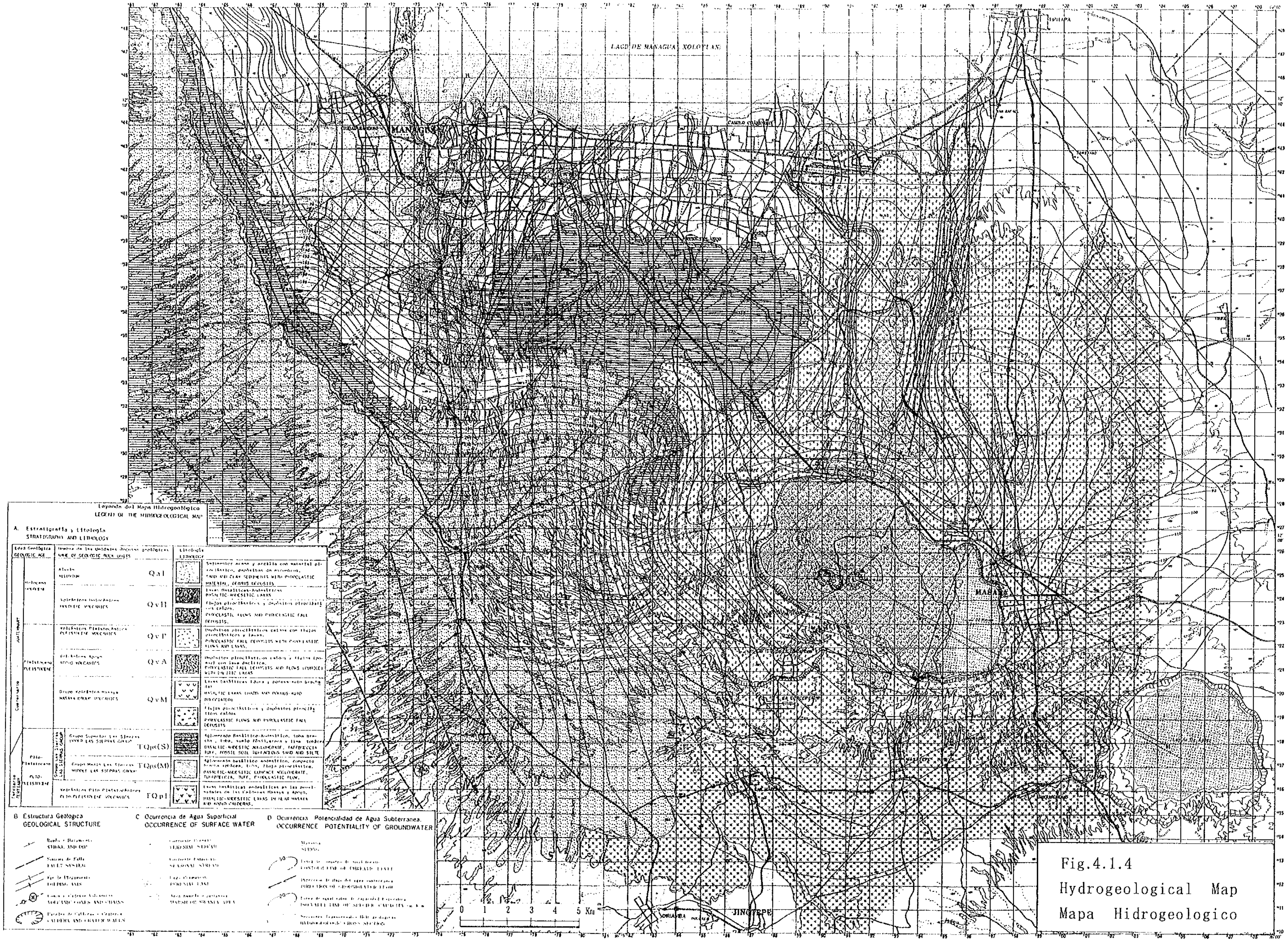


Fig.4.1.4
Hydrogeological Map
Mapa Hidrogeologico

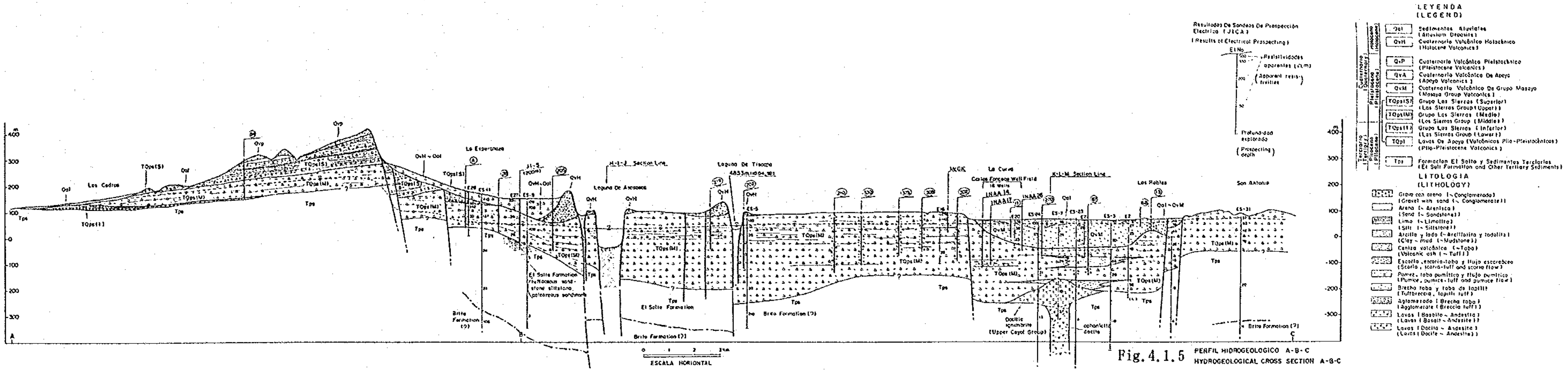


Fig. 4.1.5 PERFIL HIDROGEOLOGICO A-B-C
HYDROGEOLOGICAL CROSS SECTION A-B-C

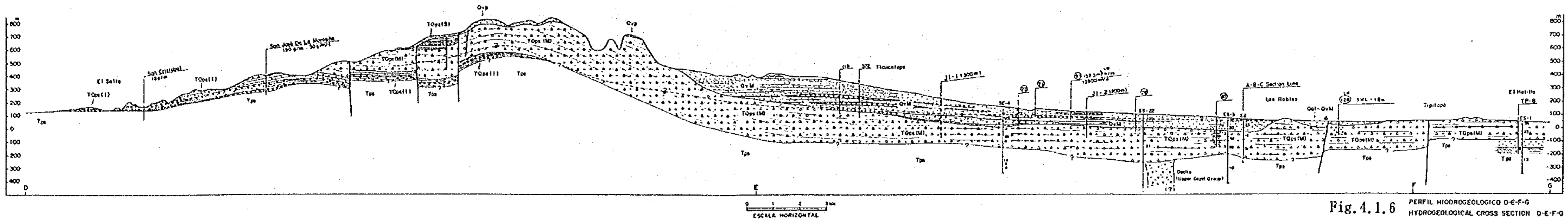


Fig. 4.1.6 PERFIL HIDROGEOLOGICO D-E-F-G
HYDROGEOLOGICAL CROSS SECTION D-E-F-G

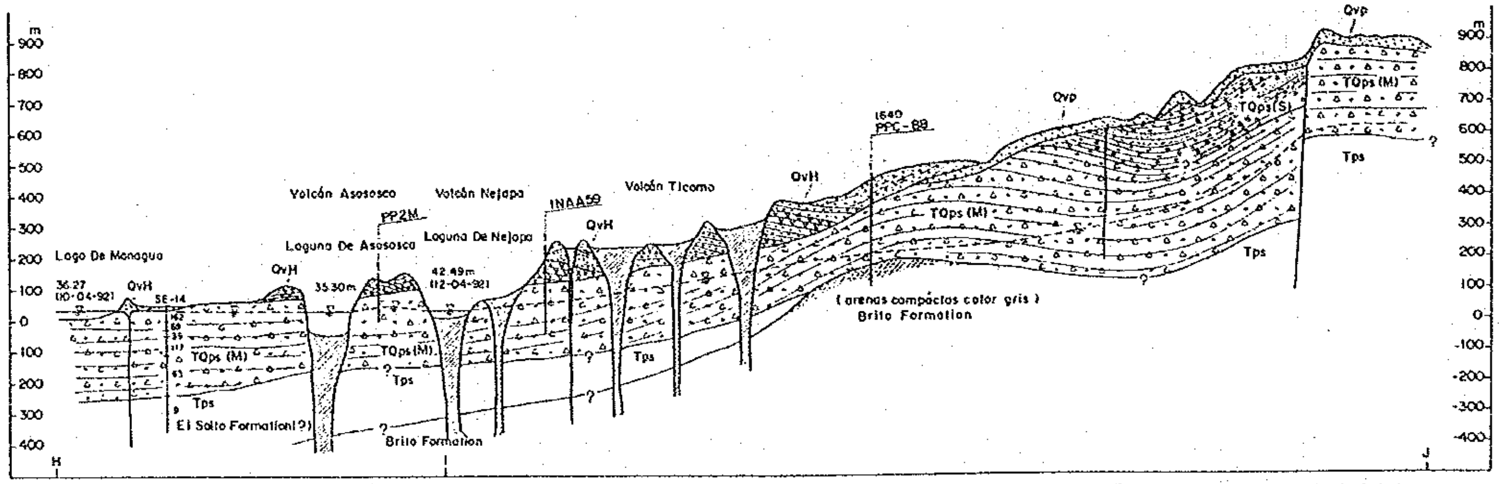


Fig. 4.1.7 PERFIL HIDROGEOLOGICO H-I-J
HYDROGEOLOGICAL CROSS SECTION H-I-J

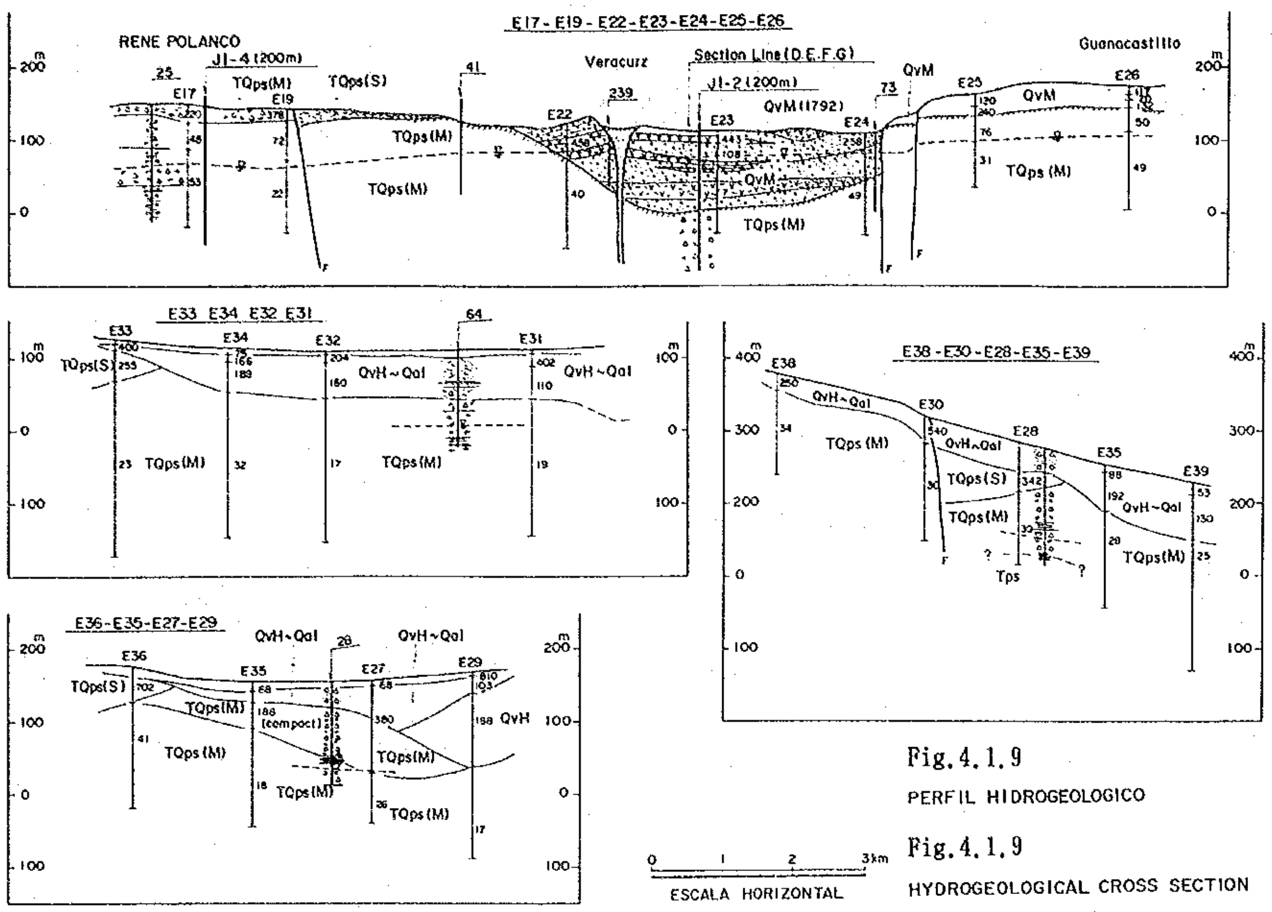


Fig. 4.1.9
PERFIL HIDROGEOLOGICO

Fig. 4.1.9
HYDROGEOLOGICAL CROSS SECTION

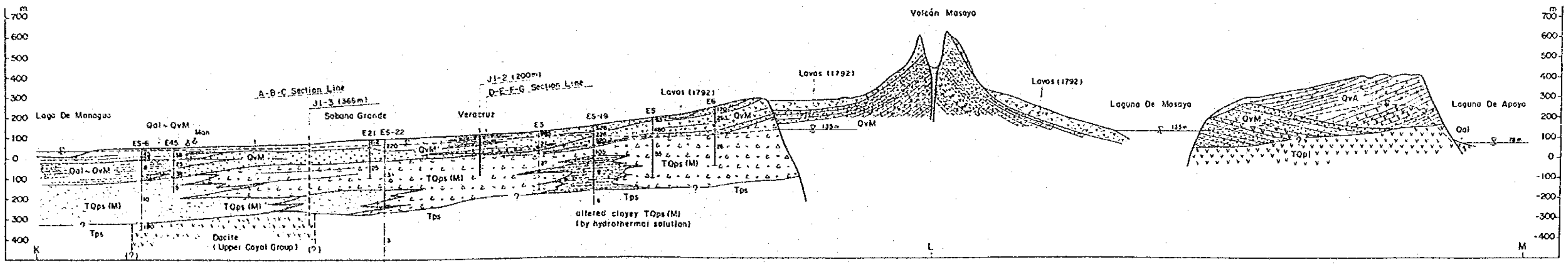


Fig. 4.1.8 PERFIL HIDROGEOLOGICO K-L-M
HYDROGEOLOGICAL CROSS SECTION K-L-M

6) Pleistocene Volcanics (QvP)

This volcanics is exposed along the volcanic chain extended in the north-south direction connecting the collapse crater of poyeque, Cerro Partido, San Carlos, Cerro Los Martinez, Ticomo and the small cones at the western slope of Sierras de Managua. Although the Pleistocene volcanics of the chain consists of basaltic to andesitic lavas and pyroclastic materials and residues of eroded volcanic bodies, it is difficult to divide the accurate boundary between the QvP and QvH.

