THE REPUBLIC OF PERU

FINAL REPORT
FOR
THE MASTER PLAN STUDY
ON
THE DISASTER PREVENTION PROJECT
IN
THE RIMAC RIVER BASIN

SUPPORTING REPORT I

MARCH 1983

JAPAN INTERNATIONAL COOPERATION AGENCY
TOKYO, JAPAN

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SUPPORTING REPORT I

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ABBREVIATION

1. Abbreviation of Peruvian Offices

CENTROMIN S.A.	Empresa Minera del Centro del Perú Center Perú Mining Company)
CAPECO +	Cámara Peruana de la Constructión (Peruvian Chamber of Construction
CONCITEC	Consejo Nacional de Ciencia y Tecnología (National Council of Science and Technology)
COOPOP	Cooperación Popular (Popular Cooperation)
CORDE CALLAO	Corporación de Desarrollo del Calao (Development Corporation of Callao)
CORDE LIMA	Corporación de Desarrollo de Lima (Development Corporation of Lima)
CORPAC	Corporación Peruana de Aviachión Comercial (Peruvian Corporation of Commercial Air Travel)
C.P.L.	Concejo Provincial de Lima (Provincial Council of Lima)
DGAF	Dirección General de Aerofotografia (Department of Aerophotographs)
DGASI	Directión General de Aguas, suelos e irrigaciones (General Direction of Water, Soil and Irrigations)
DHNM	Direccióndde Hidrología y Navegación de la marina (Navigations and Hydrographic Direction of the Peruvian Navy)
ELECTRO LIMA	Empresa de Electricidad de Lima (Electric Company of Lima)
ELECTRO PERU	Empresa de Electicidad del Perú S.A. (Electric Company of Perú)
ENACE	Empresa Nacional de Edificaciones (National Enterprise for Building)
ENAFER S.A.	Empresa Nacional de Ferrocarriles del Perú

	(Railroad National Company of Perú)
IGN	Instituto Geofísico Nacional (Geophysics Institute of Perú)
IMARPE	Instituto del Mar del Perú (Oceanic Institute of Perú)
INADE	Instituto Nacional de Desarrollo (Development National Institute)
INAF	Instituto Nacional de Ampliación de la Frontera Agrícola (National Institute for the Widening of Agriculture Lands Frontier)
INE	Instituto Nacional de Estadísticas (Statistics National Institute)
INP	Instituto Nacional de Planificación (Planning National Institute)
INFOR	Instituto Nacional Forestal y de Fauna (Forest, Fauna National Institute)
ING	Instituto Nacional Geográfico (National Geographic Institute)
INGEMMET	Instituto Geológico Minero y Metalúrgico (Metallurgy, Mining and Geologic Institute)
INVERMET	Inversiones Metropolitanas (Metropolitan Inversions)
MINIS. AERON.	Ministerio de Aeronáutica (Aeronautic Ministry)
MINIS. AGRIC.	Ministerio de Agricultura (Agriculture Ministry)
MINIS. ECON.	Ministerio de Economía y Finanzas (Economics and Finance Ministry)
MINIS. EDUCA.	Ministerio de Educación (Education Ministry)
MINIS. ENERG.	Ministerio de Energía y Minas (Energy and Mining Ministry)
MINIS. GUERRA	Ministerio de Guerra (War Ministry)
MINIS. INDUS.	Ministerio de Industria, Turismo e Integración

	(Industry, Tourism and Trade Ministry)
MINIS. INTER.	Ministerio del Interior (Interior Ministry)
MINIS. PESQ.	Ministerio de Pesquería (Fishing Ministry)
MINIS. PRESD.	Ministerio de la Presidencia (Presidency Ministry)
MINIS. PREE	Ministerio de Relaciones Exteriores (Foreign Relations Ministry)
MINIS. SALUD	Ministerio de Salud (Health Ministry)
MINIS. TRABJ.	Ministerio de Trabajo (Labour Ministry)
MINIS. TRANSP.	Ministerio de Transportes y Comunicaciones (Transports and Communications Ministry)
MINIS. VIVIE.	Ministerio de Vivienda y Construcción (Housing and Construction Ministry)
MUN. DIS. LIMA	Municipalidad Distrital de Lima (District Council of Lima)
MUN. DIS CALLAO	Municipalidad Distrital del Callao (District Council of Callao)
MUN. DIS. ATE	Municipalidad Distrital de Ate (District Council of Ate)
MUN. DIS. CHACL.	Municipalidad Distrital de Chaclacayo (District Council of Chaclacayo)
MUN. DIS. CHOS.	Municipalidad Distrital de Chosica (District Council of Chosica)
MUN. DIS. MATUc	Municipalidad Distrital de Matucana (District Council of Matucana)
MUN. DIS. SANMAT	Municipalidad Distrital de San Mateo (District Council of San Mateo)
NCTL +	Naturaleza, Ciencia y Tecnología Local (Nature, Science and Local Technology Organization)
ONERN	Oficina Nacional de Evaluación de Recursos Naturales

	(National Evaluation Office of Natural Resources)
PREDES +	Centro de Estudios y Prevencio de Desastres (Prevention Disasters and Studies Center)
PRES. CO. MI.	Presidencia del Consejo de Ministros (Presidency of the Ministries Cabinet)
SAN	Servicio AerofotogrMinisterio de Economía y Finanzas (Economics and Finance Ministry)
MINIS. EDUCA.	Ministerio de Educación (Education Ministry)
MINIS. ENERG.	Ministerio de Energía y Minas (Energy and Mining Ministry)
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MUN. DIS. CHOS.	Municipalidad Distrital de Chosica (District Council of Chosica)
MUN. DIS. MATUc	Municipalidad Distrital de Matucana (District Council of Matucana)
MUN. DIS. SANMAT	Municipalidad Distrital de San Mateo (District Council of San Mateo)
NCTL +	Naturaleza, Ciencia y Tecnología Local (Nature, Science and Local Technology Organization)
ONERN	Oficina Nacional de Evaluación de Recursos Naturales (National Evaluation Office of Natural Resources)
PREDES +	Centro de Estudios y Prevencio de Desastres (Prevention Disasters and Studies Center)
PRES. CO. MI.	Presidencia del Consejo de Ministros (Presidency of the Ministries Cabinet)
SAN	Servicio Aerofotográfico Nacional (National Aerophotographics Service)
SE/CNDC	Secretaría Ejective/Comité Nacional de Defensa Civil (Executive Secretary/Civil Defense National Committee)
SEDAPAL	Servicio de Agua Potable y Alcantarillado de Lima (Drinkable Water and Sewering Service of Lima)
SENAPA	Servicio Nacional de Agua Potable y Alcantarillado (National Drinkable Water and Sewering Service)
SENAMHI	Servicio National de Meteorología e Hidrologîa

	(Meteorologic and Hydrologic National Service)
SNI	Sociedad Nacional de Industrias (National Industry Society)
UNFV	Universidad Nacional Federico Villarreal (Federico Villarreal National University)
UNMSM	Universidad Nacional Mayor de San Marcos (San Marcos University)
UNA	Universidad Nacional Agraria (Agriculture University)
UNI	Universidad Nacional de Ingeniería (Engineering National University)

+ Private Offices

2. Abbreviation of Measurement

Length

mm	Millimeter
cm	centimeter
m	mete
Km	kilometer

Time

S or sec	second
min	minute
h or hr	hour
d	day
y or yr	year

Area

cm^2	square centimeter
m^2	square meter
ha	hectare
Km^2	square kilometer

Volume

cm^3	cubic centimeter
m^3	cubic meter
l	liter

Weight

g	gram
kg	kilogram
ton	metric ton

Other Measures

%	percent
°	degree
°C	degree centigrade
103	thousand
106	million
109	billion

Derived Measures

m^3/s	cubic meter per second
KWH	kilowatt hour
MWH	megawatt hour

Currency

US$	U S Dollar
I/.	Perú Inti
¥	Japanese Yen

3. Abbreviation of others

JICA	Japan International Cooperation Agency
GDP	Gross Domestic Product
GRODP	Gross Regional Domestic Product
GNP	Gross National Product
Ref.	Reference
O&M	Operation and Maintenance
El.	Elevation
WL	Water Level
HWL	High Water Level
FWL	Flood Water Level
LWL	Low Water Level
Fig.	Figure
Qda/Q	Quebrada (Small Tributary)
Spe	Slope

APPENDIX I

GEOLOGICAL AND TOPOGRAPHICAL FEATURE

Appendix I GEOLOGICAL AND TOPOGRAPHICAL FEATURE

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I. GEOLOGICAL AND TOPOGRAPHICAL FEATURE

1. GEOLOGICAL FEATURE

1.1 Regional Geology

There are various types of igneous, metamorphic and sedimentary rocks with different geological ages from the coastal area of Lima to the eastern area of the Andes Mountain range. Andes mountains are topographically divided into three zones, each zone corresponding to particular geological unit arranged in NW-SE trend.

On the Eastern Cordillera, there are the oldest precambrian basement rocks which consist mainly of metamorphic rocks with small intrusive bodies of basic and ultrabasic faeces. Surrounding the basements, Paleozoic rocks are distributed in the same direction. Those are composed of metamorphosed or unmetamorphosed sedimentary rocks and granites.

Some granites are considered to be of the Hercinian cycle and others to be from Paleozoic to Mesozoic in age.

The major part of Central Cordillera is occupied by sedimentary and volcanic formations of Mesozoic age and the Permian formation is exposed in the western side of this zone. The formations from Triassic to upper Cretaceous consists of marine sediments such as limestone, sandstone and slate. These are partly covered by other formations from the upper most Cretaceous to the lowest Tertiary, which are mainly composed of continental sediments.

Cretaceous formation and some formation from upper Cretaceous to lower Tertiary are exposed in the parallel arrangement with NW-SE direction between the Central and the Eastern Cordillera. The Western Cordillera is broadly occupied by Tertiary formations consisting mainly of volcanic rocks. Some cretaceous formation is partially exposed among the Tertiary rocks. Various faeces of plutonic and volcanic rocks intrude into the Tertiary.

Large batholiths consisting of tonalite, granodiorite and diorite are distributed in the western side from the Tertiary zone. Some Jurassic and Cretaceous formations, intruded by the batholiths, are also found along the coastal zone.

Quaternary deposits are found in whole areas and its major distribution is along the coastal zone.

It is considered geotectonically that primary upheaval of the Andes mountains has occurred during the Albian stage. The coastal zone has been strongly folded at the Peruvian stage, upper Cretaceous. The movement decreases toward the Andean belt.

Folding and upheaval in the andean belt have intensively occurred during Incaina stage, upper Eocene. The largest upheaval of the Mountains occurred at upper Miocene in age which is called the Quichuana stage. This stage is characterized by faulting and volcanism, which particularly occurred in south Peru.

Upheaval of the Cordillera was moderate in the Plio-Pleistocene age, on the contrary, erosion and deposition were active.

1.2 Geology of the Rímac River Basin

The geological map of the Rímac river basin is shown in Fig. I-1-1 prepared on the basis of the data collected. In general, the basin is covered by elastic sedimentary and volcanic formations of the age from Jurassic to Tertiary, intrusive rocks of the age from Cretaceous to Tertiary and also quaternary deposits.

Jurassic formations are exposed in the northern part of Lima and extend to NW-SE direction along the Pacific coast. The formations consist predominantly of andesitic extrusives associated with chert, shale and etc.

Cretaceous formations are distributed in the north-west direction, and found with irregular form among Tertiary formations and intrusive rocks in several places of the Rímac river basin. The formations are rich in calcareous marine faces indicating unconsolidated condition. These are composed of limestone associated with marl, shale and quartzite. Some volcanic faces, however, consisting of predominant andesitic lava and volcaniclastics are exposed in the coastal area. The cretaceous rocks have been notably subjected to folding with NW-SE axis, and also are cut by many faults with NW-SE and EW directions.

Some formation from upper Cretaceous to middle Eocene in age is found in a narrow zone in the uppermost reach. The formation unconformably overlies some late Cretaceous formation. The formation is principally sediments of continental condition. The lower part consists of sandstone, shale, and mudstone, and the upper mainly of conglomerate associated with sandstone and shale with red colour.

Tertiary groups and formations are extensively distributed in the middle and upper reaches. These are divided into three zones, that is, the lower, the middle and the upper. The rocks of this age are characterized by the presence of predominant volcanic materials.

The volcanic extrusives from the lower zone to the lower half of the middle zone are andesitic faces which consist mainly of lavas, breccias and tuffs intercalated with tuffaceous sandstone, lapili tuff, sandstone and mudstone.

Sequent volcanism changes to acidic faces. Therefore, many formations from the upper half of the middle zone to the upper zone comprise rhyodacitic or rhyolitic facies. These are composed of extrusive and volcanic sediments such as alteration of tuff intercalates with tuffaceous sandstone and siltstone. Trachyandesite is also found in some place.

Andesitic and basaltic rocks are seen in the uppermost horizon of the upper zone. These rocks are probably Mio-Pliocence in age.

Various facies of intrusive rocks are found in the western area of the Western Cordillera. These intrusives consist of granite, granodiorite, tonalite and etc. of Cretaceous and Tertiary age and andesite of Cretaceous. Their general trend is NW-SE parallel to the Western Cordillera. Some plutonic rocks exist in large batholiths.

Small intrusive bodies such as andesite, rhyodacite and trachyandesite are found in the Tertiary area.

There are many metal mines in the investigated area. Principal mineralization has been associated with igneous activity in Miocene deformation stage during Andean geotectonic process. The mines excavate various types of minerals which consist of galena, spherlite, chalcopyrite, barite with pyrite, etc.

Quarternary deposits are divided into Pleistocene and Holocene.

Quaternary deposits consist of terrace with various levels, glacial, recent river and talus deposits. The deposits forming the ground of Lima is largest among them in scale. Thick piles of sand and gravel with clay are found. Major part of the deposits are presumably Pleistocence in age and covered by fan deposits of the Rímac river.

1.3 Particular Geological Conditions in the Rímac River Basin

1.3.1 Weathering

Weathering processes of rock is theoretically classified into mechanical and chemical actions.

Mechanical actions proceed principally, by forming fractures. Cause of mechanical weathering is attributed to change of temperature and various types of water movement.

Rock forming minerals are decomposed through chemical actions. Oxidation and hydration in molecules of minerals are the important aspects of chemical actions. All rock in surface is disintegrating and decomposing through both weathering processes

Consequently, climatic conditions have a considerable influence on weathering process. The climate in Rímac river basin is broadly classified into three zones depending on the elevation.

- Tropical or sub-tropical zone having the elevation between 0 and 3,500 m.

- Temperate zone having altitude ranging from 3,500 to 4,100 m.

- Cold zone more than 4,100 m in altitude.

The tropical or sub-tropical zone is the so-called semi-arid climate area with less precipitation and vegetation. The temperate zone having the altitude ranging from 3,500 to 4,100 m and cold zone higher than 4,100 m in altitude are subject to precipitation relatively more than the above semi-arid climate area, and thus, the area is covered with grass. The weathering process is characterized by this climatic condition.

Fig. I-1-2 shows a lithological pattern in the basin, based on classification of bed rock by petrological nature. The kinds of rock included are shown in Table I-1-1. As seen, the granitic rocks are extensively distributed in the downstream and middle reaches of basin. On the other hand, the volcanic and sedimentary rocks, which is more durable against chemical action, are largely distributed in the middle and upstream reaches. This difference of rock distribution also characterizes the weathering in the basin.

Furthermore, it is pointed out that the Andes mountains upheaved during Tertiary are accompanied by various faults and fractures, which made the basin much more vulnerable against the weathering. Accelerated by the faults and fractures as mentioned, the basin indicates a prominent devastation.

The situation of weathering in the basin is further detailed for respective area as follows;

(A) Downstream and Middle Reaches

An extensive distribution of granitic rocks is found in the downstream and middle reaches as mentioned. A remarkable weathering process is recognized on these rocks; that is, many rocks are under the decomposed condition of granite, which is called "Masa" in Japan. The "Masa" points out such a weathering process that a rock mass, subject to the mechanical and chemical actions, alters to a sandy rock mass by keeping original structure and texture of granite.

Although the said weathering process is generally seen on rocks with coarse-grained minerals like granitic rocks, the above suggests a strong effect of mechanical and chemical actions in the area.

A huge amount of relatively large rock blocks is yielded in the area. Its reason is considered as follows:

The weathering process proceeds primarily along joint system. Then, it penetrates into the rock mass. Thus, the weathering mainly develops along the joints, resulting in the production of rock blocks separated along the weathered joints. The granitic rocks in the area have joints at a relatively large interval, and therefore, the rock blocks produced are of relatively larger size. The rock blocks in the area are mostly round-shaped, indicating the character of joints in the granitic rocks and reflecting the mentioned process of weathering.

(B) Middle and Upstream Reaches

Rocks belonging to the Cretaceous formation in the middle reaches have been affected by strong tectonic movements, which is evidenced by marls or limestones with slaty cleavages developed parallel with the bedding plane. Further, water percolating into faults softens fault clay, which eventually worsens the rock mass condition.

The volcanic and sedimentary rocks of Tertiary are distributed in the middle and upstream reaches. The process of weathering for these rocks is similar to that for the above rocks belonging to the Cretaneous formation in the middle reaches, except that the area is subject to a higher effect of freeze and dissolution.