Much of the scoria layers that cover the summit of the Sierras de Managua is considered to belong to the Pleistocene volcanics erupted on the western slope of the Sierras de Managua above mentioned.

7) Holocene Volcanics (QvH)

Holocene volcanics are mainly exposed along the above mentioned volcanic chain of the Pleistocene volcanics. The central cones and lava flows in 1972 in the Masaya volcano belong also to the Holocene volcanics.

All the Holocene volcanics in the study area are composed of basaltic lavas, cinder, scoria flows and their secondary sediments. Among them the Nejapa volcanics is observed to be underlain by the pumice layer of Apoyeque.

Tephra

The study area is widely overlain by the Quaternary volcanic ash. In this study, two typical outcrops were observed in order to make clear the stratigraphical characteristics of the Quaternary volcanic ash layers. The results of this observation are shown in Figure 4.1.10.

8) Alluvium (Qal)

Alluvium is mainly exposed in the western sub-area and along the shore of Lake Managua. In the western sub-area, it consists of mixed sediments of volcanic-ash (scoria and pumice) and a debris mainly from the Mateare Fault Scarp zone.

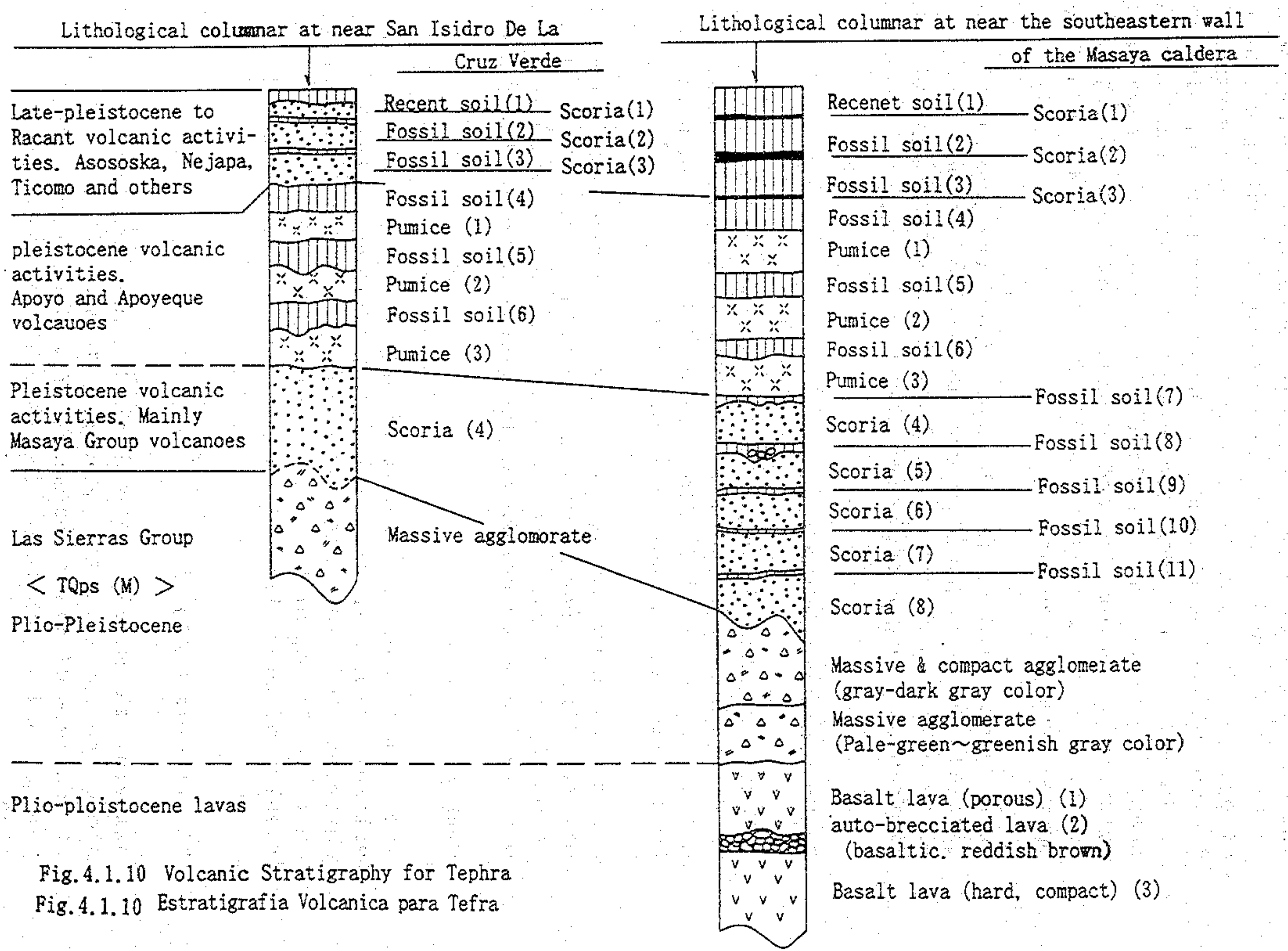


Fig.4.1.10 Volcanic Stratigraphy for Tephra
Fig.4.1.10 Estratigrafia Volcanica para Tefra

4.1.3 Structural Geology and Geologic History

In this Study, Palaeogeographical maps (Fig. 4.1.11 to 4.1.14) were prepared for the discussion of the structural geology and geologic history of the Nicaraguan Depression, which is also the site of the study area. In particular, the major purpose of this discussion is to consider the existence of hydrogeologically impermeable layers underlying the Las Sierras Group, such as the El Salto Formation and other Tertiary sedimentary rocks.

(1) Late Cretaceous to Late Miocene

Until the beginning of the Upper Cretaceous, lands in Western Nicaragua were mostly of mafic intrusions; peridotite, gabbroic and diabasic rocks, and Nicoya complex: graywacke, chert and basalt. In particular, it is estimated that the basement rocks surrounding the Study area had to be mainly composed of mafic intrusions.

At the early stage of the Upper cretaceous, transgression progressed from the southeastern area of the Pacific Coastal Plain toward the Nicaraguan Depression area. Although it is assumed that this transgression continued up to the Middle Miocene, it can also be assumed that sedimentary environment in the transgression area underwent repeated changes from marine condition to brackish or embayments and terrestrial conditions somewhere between the Cretaceous and Paleocene, and the Eocene and Oligocene, respectively. These regression stages can be estimated from the existence of surface of uncomformity in the formations. Among of them the regression between the Oligocene and the Miocene is quite evident from the existence of fossil tree trunks in the basal part of the El Faile Formation.

Through this transgression, the Rivas, Brito and Masachapa Formations, the Tamarindo Group and the El Fraile Formations were deposited in ascending order. The axial ridge of this geosyncline had to continue increasing, folding, uplifting and providing new sources of clastic debris. The total thickness of these formations is estimated to be more than 9,620 meters.

On the other hand, in the northeastern marginal area of this transgression, which is also the northeastern marginal area of the Nicaraguan Depression, Tertiary volcanic activities had progressed widely and strongly (Matagalpa and Coyol Groups). At the stage of Late Miocene, the volcanic activities of the Tamarindo Group occurred in the northwestern area of the Pacific Coastal Plain.

(2) Late Miocene to Late Pliocene

At the end of the Miocene, the sedimentary basin was strongly uplifted and folded with dioritic rocks intruding along the axial ridge of the uplifting (Rivas Anticline).

The uplifted terrestrial area had been strongly weathered and eroded. After this regression stage, the Nicaraguan Depression zone and partial areas of the Pacific Coastal Plain were occupied by shallow depth marine by the transgression of the Early Pliocene. Under the Palaeogeographical conditions shown in Figure 4.1.11, the deposition of the El Salto Formation has progressed through Pliocene age.

The distributions of the El Salto and Brito Formations regarded as low permeable basal layers of the Managua groundwater basin are shown in hydrogeological cross sections (Fig. 4.1.5 to 4.1.9) and top elevation map of hydrogeologic impermeable layer (Fig. 4.8.2). These maps were prepared based on the results of the test borehole (TP-8) carried out by the United Nations in 1973 and the results of geological reconnaissance, electric prospecting and test well drilling in this Study.

Although the main part of the sedimentary basin developed into a terrestrial flat plain in the early Late Pliocene period, a narrow and shallow sea trench along the northeastern margin of the Nicaraguan Depression and an inland lake of brackish-water are still observable as shown in Figure 4.1.12.

At almost the same period, big volcanic eruptions from the Las Sierras Group started near the center of the basin, while sporadic volcanic eruptions occurred in the northeastern margin of the Nicaraguan Depression (Fig.4.1.12).

(3) Early Pleistocene to Middle Pleistocene

The above mentioned volcanic activities of the Plio-Pleistocene mostly ended at the early Middle Pleistocene period.

The main part of the Upper Las Sierrras Group is composed of volcanic ejectas with well sorted but weakly consolidated layers of tuffaceous sandstone and siltstone. It is, therefore, considered that the sedimentary environment of the Upper Las Sierras Group, was mainly influenced by the brackish water that resulted from the transgression at the end of the Early Pleistocene.

After the sedimentation of the Upper Las Sierras Group, a sharp geotectonic movement with upliftings, faultings, gentle foldings and depressions occurred widely at the Nicaraguan Depression zone, resulting in the relative uplifting of the Pacific Coastal Plain and the Interor Highlands, and the subsidence of the Nicaraguan Depression zone (Fig. 4.1.13). However, a part of the Sierras de Managua projected into the Nicaraguan Depression remains unchanged from the subsidence.

In connection with this block movement, the boundary faults of the Nicaraguan Depression and oblique faults to the depression were formed. Many of the oblique faults are N-S and NE-SW fractures with minor diplacement, and some of them control the sub-chains of the Quaternary volcanoes (Fig. 4.1.13). The main chain of the Quaternary volcanoes indicates the existence of a tension fracture zone that was formed in connection with the above mentioned block movement. The deeper portion of this fracture zone may reach to a magma reservoir.

As a link in the chain of the crustal movement continued from the block movement above mentioned, volcanic activities ranging from the Middle Pleistocene to the Recent have been continuously occurred along the tension fracture zone and fault systems. The Managua earthquake in 1972 occured in connection with the crustal movement in the depression, and the faults (NE-SW) associated with the earthquake are primarily of tectonic origin mentioned above(Fig. 4.1.14).

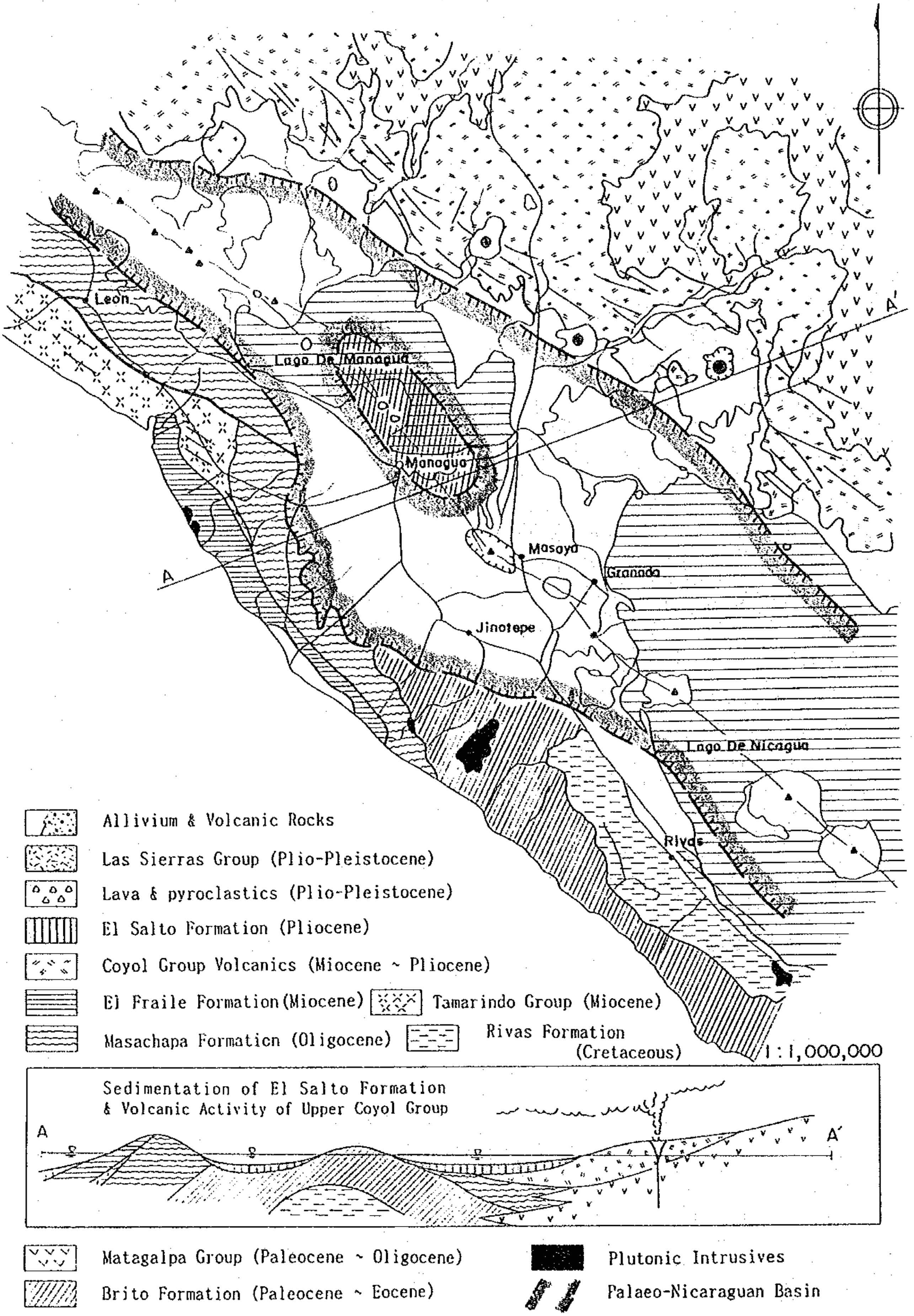


Fig.4.1.11 Palaeogeographical Map (Early Pliocene)
Mapa Paleografico (Inicio del Plioceno)