Then, various sizes of rock block as well as the clayey materials are yielded in the area. The rock blocks are very angular and relatively smaller as compared with those in the downstream reaches, reflecting the situation of joints formed in the volcanic and sedimentary rocks on the shape and size of rock blocks.

It seems that the yield of rock blocks in the area is smaller to some extent compared with the downstream reaches. The reason is considered to be the existence of vegetation. However, the area has numerous gullies where the erosion and weathering are remarkable, subject to the concentration of rainfall.

1.3.2 Unconsolidated Deposits

River terraces formed at Pleistocene are found in several places along the Rímac and Santa Eulalia river. There is a distribution of two or three-layered terrace deposit having its height ranging from 10 to 50 m in the vicinity of Chosica. There is also terrace deposits in the upstream of Chosica. These deposits consist of gravel, sand, and clay having its thickness ranging from 30 to 50 m. Gravels which occupy a large part of the deposit have its size from a fist size to block more than 1 m. These gravels are shaped roundly.

There are also old deposits which have a height of around 120 m above river bed in the upstream of Santa Eulalia river. These deposits presumed to be formed during glacial epoch are composed of various size of angular rocky materials. The similar type of deposit is also extensively distributed in many tributaries of the basin. This is the so-called "Older Huaycos" in Peru.

The deposits categorized as the formation of Holocene age are classified into various size of fan deposits, recent river and glacial deposits, and deposits on slopes of mountains or hilly side.

Qda. Chucumayo in the left bank, and Qda. Canchacalla in the right bank of Rímac river form the fan deposit at outlet of valleys. Fan deposits are also found at Qda. Redonda, Qda. Alcula, and Santo Domingo of the Santa Eulalia river.

The recent river deposits is independently identified although they include fan deposits. In the area from middle to lower reach, a thick deposits consisting of various size of gravel, sand, and clay sediment on river bed exist extensively. This sedimentation volume is considered to be enormous especially in the downstream from Carapongo.

Terrace of inundation is also noteworthy because historical trend of debris flow is to be clarified if a further investigation will be made on these terrace. It is observed during field survey that there is at least the high and two-layered inundation terrace with its height ranging 50 to 150 m near to fan deposits of Qda. Pancha. This is considered to be formed by recent inundation type of debris flow.

Slope deposits are widely distributed in areas from middle to upper reach of the basin as talus deposits or debris cones. These deposits are distributed on steep slope having gradient from 36 to 38 degree.

2. TOPOGRAPHIC CONDITION

2.1 Regional Topography

Whole country of Peru is classified into three regions based on characteristics of geography and climate. These are denominated as the Costa along the Pacific Ocean, the Sierra along the Andes Mountain Range and the Selva in the regions of Amazon river basin.

The Costa is roughly defined as the coastal belt up to 500 m in altitude. This belt without river flowing down from the Andes is occupied by desert areas as was affected by the cold Peruvian current.

The Andes Mountains of Perú are initially divided into three sectors, that is, the northern, the central, and the southern. The Rímac river basin belongs to the northwestern area of the central Andes mountains.

The Central Andes similar to the northern Andes is classified into three cordillera as follows; the western, the central and the eastern. The first has the mountains higher than the other cordilleras. Many mountains are over 5,000 m in height and have permanent snow or ice. The central and the eastern cordillera have sustained the erosion more strongly than the western.

Therefore, their altitudes are arranged in order of the Western, the Central and the Eastern from lower to higher.

The Mantaro and Apurimac rivers flow eastward crossing respectively the Central Cordillera. The river after conjunction of the two rivers crosses the Eastern Cordillera and enters to the Amazon.

The Urubamba river also crosses the Eastern. The river flows down the southern area between the central and the eastern cordillera and its water is originated from the northwestern slope of the southern Andes.

The part acrossing the two cordilleras is called Pongo in Spanish, which has a signification of Sitio of rivers. The rivers of the parts are narrow and rocky, moreover have canyon in common.

Topographic differences among the three cordilleras are due to different geo-historical process.

The Western Cordillera is the youngest and has been largely upheaved during tertiary age. The cordillera makes the backbone of Peru and divide the country between the Pacific and the Atlantic Ocean.

This cordillera is arranged in a direction of NW-SE in parallel to the coastal zone of the Pacific Ocean and situated close to the Pacific. As a result, all rivers in the Western side of the Cordillera are much shorter than those toward the Atlantic Ocean.

That is, all rivers in the western side of the Cordillera are very short and have remarkably steep gradient as seen in the Chillón, the Rímac and the Lurin rivers.

The Selva is distributed in the east from the Andean Mountains, mentioned above. This is divided into two zones, that is, the high Selva and the low Selva. In this case, the former is in altitude from 500 to 1,500 or 2,000 meters and characterized by formations of many valleys. The latter is a extensive peneplain in height lower than 500 m. It is considered geologically that the Precambrian Brasilian Schield has constituted the peneplain.

There is no intention in this report to fix the topographical division. It should be recognized that topography has been changed by internal geological activity and external erosion process through long geological periods. During our living time, however, the erosion process is the most important factor changing surface topography except particular volcanic and seismic activities.

2.2 Topography of the Rímac River Basin

Topographic map of 1/100,000 in scale covers whole area of the Rímac river basin. Fig. I-2-1 shows a division in elevation at 1,000 m contour interval. The relief energy which is defined as a height difference in a unit area is given in Fig. I-2-2, which shows the relief energy for every 4 Km^2 prepared by using maps of 1/100,000 in scale. In Fig. I-2-3, the relief energy is simplified, dividing into four stages of (A) 0 - 450 m, (B) 500 - 950 m, (C) 1,000 - 1,450 m and (D) more than 1,500 m.

The division (A) includes a extensive surface of a alluvial fan of Lima except two parts in the plateau. (B) is found near the fan of Lima and in the areas over 4,400 m in altitude. The greater part of the basin is included in the divisions (C) and (D). This fact shows clearly that in general mountain slopes of this basin are very steep.

From these evidences mentioned above, the Rímac river basin could be topographically classified into four reaches of the uppermost, the upper, the middle and the lower reach.

The topographic characteristics of each of these divisions are explained as follows:

(1) The Lower Reach: River mouth - Caranpongo

Thick accumulations consisting of gravel and sand with clay are found on the coastal cliff. It seems that the deposits formed principal flat plane of probably Pleistocene age. After the Pleistocene, the plane has been covered by alluvial deposits and also eroded by river flow in some cases. It appears that the presence of the Surco river, branching off from the top of the fan, is a clear indication of older inundations and erosions. Such a phenomenon can be commonly found on top parts of fan deposits.

The Rímac river is, at present, flowing down in the northern part of the city. The width of the river is 80 to 60 m at the river mouth. The river stretch from 9 Km to 10.5 Km forms the extremely narrow portion with about 15 to 20 m in width and about 20 m in height. The river stretch from the extremely narrow portion to the Intake of La Tarjea is 40 to 80 m in width.

These sections can be classified as the river in the city, and has been remarkably changed artificially.

The upper stream from La Atarjea is as wide as 200 to 300 m or 400 m. It seems that the riverbed has been elevated by sediments of gravels, sands, and others. Similar conditions continue toward Chaclacayo.

A large part of mountains in this reach consists of granitic rocks and forms steeper slopes over 30 degrees except the bottom portion of slope.

(2) The Middle Reach: Caranpongo - Matucana

Conditions of the middle reach are comparatively variable. The terrace planes are found along the river. The banks of the river are relatively low.

The river has many tributaries such as Qda. Canchacalla, Rio Seco, Qda. Chucumayo and Qda. Pancha. These tributaries create large fans in their mouths.

The middle reaches are a full mature V-shaped valley of which river beds are commonly covered with thick alluvial deposits. Although the river has steeper gradients, outcrops of rocks are not found in any river beds. Such feature indicate obviously the fact that the valley is in the lateral erosion stage at present.

The slopes of valleys, including the Rímac river and the tributaries, are very steep, and have bluffs in many places. Except rock exposures, talus deposits or debris cones are found on the slopes and their inclinations are as steep as 36 to 38 degrees.

(3) The Upper Reach: Matucana - Chicla

The Rímac river is flowing down in the valley of high mountains of 4,000 to 5,000 m in altitude. The long slopes and high bluffs are found in many places. Therefore, all small gullies form slopes of taluses or debris cones on a large scale.

The river cuts deep valleys and gorges. In this area, V-shaped valleys are being actively deepened at present.

(4) The Uppermost Reach: Plateau Zone
over EL.4,100 - 4,600 m

The plateau is located over 4,100 to 4,600 m in altitude. Many mountains and hills with permanent snow or ice are found in this area. The highest mountain is Nudo Sullcon of 5,650 m over sea level. The Ticlio pass is located on the border of the Rímac river basin and the river basin of Amazon, and 4,843 m in altitude.

3. GEOLOGICAL AND TOPOGRAPHIC CONDITION IN DISASTER PRONE AREAS

3.1 General

Each disaster prone area has respective characteristics in the geological and topographic conditions.

The geological and topographic characteristics, of which clarification will be useful for examining the effective disaster prevention measure, are discussed for the major disaster prone areas as follows;

3.2 Qda. Quirio

(A) Geological Condition

Qda. Quirio is situated on the right bank of Rímac river near Chosica. The complex of plutonic rocks with various facies is extensively distributed in the area. The granite which is the basement complex is subject to the severe weathering, yielding numerous rock blocks which fully cover the slope of the basin. The cracks are deeply developed into the base rock, and therefore, the weathering also reaches deeply below the surface, resulting in the unlimited yield of rock blocks.

Fig. I-3-1 shows the distribution of deposits in Qda. Quirio.

As seen, the older debris flow deposit is distributed in the upper reaches of Qda. It has a width of about 100 m in the middle reaches and vanishes at the upstream of the confluence of two major tributaries. The deposit consists of various sizes of rock blocks, rock fragments, sands and clay which are irregularly and loosely mixed in the deposit. No beddings or joints are recognized. The rock blocks are of irregular shape but round-shaped without the corner. The rock blocks decomposed due to the severe weathering, which indicate to be very old debris flow deposit, are also found partially.

In the lower reaches, a debris flow deposit covering the river terrace along the Rímac river is found as shown in the Figure. The above is evidenced by the fact that the deposit containing the granitic materials covers discordantly the river terrace of about 20 m in height which consists of the andesite materials along the right bank of Rímac river. It is considered that the debris flow which eroded the older deposit in the upper reaches as well as the river terrace has created the fan deposit in the position.

(B) Topographic Condition

Qda. Quirio has a drainage basin of about 10 Km^2 in the catchment area and 5.6 Km in the longest stretch. The altitude varies from 2,020 m at highest to 805 m in lowest.

The basin is of the so-called dendritic valleys, having two major tributaries which meet at 2,500 m from the Rímac river.

The average gradient is as follows:

- Rímac river to the confluence of two major tributaries --- 6 degree
- Confluence to 1,400 m in altitude --- 12 degree
- 1,400 m to 1,800 m in altitude --- 31 degree

Fig. I-3-1 indicates an outline of the basin. The development of gullies due to erosion of the old deposit is remarkable in the basin. The gully in the middle reaches, which is the largest one in the basin, has been developed to 20 m in width and 20 to 30 m in height, spreading the deposit in the lower reaches. The mountain slope in both sides of valley is as steep as about 40 degree with the surface fully covered by unstable rock blocks which easily collapse by rainfall or earthquake.

As such, the topography of the basin is continuously being changed due to the repetition of erosion and sedimentation. It is also pointed out that the topography is considerably changed by a heavy rainfall.

3.3 Qda. Pedregal

(A) Geological Condition

Qda. Pedregal is located adjacent to Qda. Quirio as mentioned in the previous section. Thus, the rock property and the state of weathering are almost same as those in Qda. Quirio; that is, the plutonic rocks with various facies are fully distributed in the area. The weathering is so remarkable that the unstable rock blocks fully cover the basin.

Fig. I-3-1 also shows the state of distribution of deposit in the basin. As seen in the Figure, the old debris flow deposit in this basin consists of two kinds. The old debris flow deposit (I) is largely distributed from upstream to downstream reaches of the basin. Its width is as large as 200 to 300 m. The old debris flow deposit (II) which came out from a small tributary in the right side of basin is distributed in a small scale as shown in the Figure. The deposit, consisting of the rock blocks, rock fragments, sand and clay which are loosely mixed, is vulnerable to the erosion. Then, the gullies are remarkably developed through this old debris flow deposit.

In the downstream reaches of the basin, a fan deposit where the eroded old deposit in the middle and upper reaches spread, is formed in a large scale. Its width is approximately 1.0 km at the downstream end. This fan consists mainly of the large rock blocks. In addition to the above, several alluvial cones are also found at the exits of small tributaries, which are shown in the Figure as Fan (II).

(B) Topographic Condition

The drainage basin is measured at 10.6 Km^2. The altitude ranges from 2,330 m at highest to 850 m at the confluence with the Rímac river. The length of basin is approximately 6.0 Km in the longest stretch. The gradient varies from about 7 degree in the lower and middle reaches to about 23 degree in the upper reaches.

This guebrada also has the dendritic valleys, divided into two major sub-basins at about 3.0 Km from the Rímac river.

The debris flow terrace is extended in a large scale up to 4 Km from the confluence with the Rímac river, although the terrace vanishes where the gradient becomes as steep as 23 degree.

The gullies are remarkably developed through the debris flow deposit as shown in the Figure. The gully is eroded by 20 to 30 m deep near the confluence of two major tributaries, although the depth of erosion diminishes to 2 or 3 m at the top of fan deposit where the inundation of debris flow is caused. A sign showing the process of gully development is recognized in the area: that is, cracks are seen on both side walls of gully. The erosion of gully bed induces the collapse of gully side walls, resulting in the development to larger gully.

The old debris flow channels are recognized at the top of fan deposit, indicating the fact that the so-called swing phenomenon occurred there, for which a due attention should be paid in examining the countermeasure.

3.4 Qda. Carosio

(A) Geological Condition

The quebrada is located in the immediate upstream of Qda. Pedregal as mentioned in the preceding section. Then, the rock property and the extent of weathering are similar to that of Qda. Pedregal.

The major unconsolidated materials in the quebrada are the talus deposit along the valleys, alluvial cone in the downstream reaches of quebrada and terrace deposit along the Rimac river as seen in Fig. I-3-2. The alluvial cone covers the terrace deposit. No old debris flow deposit is found in the quebrada.

(B) Topographic Condition

The quebrada has a small drainage basin of 0.5 km^2. The length of stretch is about 1.4 km. However, the slope along the valley is as steep as 22 and 35 degree in the middle and upstream reaches respectively. Many small valleys are distributed dendritically as seen in Fig. I-3-2.

The disaster is caused by the talus deposits which flow down along the steep slope at the time of heavy rainfall.

3.5 Qda. Corrales

(A) Geological Condition

Fig. I-3-2 also shows the geological condition in Qda. Corrales.

The quebrada, located adjacently to Qda. Carosio as seen in the Figure, has the same geological condition as that in Qda. Carosio mentioned in the preceding section, although the scale of the unconsolidated material deposit is slightly larger compared with that of Qda. Carosio.

(B) Topographic Condition

The drainage basin is relatively small, having a catchment area of about 1.0 km. The length of stretch is about 2.0 km. The small valleys distributed dendritically as shown in the Figure have a steep slope more than 30 degree.

Similar to the Qda. Carosio, the disaster in the area originates from the talus deposits which are extensively distributed along the valleys.

3.6 Qda. Rio Seco

(A) Geological Condition

Qda. Rio Seco is located on the left bank of Rímac river at about 20 Km upstream from the confluence of the Rímac and Santa Eulalia rivers.

The basement complex in this basin is composed of volcanic sediments and lavas. Hard andesite lavas are distributed in the upper altitude. On the other hand, the volcanic breccia and pyroclastic rocks are distributed in the middle and lower altitude.

In the former, a series of scarp is created since the andesite lavas are relatively resistible for the erosion. In the latter which is vulnerable against the weathering, th talus is distributed extensively. The size of rock blocks in the talus is relatively smaller compared with those in the granite zone; that is, the size is limited to 1 to 2 m at maximum. The shape is angular.

There are various decomposed deposits such as the river terrace deposit, old debris flow deposit and fan deposit, etc. of which distribution is as shown in Fig. I-3-3.

The river terrace deposit consists mainly of circular gravels of 10 to 20 cm in size with a sandwiched debris flow deposit composed of angular rock fragments. The height of this river terrace deposit is approximately measured at 50 m above the Rímac river bed.

The old debris flow deposit (I) with a thickness of about 60 m covers the above river terrace deposit. The deposit is largely composed of angular rock fragments of andesite from boulder to gravel in size. This is considered to be the debris flow deposit from the Rio Rimac in the geological age of Pleistocene.

Besides the above, the old debris flow deposit (II) with about 5 m in height is found in the basin of Qda. Rio Seco as shown in Fig. I-3-3. The deposit is distributed with about 300 m in width along the valley, forming a debris flow terrace. The deposit consists mainly of fine-grained materials such as sand and clay associated with small amount of andesite blocks, such characteristic is quite different from that of the deposit (I). This deposit is also considered to be the product in Pleistocene.

The recent debris flows occur in the gully created in these old debris flow deposits and spread the materials at the top of fan.