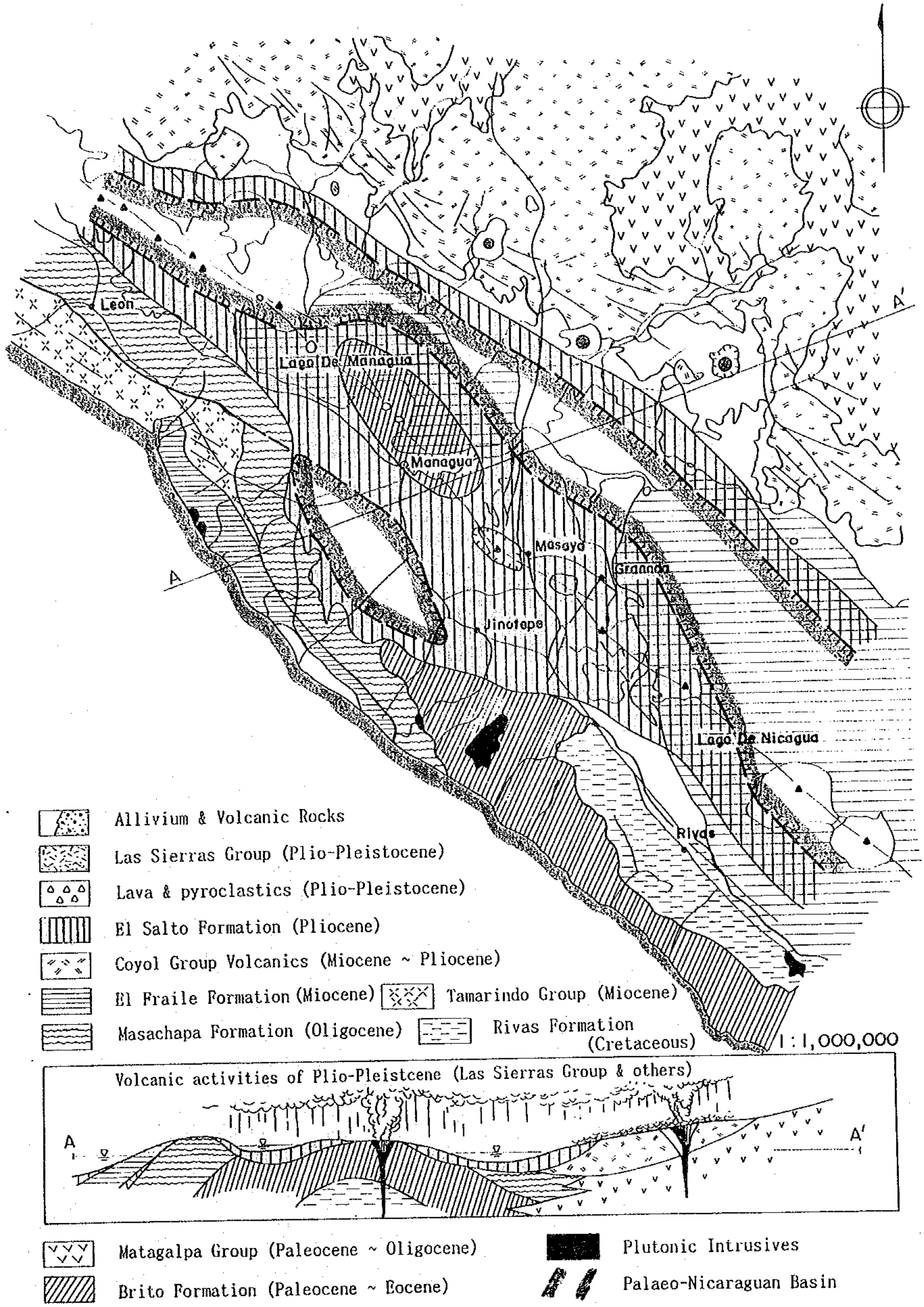


Fig.4.1.12 Palaeogeographical Map (Late Pliocene)
Mapa Paleografico (Fines del Plioceno)

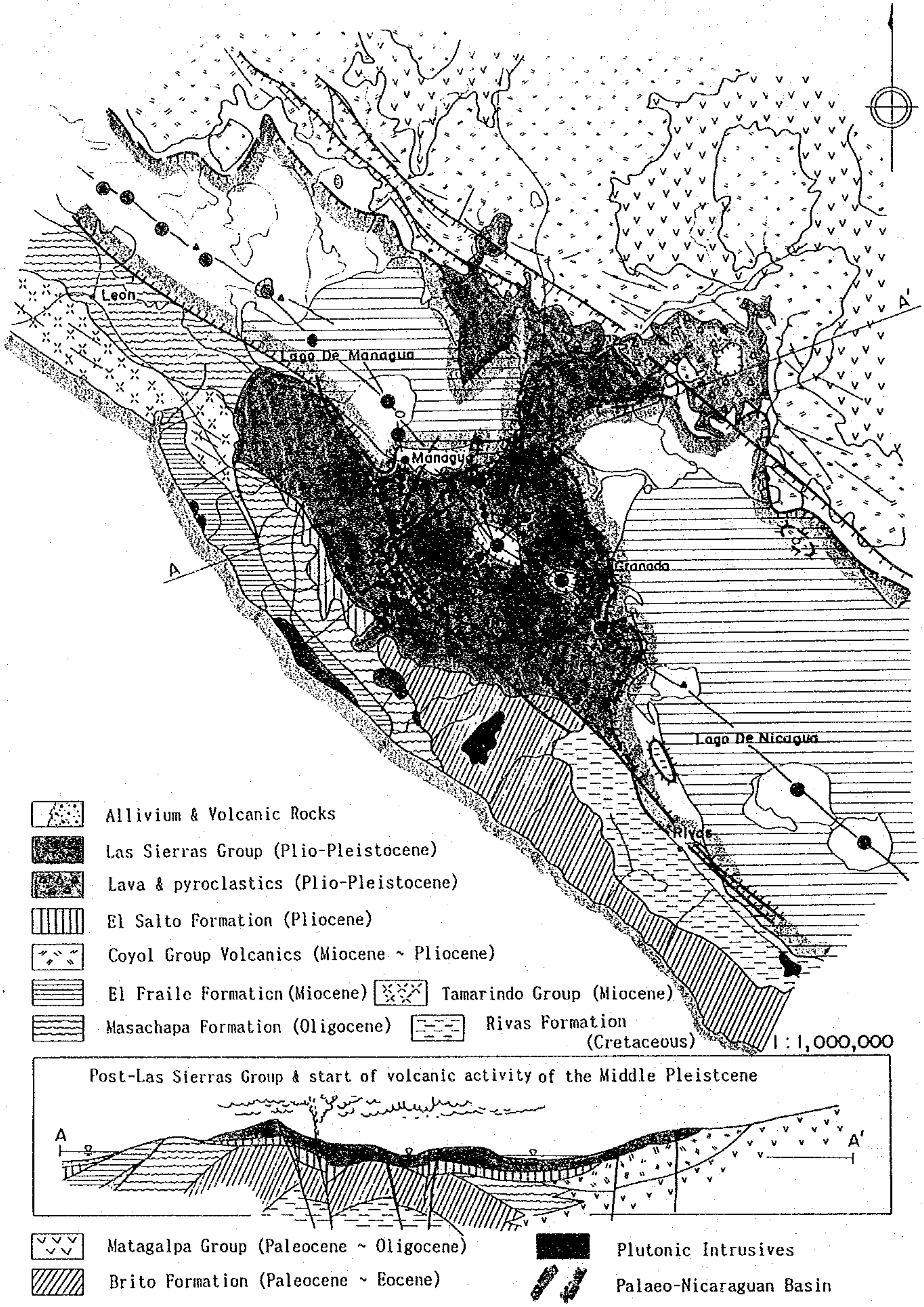


Fig.4.1.13 Palaeogeographical Map (Middle Pleistocene)
Mapa Paleografico (Mediados del Pleistoceno)

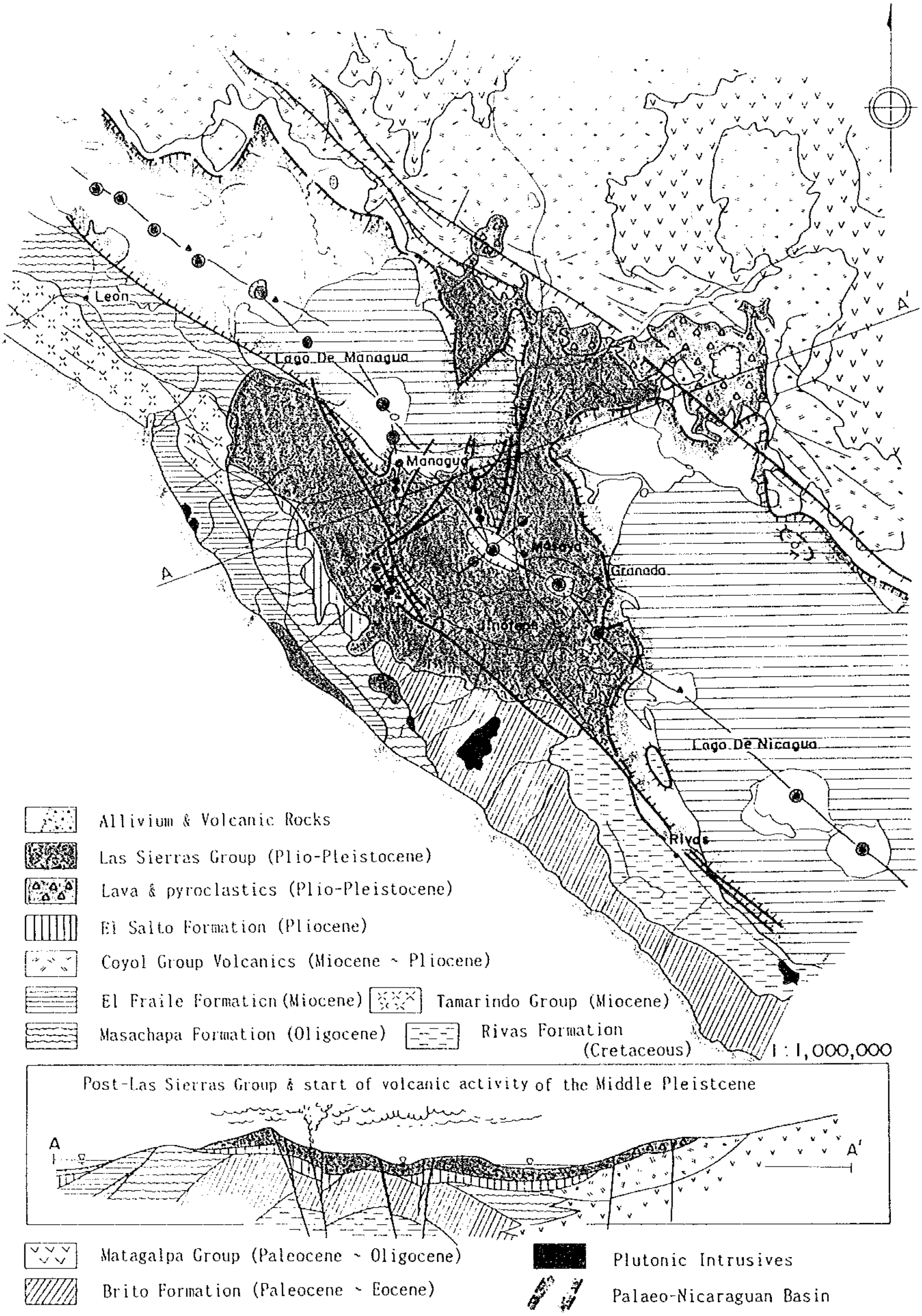


Fig.4.1.13 Palaeogeographical Map (Middle Pleistocene)
Mapa Paleografico (Mediados del Pleistoceno)