(B) Topographic Condition

The drainage basin of Qda. Rio Seco is as large as 49.3 Km^2. The altitude varies from 4,615 m at highest to 1,520 m at the confluence with the Rímac river. The gradient along the valley is relatively gentle; that is, 5 to 7 degree in the lower reaches and about 20° in the upper reaches.

A long and slender fan deposit is distributed in the mouth of valley. The fan has a length of about 1,300 m and a width of 600 m at the downstream end of fan.

The gully is created as shown in the Figure. The present gully is not eroded so deeply, i.e. 2 to 3 m deep in average with 10 to 15 m width. However, the above does not mean the erosion in the basin is not severe in consideration of the large quantity of fan deposit. It is judged that the eroded gully has been backfilled.

It is pointed out that the topography in Qda. Rio Seco is artificially changed by the traffic facilities such as the bridge and tunnels of the railway and traffic road which cross the valley. These structures are not provided properly for the debris flow. For example, the gully is extremely made narrow by the railway bridge where the inundation of debris flow is caused.

It is also pointed out that the fan deposit in Qda. Rio Seco has a noteworthy effect on the topography of the Rímac river; that is, the fan deposit dams up the Rímac river, resulting in the heap of sediments in the upstream reaches of the Rímac river. It is considered the large river bed plane in the immediate upstream, where the developed houses and facilities are seriously vulnerable to the flood inundation, has been created through the said process.

3.7 Qda. Paihua

(A) Geological Condition

Qda. Pahua is located on the right bank of the Rímac river near Matucana at around 30 Km upstream from the confluence of the Rímac and Santa Eulalia rivers.

The geology of the basin consists of the volcanic sediments and lavas in Tertiary, having many and fine cracks under the effect of folding.

The old debris flow deposit is distributed from the confluence with the Rímac river to several hundreds meters upstream. Further upstream reaches create some waterfalls in the Tertiary rock.

The materials of deposit contain various sizes of angular rock fragments. The size varies from less than 2 cm to 50 cm in diameter. The size is relatively small, reflecting the situation of cracks of the base rock in the basin.

(B) Topographic Condition

The drainage basin of Qda. Paihua is measured at 16.8 Km^2. The altitude varies from 4,760 m at highest to 2,400 m at the confluence with the Rímac river. The ridge near the boundary with the adjacent Qda. Pancha indicates a plateau with a gentle slope.

The basin shows a simple shape without the tributary. The average gradient along the valley is approximately 15 degree, having several water-falls on the way.

The gully is developed through the old debris flow deposit The present gully is eroded by 8 to 15 m deep and about 10 m wide. However, an information that the gully was of a very small scale about ten years ago is obtained. Thus, the gully erosion is considered to have been severely accelerated by the recent debris flows, especially by one occurred in 1983.

The Qda. Paihua has no fan deposit. This fact represents that no large debris flows have been experienced in the past. As such, the Qda. Paihua meets directly with the Rímac river without the fan deposit, and thereby, the debris flow seriously interrupts and dams up the Rímac river, causing the flood inundation at the immediate upstream, which attacks the nearby town, Matucana, railway and traffic road.

3.8 Qda. Cashahuacra

(A) Geological Condition

The Qda. Cashahuacra is located on the right bank of the Santa Eulalia river at 2 Km upstream of the confluence with the Rímac river.

The area belongs to the zone of plutonic rocks with various plutonic facies, strongly showing its characteristics; that is, the large rock blocks of granite composing the basement complex of the area fully cover the mountain slopes. The weathering in the area is intensive, accelerated by the fractures developed deeply into the granite.

Major unconsolidated deposits in the basin are classified into three kinds of the river terrace in three stages along the Santa Eulalia, old debris flow deposit in the middle reaches of the basin, and fan deposit in the downstream reaches of the basin. The distribution of the above deposits are shown in Fig. I-3-4.

The river terrace exists in three stages along the Santa Eulalia river as shown in Fig.I-3-4. The old debris flow deposit distributed along the valley creates a debris flow terrace with a height of 20 m at maximum.

Its width is measured at about 200 m along the upper tributaries and enlarged up to 400 m in the downstream of the confluence of two tributaries. The properties of the materials of deposit are similar to those in other quebradas belonging to the zone of plutonic rocks such as Qda. Quirio and Qda. Pedregal as mentioned in the preceding sections. A considerable amount of talus distributes covering this debris flow deposit. The distribution of talus extends up to a high elevation on the slope of 30 to 40 degree. The fan deposit is divided into two kinds, i.e. Old and new ones. The old one spread in the left side. On the other hand, the recent debris flows spread in the right side as shown in the Figure. These fan deposits cover the river terraces created by the Santa Eulalia river. The old fan deposit is judged to be the product in Pleistocene in view of the state of decomposition of granite blocks contained.

(B) Topographic Condition

This quebrada has a drainage basin of 15.1 Km^2. The altitude varies from 2,600 m at the top of quebrada to 980 m at the mouth of quebrada.

The quebrada branches to two tributaries at about 2,200 m from the mouth. The gradient of the valley changes as follows:

- Mouth to the confluence of two tributaries --- 4 degree
- Confluence to 1,600 m in altitude --- 10 degree
- 1,600 to 2,600 m in altitude --- 27 degree

In the downstream reaches of the valley, a large fan deposit distributes with 1,000 m in length and 1,200 m in the width at its downstream end. The gullies are eroded as shown in Figure. The gully in the old fan deposit (Denoted as Gully "A") is of a small scale, suggesting that the debris flows do not arise recently through this Gully "A". The Gully "B", which is created through the relatively recent fan deposit (Denoted as "Older Fan II"), is intensively eroded with a depth more than 10 m and 10 to 15 m wide. The recent debris flows are caused through this Gully "B". Then, it is noted that the erosion of the Gully "B" and variation of topography due to its debris flow are remarkable recently as understood by the fact that the erosion in Gully "B" was limited to a minor extent before the debris flow in 1983 and that the large alluvial cone in the downstream of Gully "B" was piled up by two events in 1983 and 1987. It is also noted that the facilities of traffic roads crossing the valley effect on the inundation of debris flow and variation of topography in the area.

Tables

Table I-1-1 LITHOLOGY UNITS

LITHOLOGY UNITS

UNIT I	QUATERNARY DEPOSITS	
UNIT II	VOLCANIC ROCKS	
	II An	ANDESITE
	II rda	RHYOLITE
	II Ta	TRAQUYANDESITE
	II br	BRECCIA
UNIT III	VOLCANIC - SEDIMENTARY ROCKS	
	III A	VOLCANIC CONGLOMERATE, ANDESITIC EXTRUSIVES, SILT AND SANDSTONE
	III B	TUFF, TUFFACEAS SANDSTONE AND LIMESTONE
	III AB	INCLUDE ROCKS OF III A AND III B
	III C	SANDSTONE, ANDESITE AND CONGLOMERATE
	III D	TUFF, SANDSTONE AND SILSTONE
	III E	ANDESITE EXTRUSIVE
	III	ANDESITIC LAVAS, MUDSTONE, MARL CHERT
UNIT IV	SEDIMENTARY ROCKS	
	IV A	LIMESTONE
	IV B	SHALE, SANDSTONE, QUARZITE, SILSTONE
	IV C	SANDSTONE, SILSTONE, SHALE, CONGLOMERATE
	IV D	LIMESTONE, SILSTONE
UNIT V	INTRUSIVE ROCKS	
	V gr	GRANITE
	V Tgd	TONALITE - GRANODIORITE
	V MZ-gd	MONZONITE - GRANODIORITE
	V di	DIORITE
	V gd	GRANODIORITE
	V Tdi	TONALITE - DIORITE
	V gb-di	GABRO DIORITE