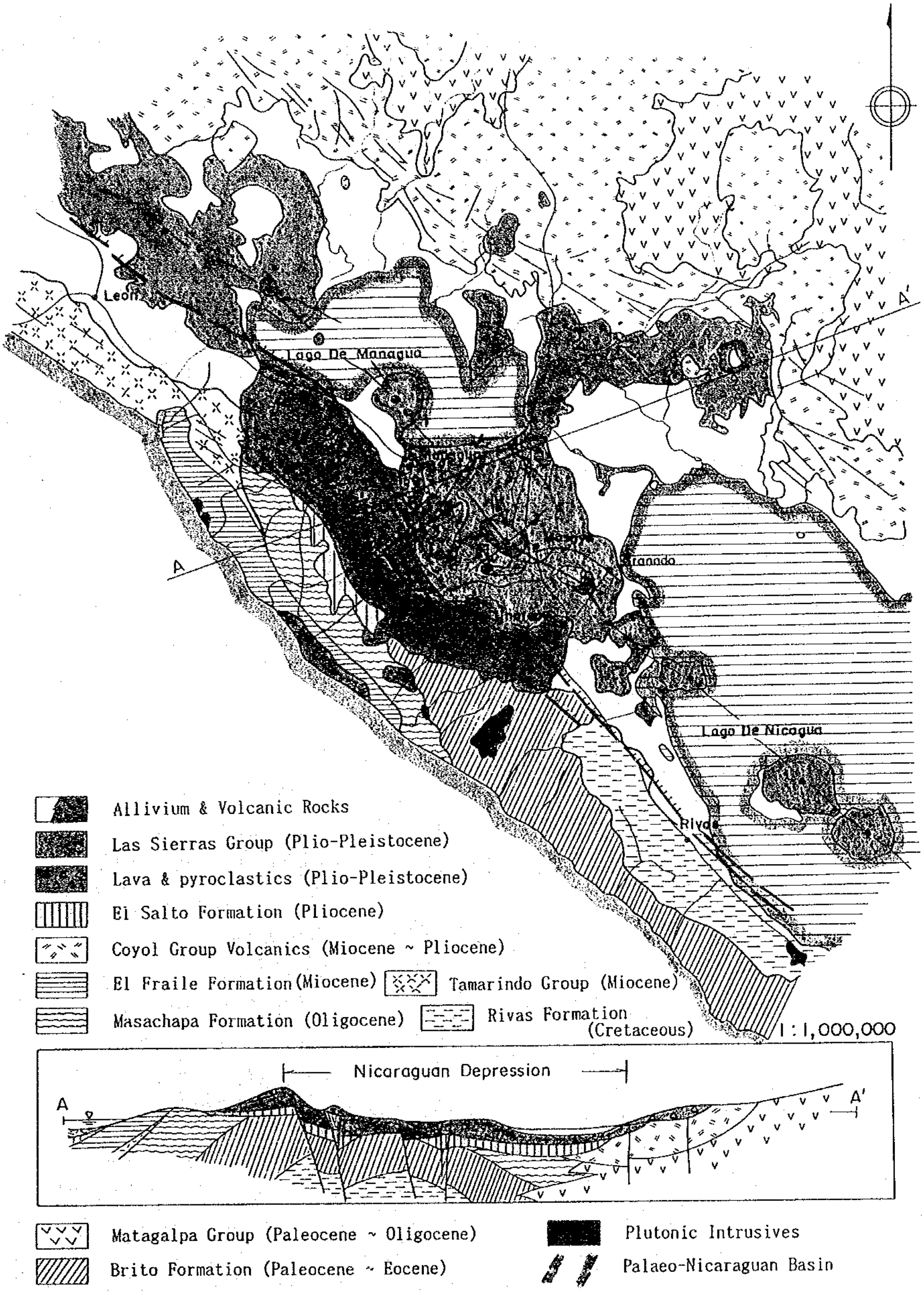


Fig.4.1.14 Palaeogeographical Map (Late Pleistocene to Recent)
Mapa Paleografico (Finales del Pleistoceno-Reciente)

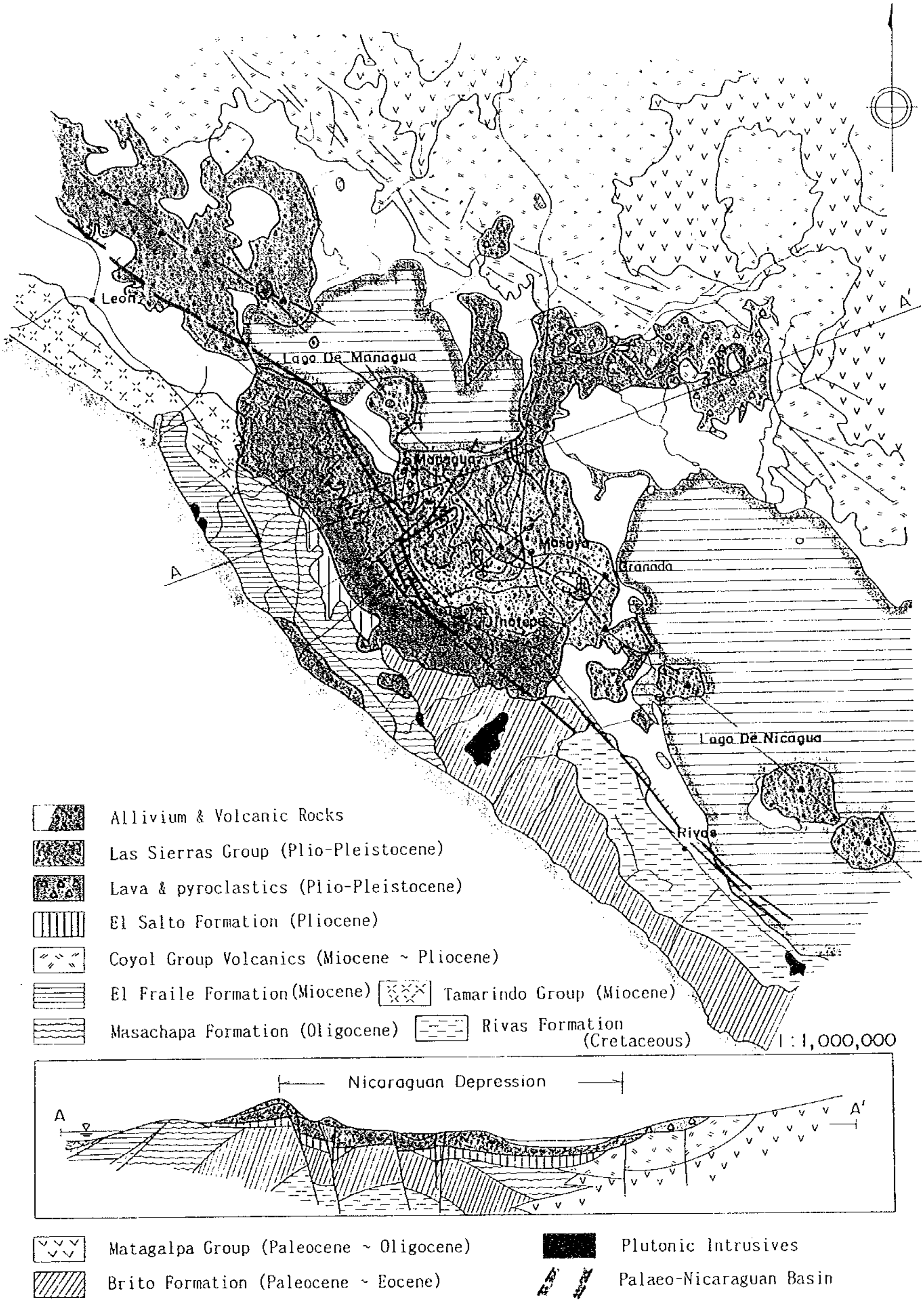


Fig.4.1.14 Palaeogeographical Map (Late Pleistocene to Recent)
Mapa Paleografico (Finales del Pleistoceno-Reciente)

4.2 Climate

The climatic condition of the Study area is classified as tropical savanna, the average low temperature being 25.6 °C in December and the average high is 28.8 °C in April.

The rainy season mainly starts in May and ends in October or November, while the dry season starts in November and ends in April. Fig. 4.2.2 shows the meteorological stations and the annual isohyet in the Study Area. Average annual rainfall fluctuates from 1100mm to 1500mm, depending on elevation. The lowest value is observed in the south coast of the Lake Managua and the highest is observed in the mountainous area.
Fig. 4.2.1 shows temperature and rainfall distribution in A.C. Sandino and Masatepe stations.

Annual evaporation varies from 1800 mm to 2700 mm, almost corresponding to the elevation, and the potential evapotranspiration is considered high.

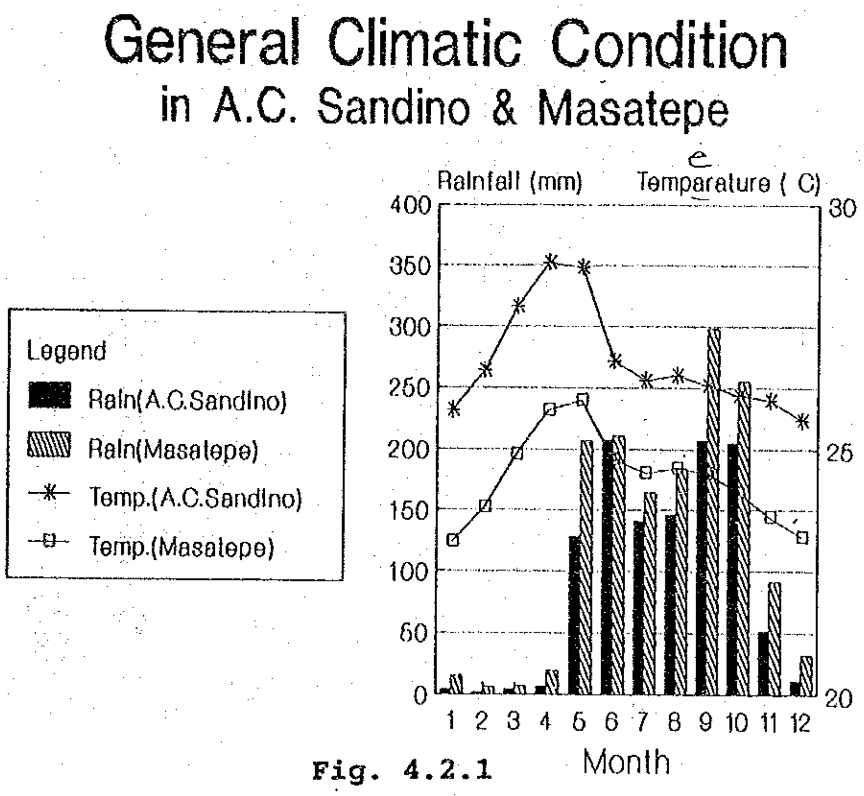


Fig. 4.2.1

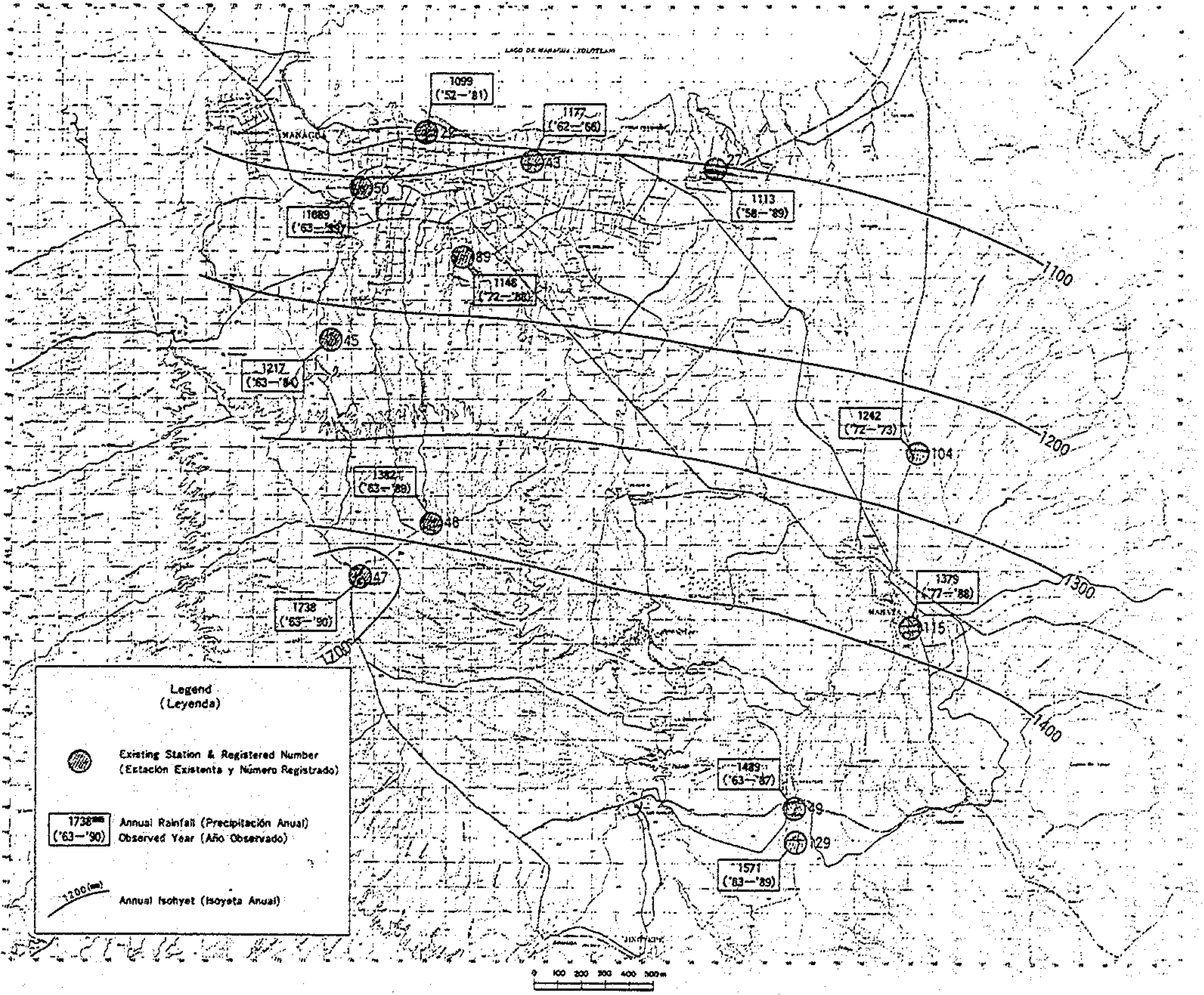


Fig. 4.2.2 Location of Meteorological Station

4.3 Surface Water

The drainage system in the Study Area is divided into five catchment areas, of which I, II (342 km²) cover the western mountainous area and the coast of Lake Managua, while III, IV and the Lake Masaya catchment area (538 km²) cover local cities like Masatepe, La Concepción and Lake Masaya in the south and Mocuana river in the northeast (See Fig. 4.3.1).

Catchment Area	
I	120 km²
II	222 km²
III	136 km²
IV	183 km²
Lake Masaya	219 km²
Total	880 km²

There are five lakes in the Study Area, including the Lake Managua, which is the secondary largest in Nicaragua, located north of the Managua City. All of the surface water and ground water in the catchment area south of the Lake Managua flows in this lake. The Tipitapa River is connected to the Lake Nicaragua, which is the largest lake in Central America, however, no water is normally observed in this river due to the absence of inflow and outflow rivers.

Historically, the domestic water of the Managua city has been supplied from the Lake Asososca located in the northwestern part of the Study Area, accounting for 30% of water sources even now.

A large scale spring zone at 50-60 m in elevation can be found in the eastern part of the Airport, located in the northeast of the Study Area. The total discharge from this zone is almost considered as the base flow of the upper catchment area, i.e., III and Lake Masaya catchment area.

The Mocuana river is the sole perennial river in the Study Area and its water originates from the groundwater recharged by the mentioned spring zone. According to the discharge measurement in 1991-1992, the stream flow of the Mocuana river is calculated as 1.0 - 1.40 m^3/sec, and total base flow of the spring zone is estimated as more than 1.35 m^3/sec. Other rivers in the western part of the Study Area are seasonal, normally flowing only 2-3 hours after heavy rain in the upstream area during rainy season.

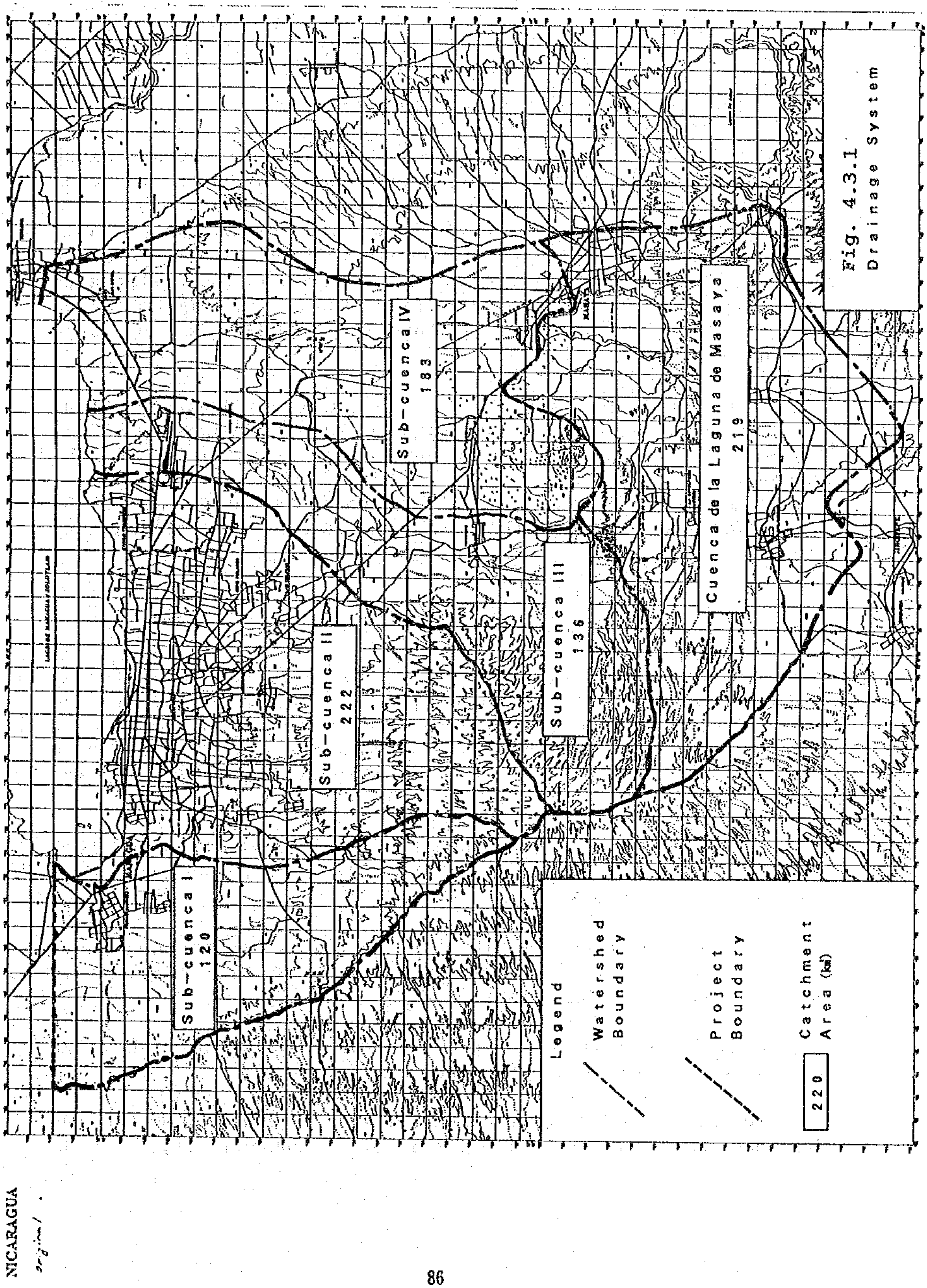


Fig. 4.3.1
Drainage System

NICARAGUA
original

4.4 Groundwater Level

(1) Groundwater level of the Study Area

Continuous water level monitoring and simultaneous observation in the rainy and dry seasons were conducted in order to evaluate groundwater characteristics in the Study area.
The results of the observation is shown in the groundwater table map in Fig. 4.4.1. The groundwater flows in the western mountains of the Study Area along with the mountainous slopes to Lake Managua, however, the groundwater flow is inferred to change its direction and to flow to Lake Asosoca because of large pumping discharge.

In the eastern part of the Study Area, the groundwater flows from southwestern mountainous zone to Masaya Cardera and Lake Masaya, changes its direction and go to the north to Lake Managua.
The spring water observed in the Lowland of Savana Grande in 50-60 m above sea level, is the terminal point of this groundwater flow.

(2) Water level of Managua and Asososca lakes

Lake Asososca, mentioned in Section 4.3, has been playing a very important role as a domestic water source of the Managua city. However, water level has constantly decreased due to over pumping from 1980, and the Asososca's water level was 35.0 m in 1992 against a water level of 36.5 m recorded in 1992 in Lake Managua.

Fig.4.4.2 shows the groundwater table around Lake Asososca in 1963, 1970 and 1978. The lake water level has been noticeably decreasing due to pumping.

Fig. 4.4.3 shows the levels of Asososca and Managua Lakes in 1966-1967; from 1968, the water level of Lake Asososca is getting lower than Lake Managua.

Fig. 4.4.4 shows the water level of lake Asososca in 1972-1991 with rainfall and extraction.

The water quality of the Lake Managua is contaminated by the drainage of factories and domestries in Managua City. It is considered that water intrusion from Lake Managua to Lake Asososca will occur if the water level of Lake Asososca goes on decreasing. Besides, a study conducted by INETER pointed out that groundwater could be contaminated by the waste water from the industries implanted between the two lakes.

Consequently, recovery of Lake Asososca's water level is an essential objective in the Study Area. Since 1989,INAA has taken measures to reduce pumping discharge in this lake, however, recovery has not been observed yet because of dry climate condition during the recent years.

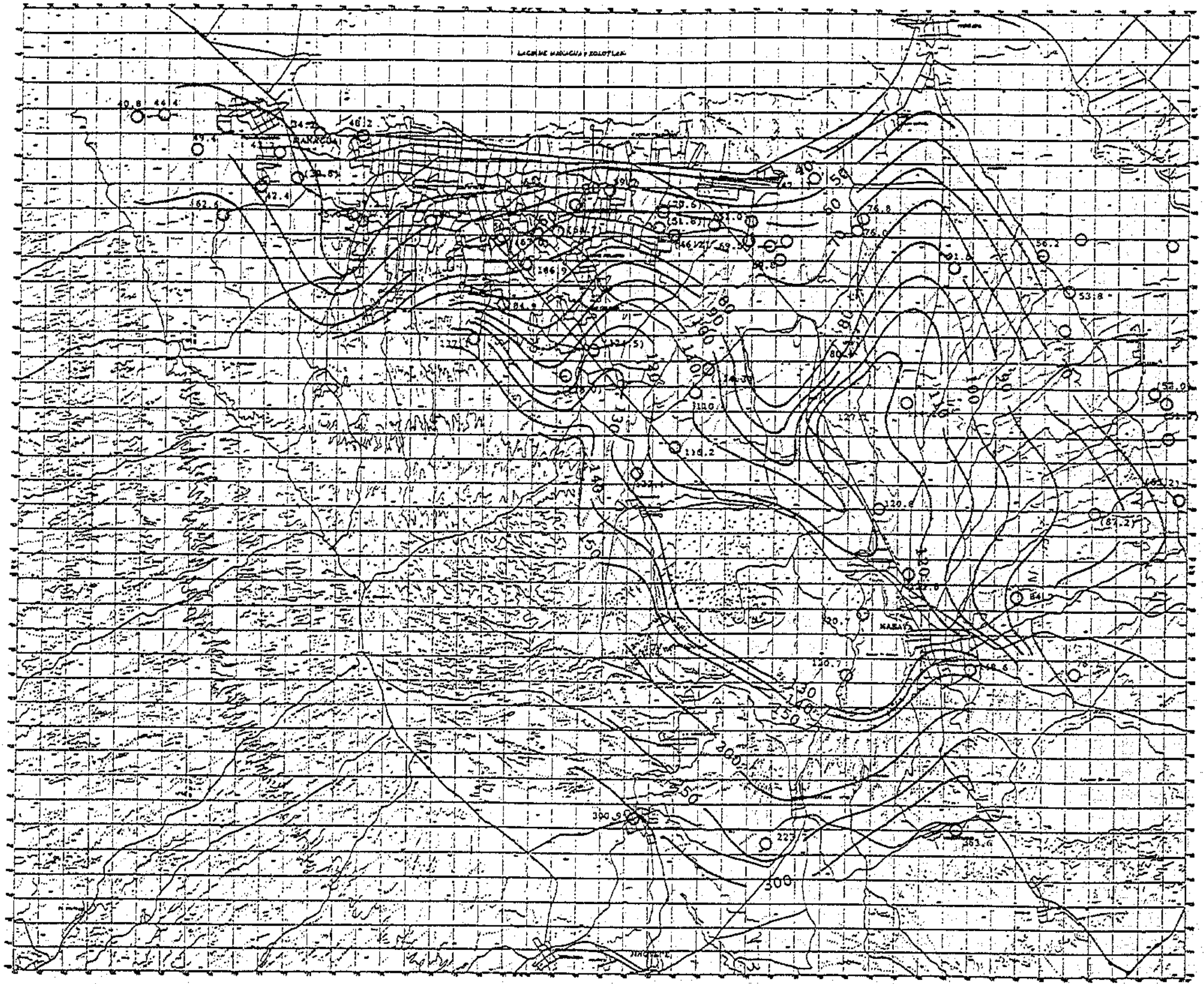
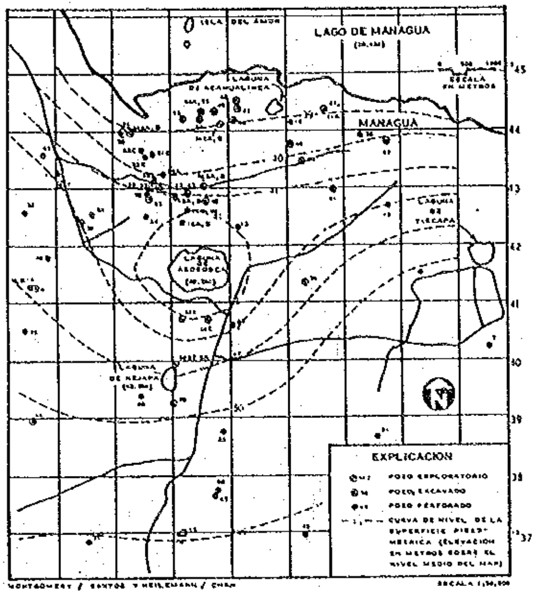


Fig. 4.4.6 Mapa de Curva de Nivel Freático al Final de la Estación Seca del Año 1992