Figures

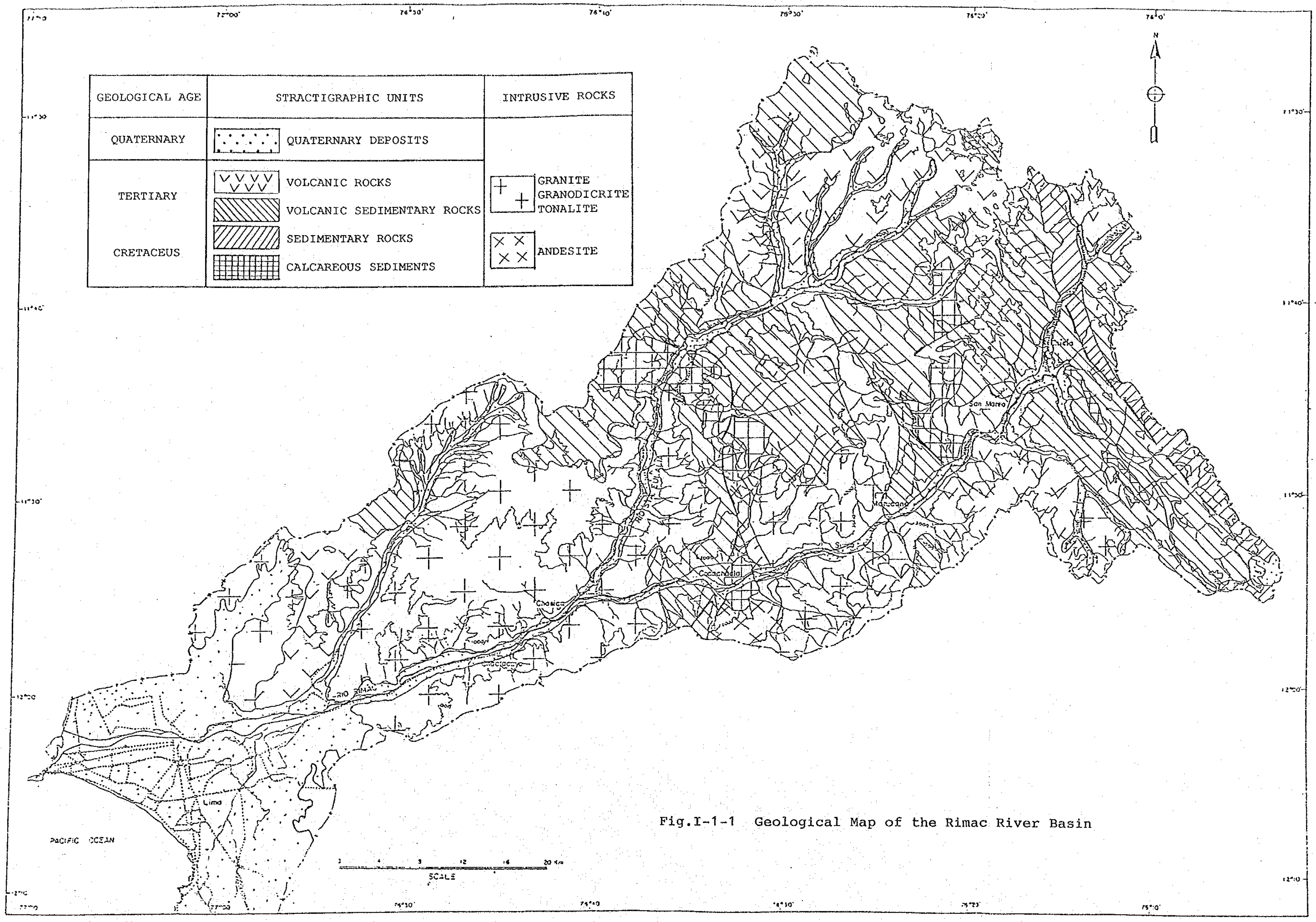

Fig.I-1-1 Geological Map of the Rimac River Basin

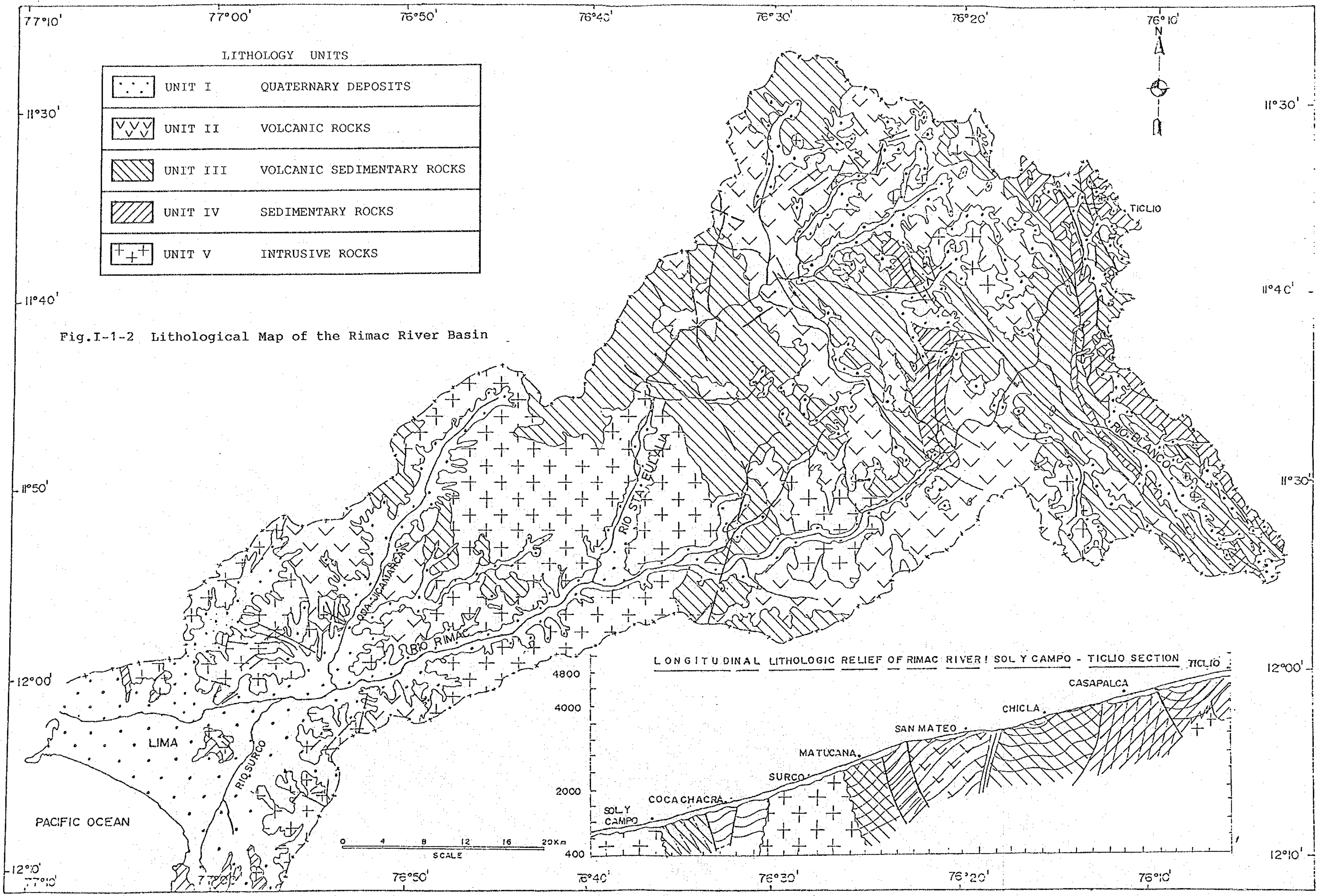

Fig.I-1-2 Lithological Map of the Rimac River Basin

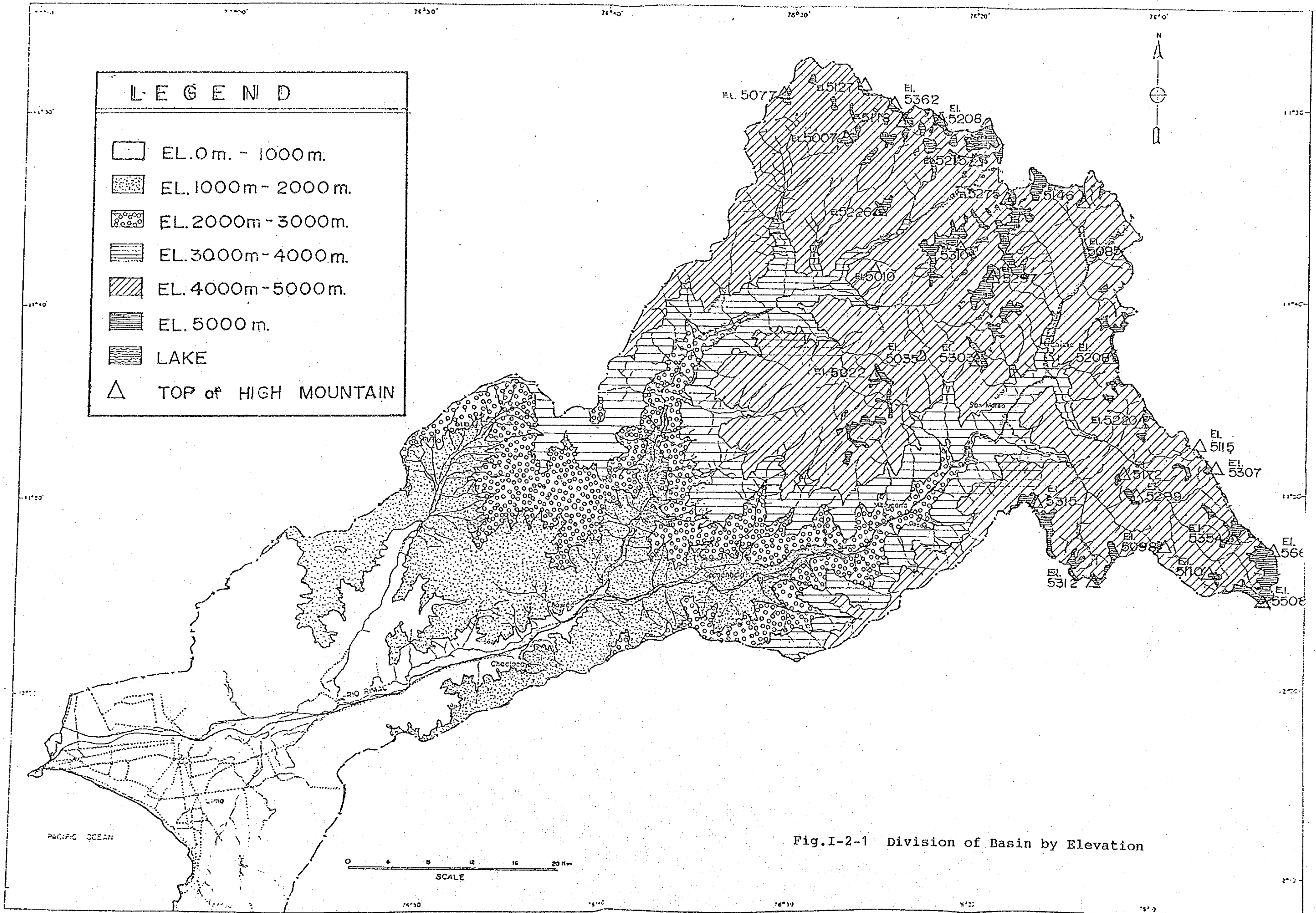

Fig.I-2-1 Division of Basin by Elevation

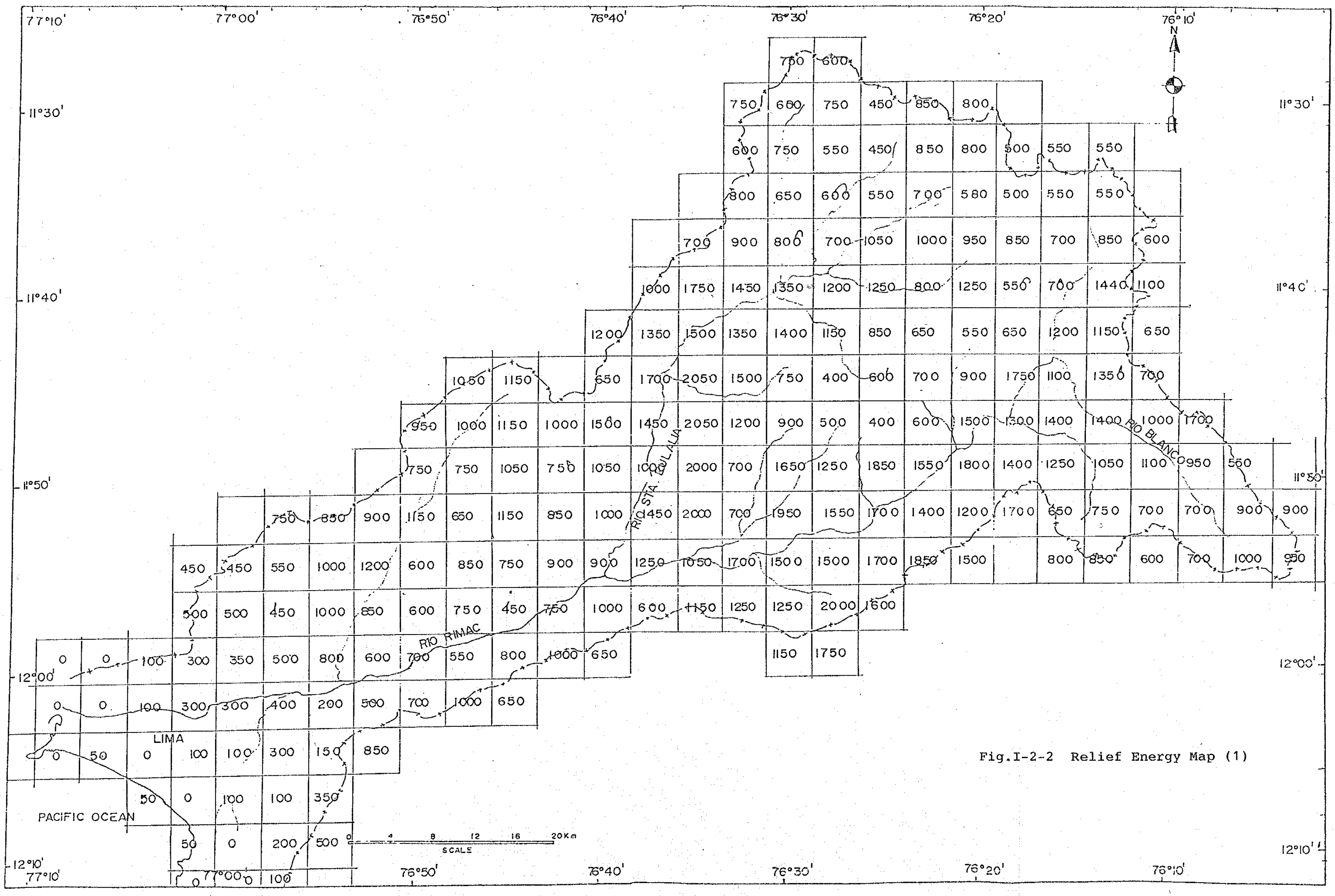

Fig.I-2-2 Relief Energy Map (1)

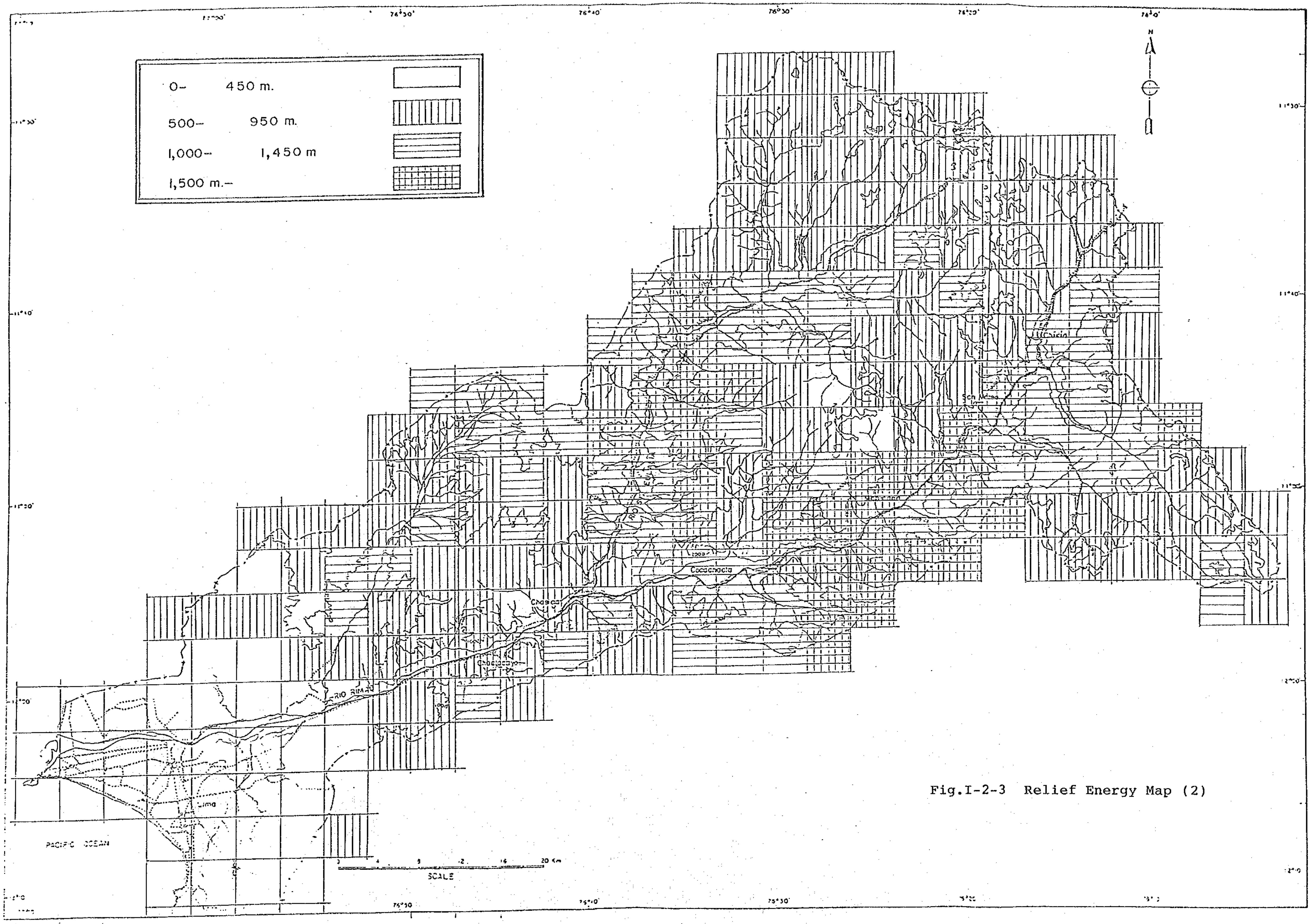

Fig.I-2-3 Relief Energy Map (2)