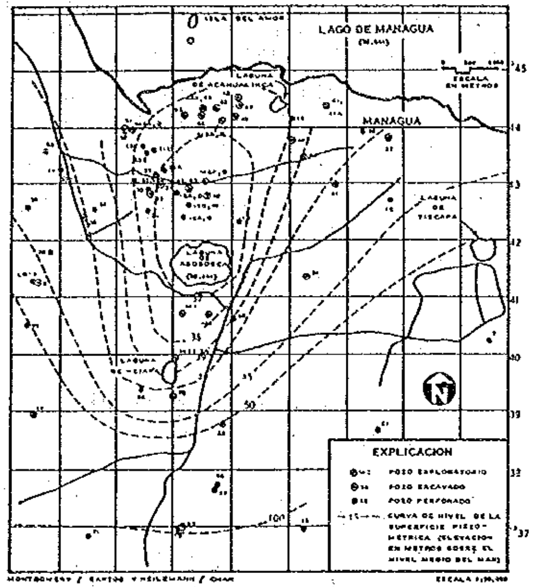
Fig. 4.4.1 Groundwater Table

4-79

MAYO 1963



MAYO 1970



MAYO. 1978

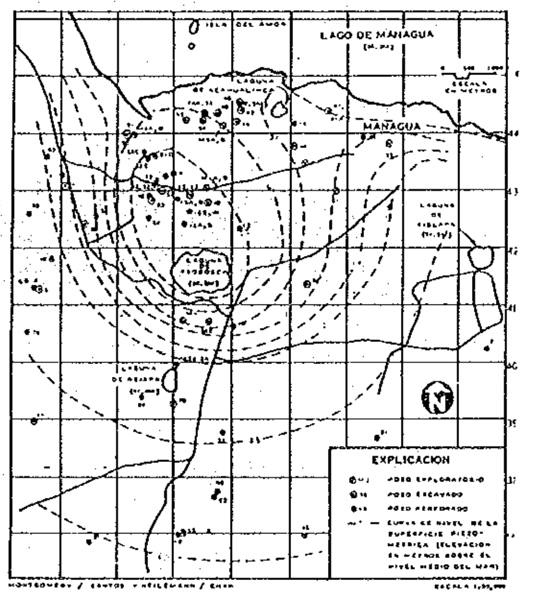


Fig. 4.4.2 Groundwater Level around Lake Asososca in 1963, 1970, 1978

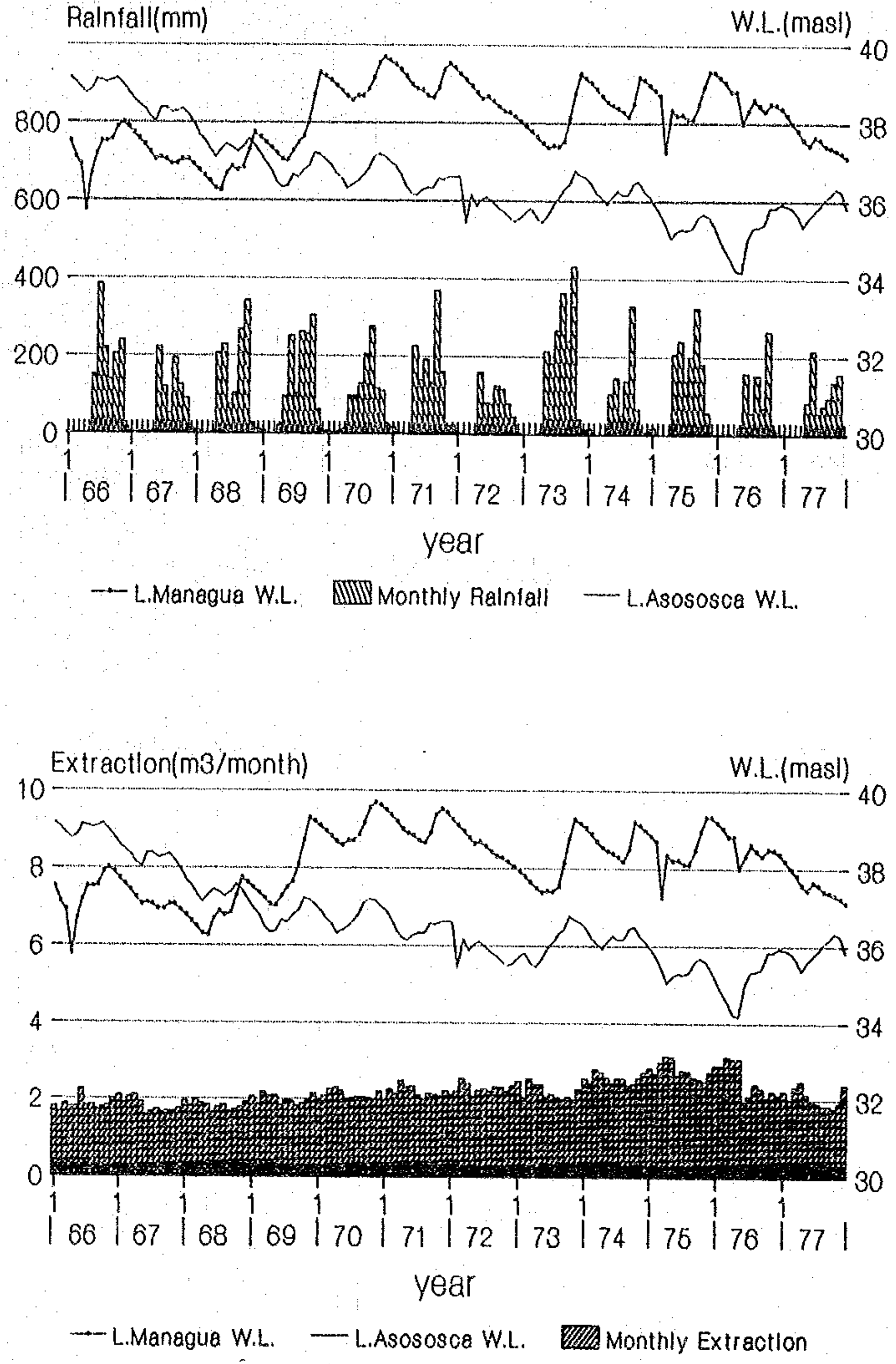


Fig. 4.4.3 Monthly Water level of Managua and Asososca lakes

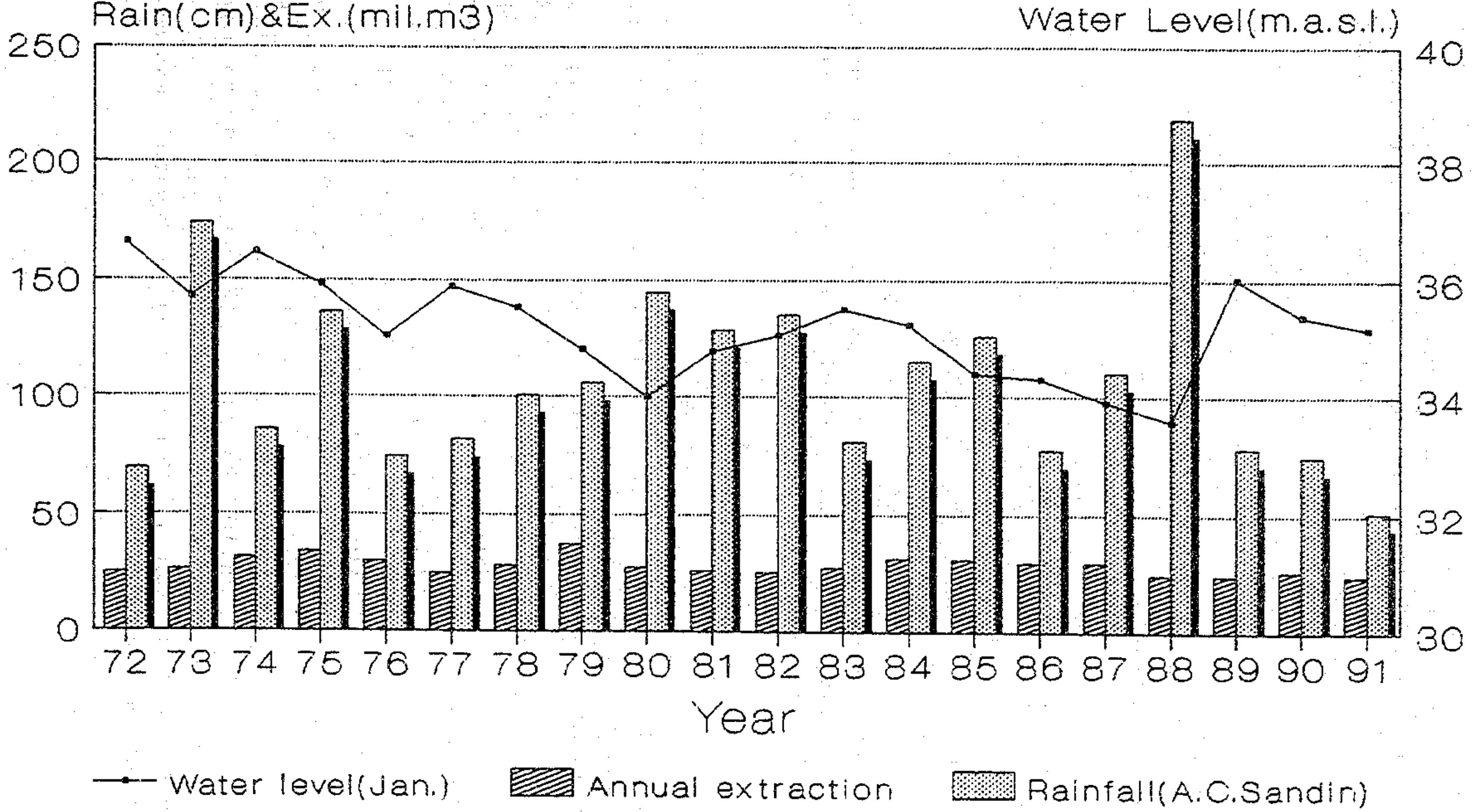


Fig. 4.4.4 Water Level of lake Asososca

4.5 Groundwater Use

According to the groundwater use survey conducted in 1991, INAA's extraction for drinking water was almost 90 % of the total production, and irrigation & industry uses are very small.

	Unit: million m^3
INAA	98.01
Municipal	6.65
Industry	5.88
Agriculture	1.24
Total	111.82

(1) Main wells of INAA Central Managua

The following table summarizes the annual production, distributed among the INAA Central Managua's main well fields during 1972-1991 period. (See Fig. 4.5.1 and 4.5.2.)

unit:million m^3 & (%)

Location	1972	1975	1980	1985	1990	1991
Lake Asososca	25.10	33.90	27.20	31.09	25.94	24.00
	(100)	(100)	(49)	(48)	(27)	(24)
Carlos Fonseca	-	-	20.07	21.39	20.20	21.99
	(0)	(0)	(38)	(33)	(21)	(22)
Sabana Grande	-	-	-	-	4.73	5.45
	(0)	(0)	(0)	(0)	(5)	(5)
Veracruz	-	-	2.05*	2.05*	3.21	3.89
	(0)	(0)	(4)	(3)	(3)	(4)
Other	-	-	5.14	10.12	40.82	46.69
	(0)	(0)	(9)	(16)	(44)	(46)
Total	25.10	33.90	55.09	64.65	97.04	102.02

* Annual production in Veracruz is estimated according to operation hours.

The table shows how water sources have shifted during the 1972-1991 period, from the concentrated extraction from Lake Asososca to expanded extraction from Carlos Fonceca, Sabana Grande, Veracruz well fields plus some wells located in the city.

Annual pumping discharge rapidly increased in the past twenty years, from 1.5 million m^3 in 1972 to 6.65 million m^3 in 1991, along with the expansion of Managua City. Drinking water supply system is considered to have been improved during this period.

The groundwater production for the industry decreased of 50% from 10.90 million m^3 in 1972 to 5.88 million m^3 in 1991, because many factories were closed or changed of water source and adopted the public water supply services provided by INAA.

The groundwater is also been used for agriculture purpose, mainly as irrigation water in the National Cereal Seed Production Center (CINGB) in Savana Grande. Water use for qgriculture is estimated to be 1.24 million m^3, considering the area of irrigated area.

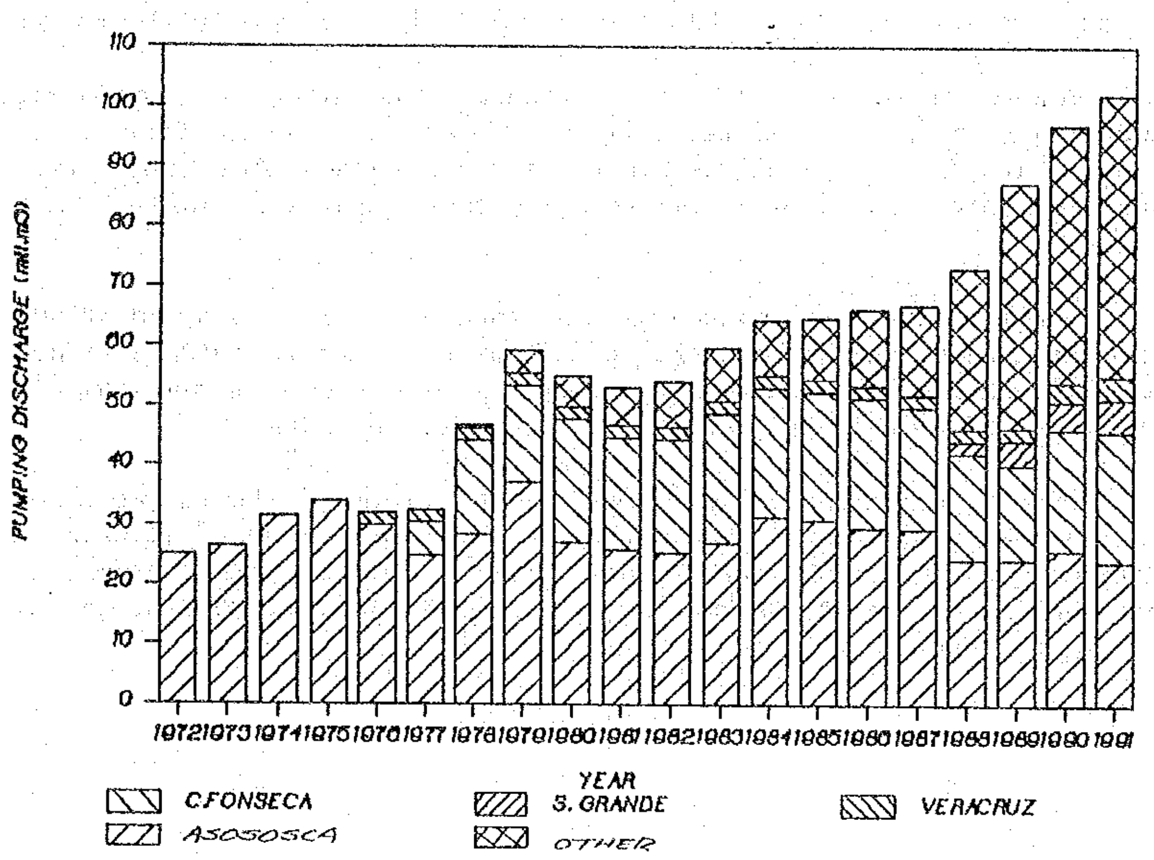


Fig. 4.5.1 Annual Pumping Discharge in 1972-1991

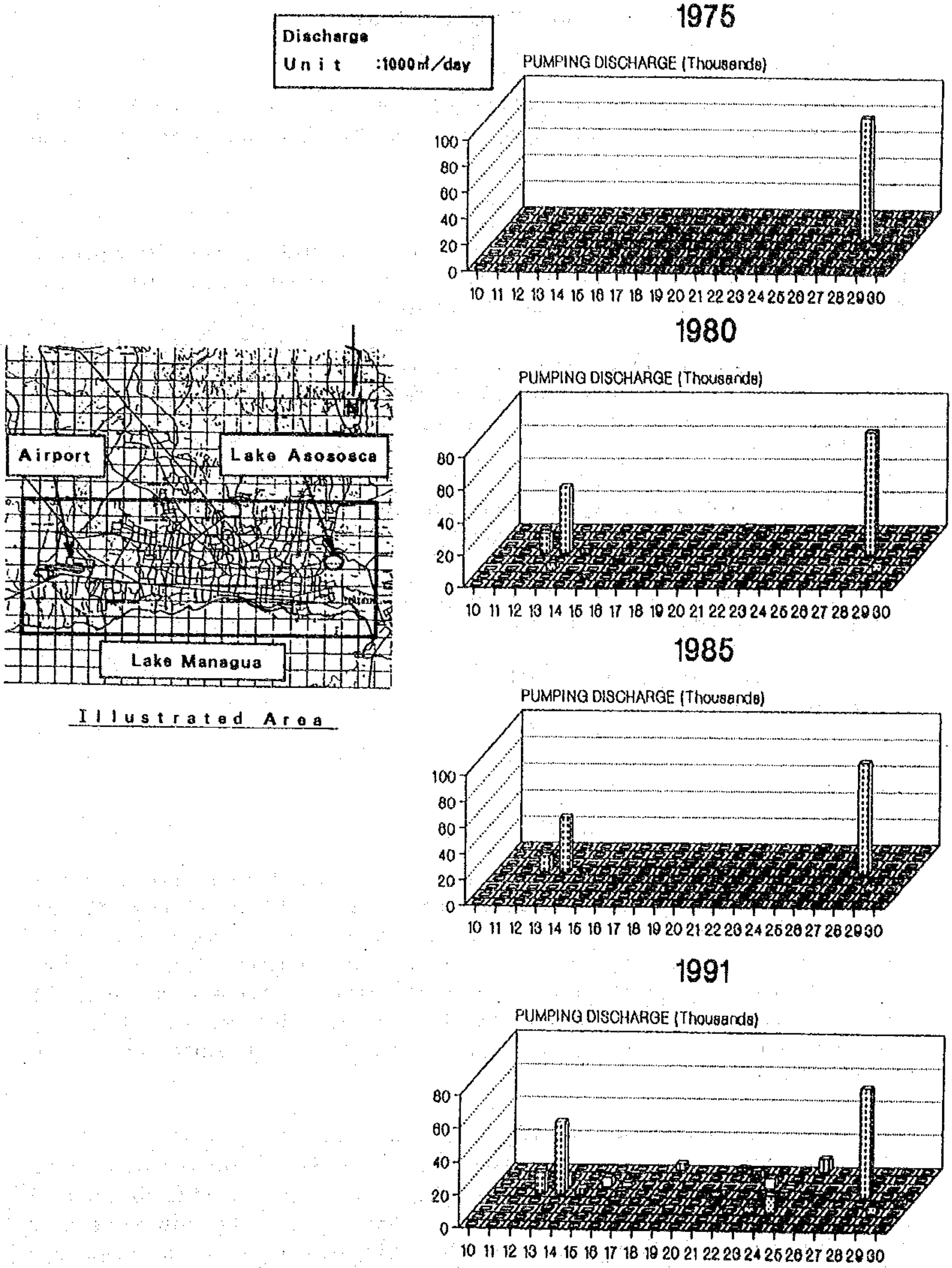


Fig. 4.5.2 Histry of Daily Pumping Discharge in 1km x 1km

4.6 Test Well Drilling and Pumping Test

In this Study, test drilling of 5 wells, cumulative drilling depth of 1,266 meters and pumping test at 7 sites were carried out with the following purposes.

a) To investigate groundwater occurrence and hydraulic aquifer characteristics and to evaluate the overall potential of groundwater resources in the Study area.

b) To examine groundwater suitable as drinking water source, and to clarify groundwater flow mechanism by comparing the chemical components of groundwater in different geohydrologic sub-areas and aquifers.

c) To select priority areas and to formulate a groundwater development plan for the selected priority areas.

The test drilling results and the pumping test are summarized in Table 4.6.1, 4.6.2 and Figure 4.6.4.

The following major findings were obtained from test well drilling.

(1) JI-1 Well

This test well was drilled to investigate groundwater occurrence and hydraulic aquifer characteristics of the Middle Las Sierras Group, and to confirm existence of hydrogeologically impermeable basal layers from electric prospecting results. Although this test well drilled supposing to be 400 meters, it was only drilled to a depth of 300 meters due mainly to very unstable formation of very loose ash flow of more than 220 meters thick.

Based on existing geological data and information, it is believed that the Middle Las Sierras Group is composed mainly of basaltic compact agglomerate and partially of thin beds of porous scoria like the aquifers. However, this test well has revealed the existence of a formation somewhat different from the commonly known Middle Las Sierras Group. The compact agglomerate of the Middle Las Sierras Group from the ground surface is only 80 meters thick, and a very thick formation of volcanic materials composed of scoria flow with fossil soils, basaltic porous lava and pyroclastic flows and ash flows more than 220 meters thick are underlain. These volcanic materials underlying the well known Middle Las Sierras Group are considered to be one of the initial volcanoes of the Las Sierras Group. A presumed geological structure and a schematic geological section of the area are given in Figures 4.6.1, and 4.6.2, and area is shown in Figure 4.8.2. If the presumed structure is correct, this would prove the are to be hydrogeologically promising as it forms a good groundwater reservoir (Sc:19,464.48 m^3/day/m).

(2) JI-2 Well

This test well was drilled with a target depth of 200 meters to investigate groundwater occurrence and hydraulic aquifer characteristics of the Masaya Group Volcanics and Middle Las Sierras Group.

This test drilling work confirmed that the principal water bearing formation in the area is the Masaya Group Volcanics composed of fissured and porous basaltic lava, auto-brecciated basaltic lava and pyroclastic flows such as porous scoria and ash beds. Specific capacity (Sc) obtained from the pumping test of this test well was 687.77 m^3/day/m.

(3) JI-3 Well

The major purposes of this test well drilling was carried out mainly due to the following 3 reasons:

a) To investigate groundwater occurrence and hydraulic aquifer characteristics of the Masaya Group Volcanics and Middle Las Sierras Group.

b) To confirm existence of hydrogeologically impermeable basal layers from electric prospecting results (Fig. 4.6.3).

c) To investigate geothermal conditions at the deeper portion of the area in connection with the hot spring at Tipitapa and its surroundings.

Although the primarily intended depth of the test well was 400 meters, the actual drilled depth was only 366 meters because of the achievements of the above mentioned study purposes.

The major findings of this test well drilling works are the following:

(a) The principal aquifers of the area are pyroclastic fall and flow beds consisting of scoria and rock fragments of the Masaya Group volcanics and weathered agglomerate with fossil soil and scoria beds of the Middle Las Sierras Group. Specific capacity (Sc) obtained from the pumping test of this test well was 1,118.64 m^3/day/m.

(b) The basal layer is composed of dacite (dyke) and dacitic ignimbrite of the Upper Coyol Group. This basal layer were confirmed by the drilling at the depth from 266 to 366 meters.

(c) The lithology in this test well varies from the Middle Las Sierras Group to dacitic ignimbrite and dacitic intrusive rock of the Upper Coyol Group at the depth of 266 meters, and in this connection, the temperature in the well increased from 35 °C to 39.5 °C.

In this test well, 4 water samples were taken at depths of 164.59, 214.58, 264.57 and 314.55 meters. The chemical component of the water was a combination type of shallow groundwater [Ca(HCO3)] and semi-confined groundwater (NaHCO3).

(4) JI-4 Well

This drilling site was selected to investigate the hydraulic aquifer characteristics of a zone in the Middle Las Sierras Group with a low yielding capacity.

The main aquifers of the area are weathered agglomerate with fossil soil beds, and specific capacity (Sc) obtained from pumping test was 123.77 m^3/day/m.

(5) JI-5 Well

This test well was drilled to investigate hydrogeological structure of the Los Brasiles Valley and aquifer characteristics of the Middle Las Sierras Group, and to investigate lithological conditions of the El Salto Formation.

The main aquifers of the area are weathered agglomerate with fossil soil beds, fractured agglomerate, and basal layer of tuffaceous coarse sandstone and fine conglomerate on top surface of the El Salto Formation.

The existence of the El Salto Formation has been confirmed at depths between 167.64 and 200 meters, consisting of tuffaceous sandstone and siltstone with sandy tuff, tuffaceous fine sandstone with fine fragments of shell fossil, and tuffaceous fine conglomerate with calcareous gravel.

The hydrogeological structure of the Los Brasiles Valley is represented in Fig. 4.1.5. Specific capacity obtained from the pumping test was 804.19 m^3/day/m.

Cuadro 4.6.1 Caracteristicas generales de 7 pozos exploratorios

Table 4.6.1 General Feature of Seven Test Wells

Nombre de Pozo (Well Name)	JICA No. 1	JICA No. 2	JICA No. 3	JICA No. 4	JICA No. 5	Juan Ramon Robles	No.1285
1.Direccion (Address)	Las Madrigales	Veracruz	Sabana Grande	Socrates Sandino	Bello Amanecer	El Pique	Hermanos Rosales
2.Latitud (Latitude) Longitud (Longitude)	12° 03′ 30″ 86° 11′ 43″	12° 06′ 08″ 86° 09′ 32″	12° 08′ 50″ 86° 08′ 59″	12° 06′ 43″ 86° 12′ 51″	12° 08′ 22″ 86° 20′ 51″	12° 05′ 53″ 86° 09′ 44″	11° 59′ 40″ 86° 06′ 29″
3.Elevacion (Elevation)	Aprox. 220m	Aprox. 125m	Aprox. 78m	Aprox. 86m	Aprox. 145m	Aprox. 109m	Aprox. 255m
4.Diametro del ademe (Diameter of Casing Pipes)	12″ 3/4	12″ 3/4	12″ 3/4	12″ 3/4	12″ 3/4	13″ 1/2	6″
5.Perforado por (Drilled by)	JICA Study Team	JICA Study Team	JICA Study Team	JICA Study Team	JICA Study Team	—	—
6.Fecha de inic.y final de la perfor (Bigining and Completion Date of Drilling)	Jun.10 1992 Nov.16 1992	Jun.17 1992 Nov.18 1992	Jun.15 1992 Nov.14 1992	Jun.19 1992 Oct.20 1992	Jun.18 1992 Oct.23 1992	— —	— —
7.Tiempo que tomo(Spent days) (dias:days)	160	155	153	116	63	—	—
8.Posicion de rejilla (Screen Position) 1)Tipo puente(Bridge Type) (Nivel de tierra -m) (Ground Level -m)	107.28 ~156.05 174.80 ~186.99	88.84 ~105.91 118.16 ~152.30 170.68 ~182.58	19.46 ~ 29.21 41.71 ~ 92.92 141.12 ~155.75 218.13 ~220.59	109.00 ~130.90 137.20 ~156.70 162.90 ~175.10	114.80 ~151.40	—	—
2)Jhonson (Nivel de tierra -m) (Ground Level -m)	186.99 ~210.16	71.44 ~ 88.84	105.42 ~128.62	175.10 ~192.50	163.60 ~181.00	—	—
9.Longitud de rejilla (Screen Length) 1)Tipo puente (Bridge Type)	60.96	63.74	78.05	53.60	36.60	—	—
2)Johnson (m)	23.17	17.40	23.20	17.40	17.40	—	—
10.Temperatura de agujero (Temperarure of Borehole)(℃)	—	34.0 (200m)	35.3 (280m)	32.0 (200m)	40.7 (200m)	—	—
11.Temperatura de agua (Temperature of Water) (℃)	—	28.6	33.5	30.9	35.0	30.3	—
12.Conductividad(Conductivity) (mS/cm)	—	1.180	—	0.361	1.000	1.003	—

Cuadro 4.6.2 Resultados de pruebas de bombeo
Table 4.6.2 Results of Pumping Test

Nombre de Pozo (Well Name)	JICA No. 1	JICA No. 2	JICA No. 3	JICA No. 4	JICA No. 5	Joan Ramon Robles	No. 1285
1. Profundidad (Well depth) (m)	300	200	366	200	200	138	—
2. Longitud de rejilla (Total Screen Length) (m)	84.13	81.14	101.25	71.00	54.00	—	—
3. Principal formacion acuifera (Main Formation of Aquifer)	TQps(M)	QvM, TQps(M)	QvM, TQps(M)	TQps(M)	TQps(M)	QvM	TQps(M)
4. Fecha de bombeo (Pumping Test Date)	Nov.14~16 1992	Nov.16~18 1992	Nov.12~14 1992	Oct.14~18 1992	Oct.21~23 1992	Oct.03~05 1992	Jul.08 1992
5. Nivel estatico de agua (Static Water Level) (G.L.-m)	104.24	43.47	14.52	94.28	100.18	39.80	96.73
6. Caudal (Discharge Rate) (m^3/d)	1,483	2,469	2,998	1,472	1,472	2,470	87
7. Descenso (Drawdown) (m)	0.076	3.59	2.68	11.89	1.83	8.37	0.47
8. Capacidad Especifica (C.E.) (Specific Capacity) (m^2/d)	19,464	688	1,119	124	804	295	183
9. Transmisivilidad (Transmissivity)							
1) a. Theis	—	915	—	147	50	123	323
b. Jacob	—	1,291	3,658	150	267	192	354
2) Recuperacion (Recovery Test)	—	1,290	3,429	112	—	105	332
3) T=1.22×C.E.	23,746	839	1,364	151	981	360	223
10. Storage Coefficient	—	3.24×10^{-5}	—	1.82×10^{-4}	—	—	—
11. Aquifer Loss Coefficient (d/m^2)	—	—	5.92×10^{-4}	4.42×10^{-3}	—	—	—
12. Well Loss Coefficient (d^2/m^5)	—	—	1.10×10^{-7}	2.57×10^{-6}	—	—	—

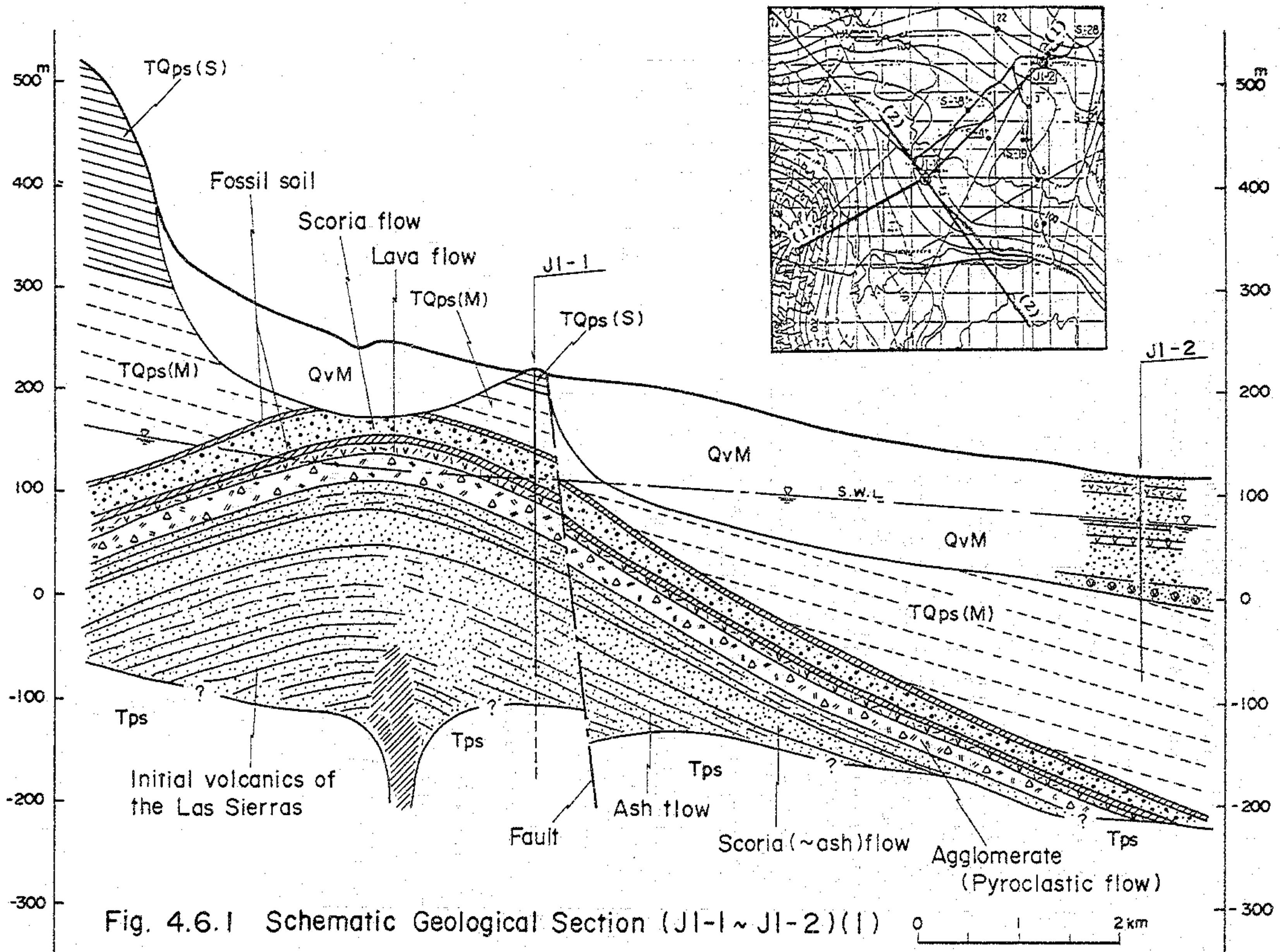


Fig. 4.6.1 Schematic Geological Section (J1-1 ~ J1-2)(1)

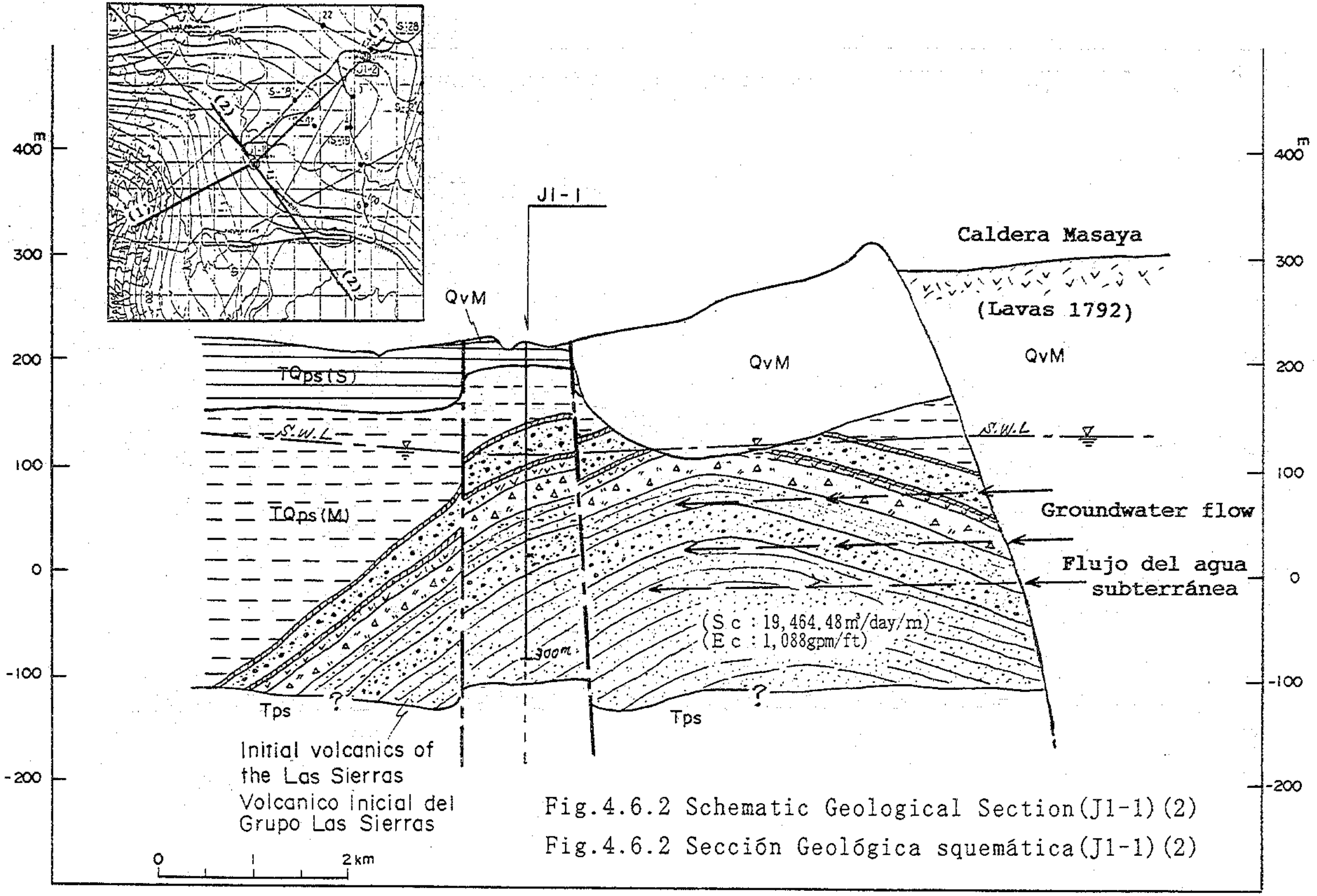


Fig.4.6.2 Schematic Geological Section(J1-1)(2)

Fig.4.6.2 Sección Geológica squemática(J1-1)(2)

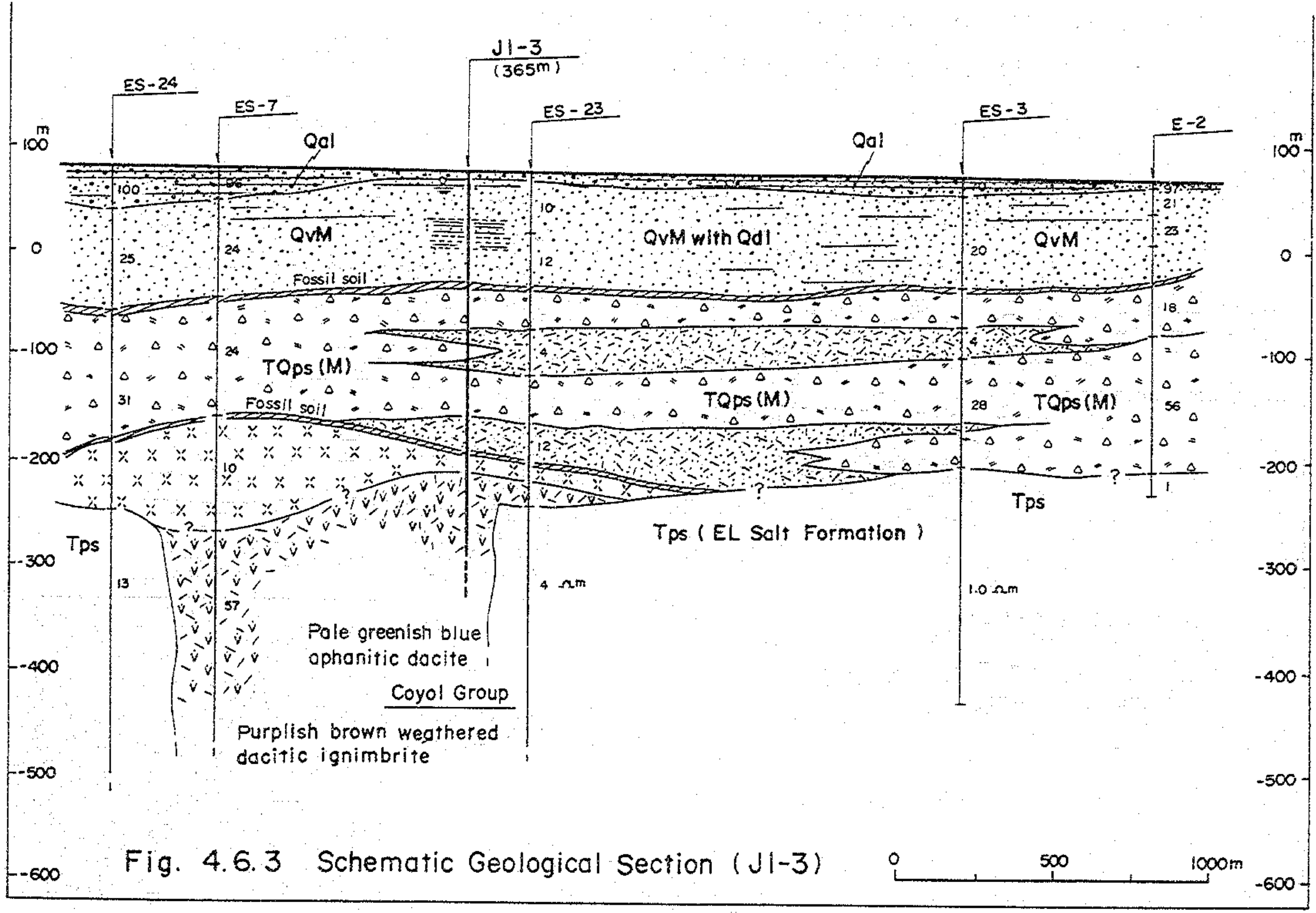


Fig. 4.6.3 Schematic Geological Section (JI-3)

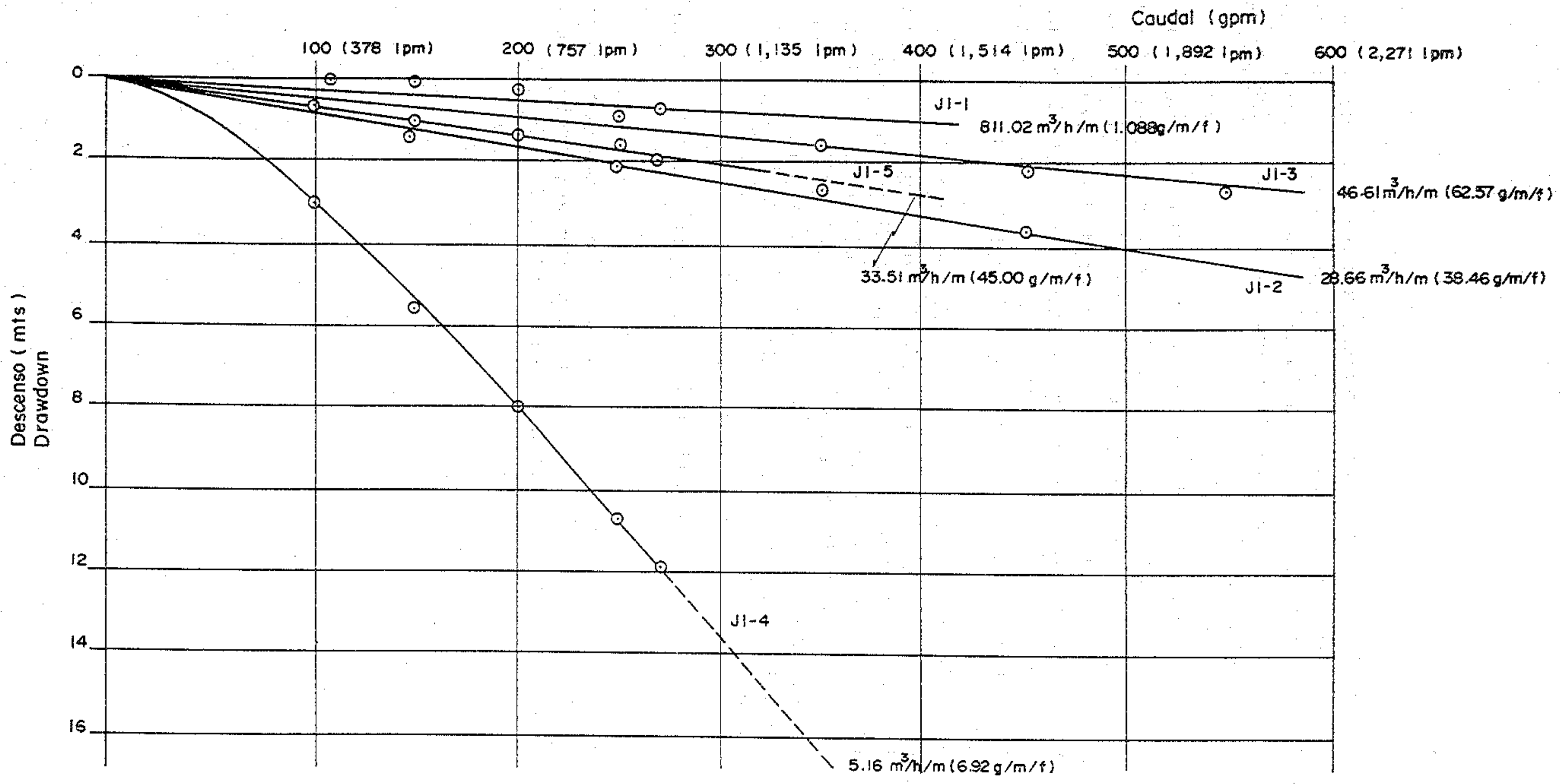


Fig. 4. 6.4 Pruebas de Bombeo a Descarga Variable

Fig. 4. 6.4 Step Drawdown (Discharge) Test

4.7 Water Quality

Water quality analysis of groundwater samples was conducted in order to evaluate its suitability for drinking water, and to understand the hydrogeological groundwater flow. According to the results of analysis, most of groundwater in the Study Area is suitable for drinking.

The locations plotted in the trilinear diagram show the characteristics of water with respect to the groundwater flow system. In the case of the Study Area, most of the points are distributed in areas high in (CO^3+HCO^3), except for Lake Apoyo and Lake Nejapa, both considered to be largely influenced by volcanic activity. The hot spring water in Tipitapa is also located in the same position. (See Fig.4.7.1.)

Moreover, samples taken from the upstream area (where the period of stay is short) like Km 16 Leon and San Marcos are located in areas where the Ca+Mg ratio is small. The samples taken downstream (where the period of stay is longer), on the other hand, are located in areas were the Na+K ratio is big. This may be attributed to the ion cation exchange process, wherein an Na2+, K+, Mg2+, to Ca2+ exchange process is generally considered favorable.

Most of the plotted conditions clearly indicate similar conditions.

The stiff pattern diagram also shows the same condition described above, and an increase in ion concentration was observed in the samples from Sabana Grande-Cofradia-San Rafael. See Fig.4.7.2.