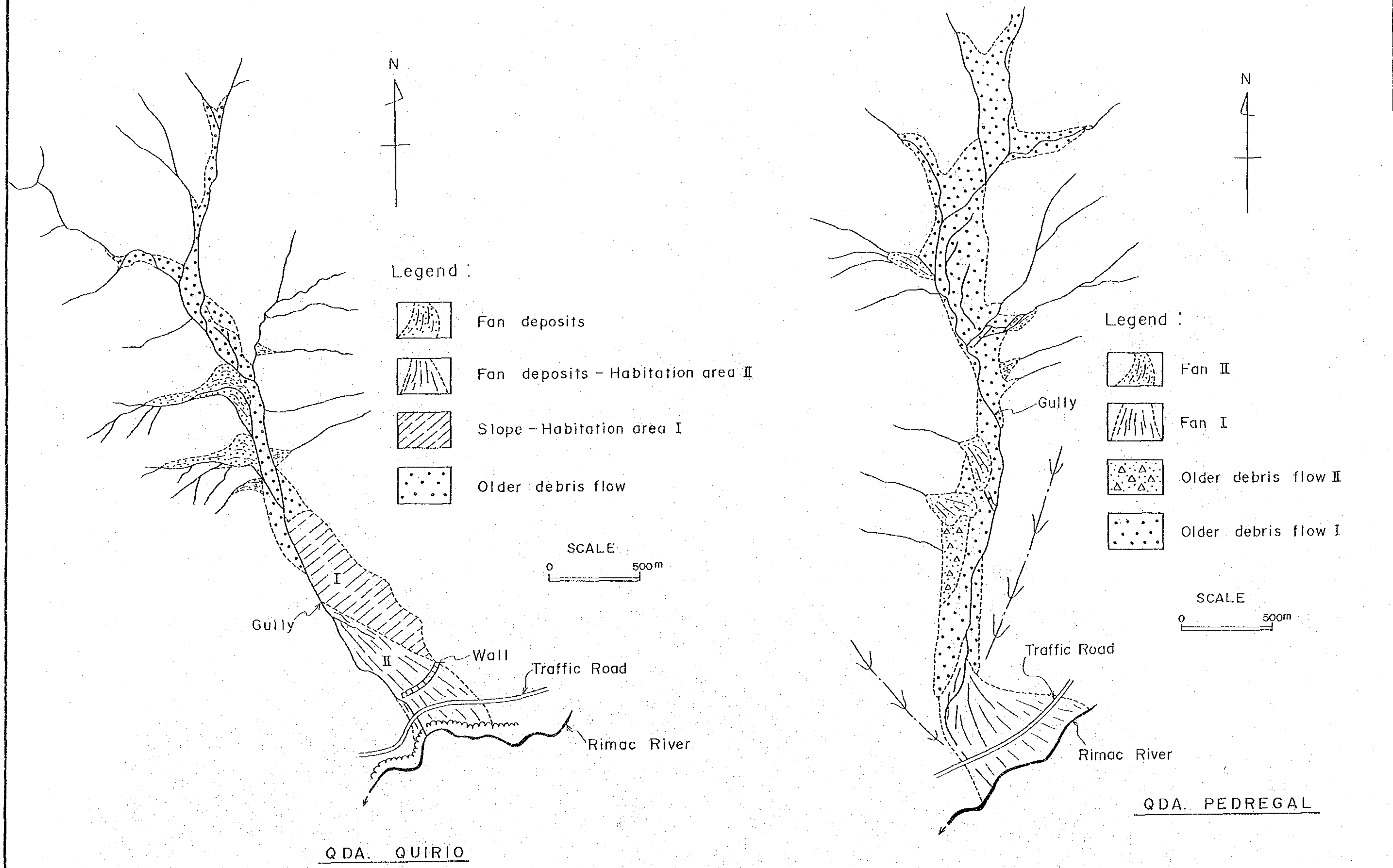

Fig.I-3-1 Distribution of Unconsolidated Materials in Qda.Quirio and Pedregal

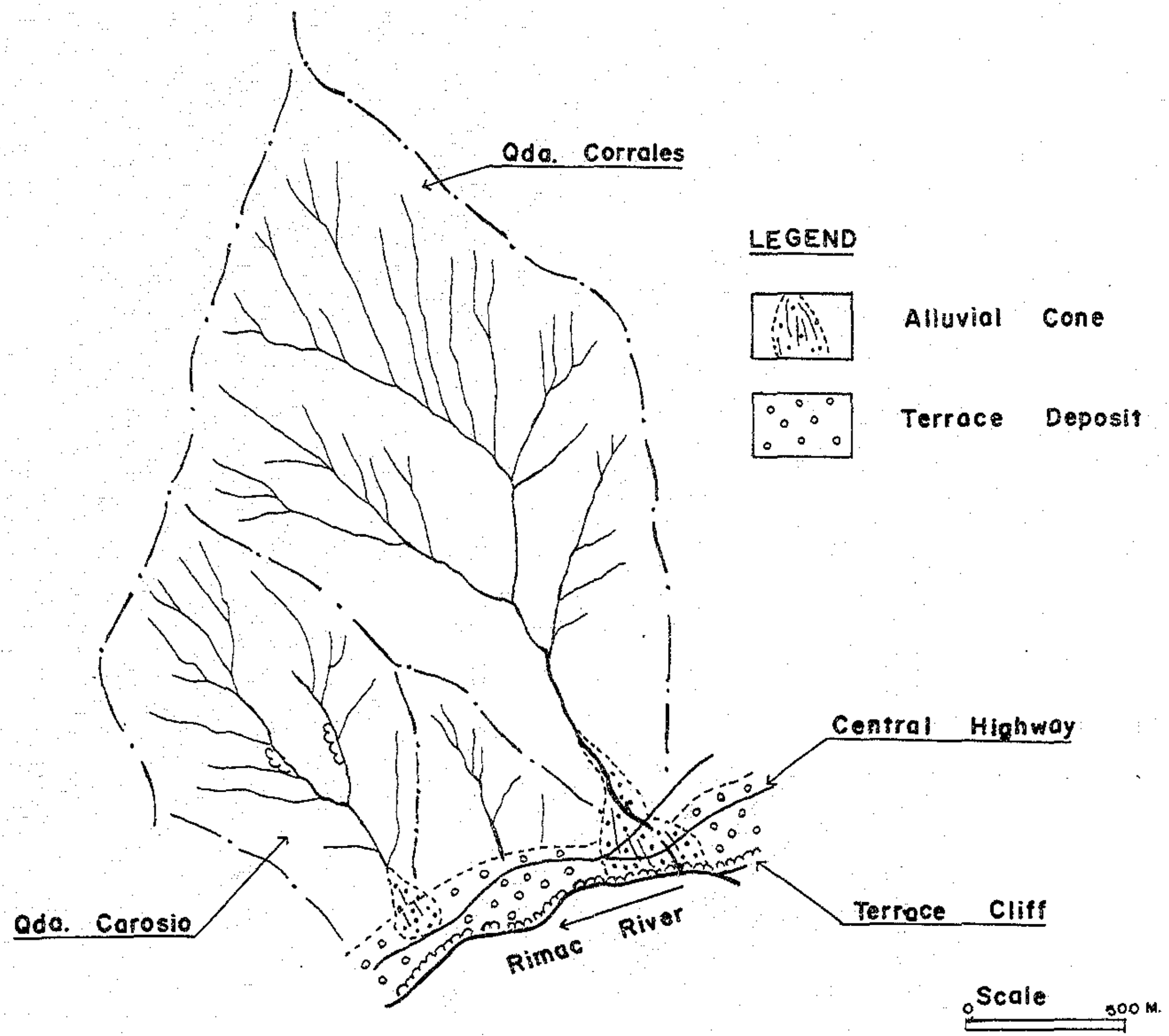

Fig.I-3-2 Distribution of Unconsolidated Materials in Qda.Carosio and Corrales

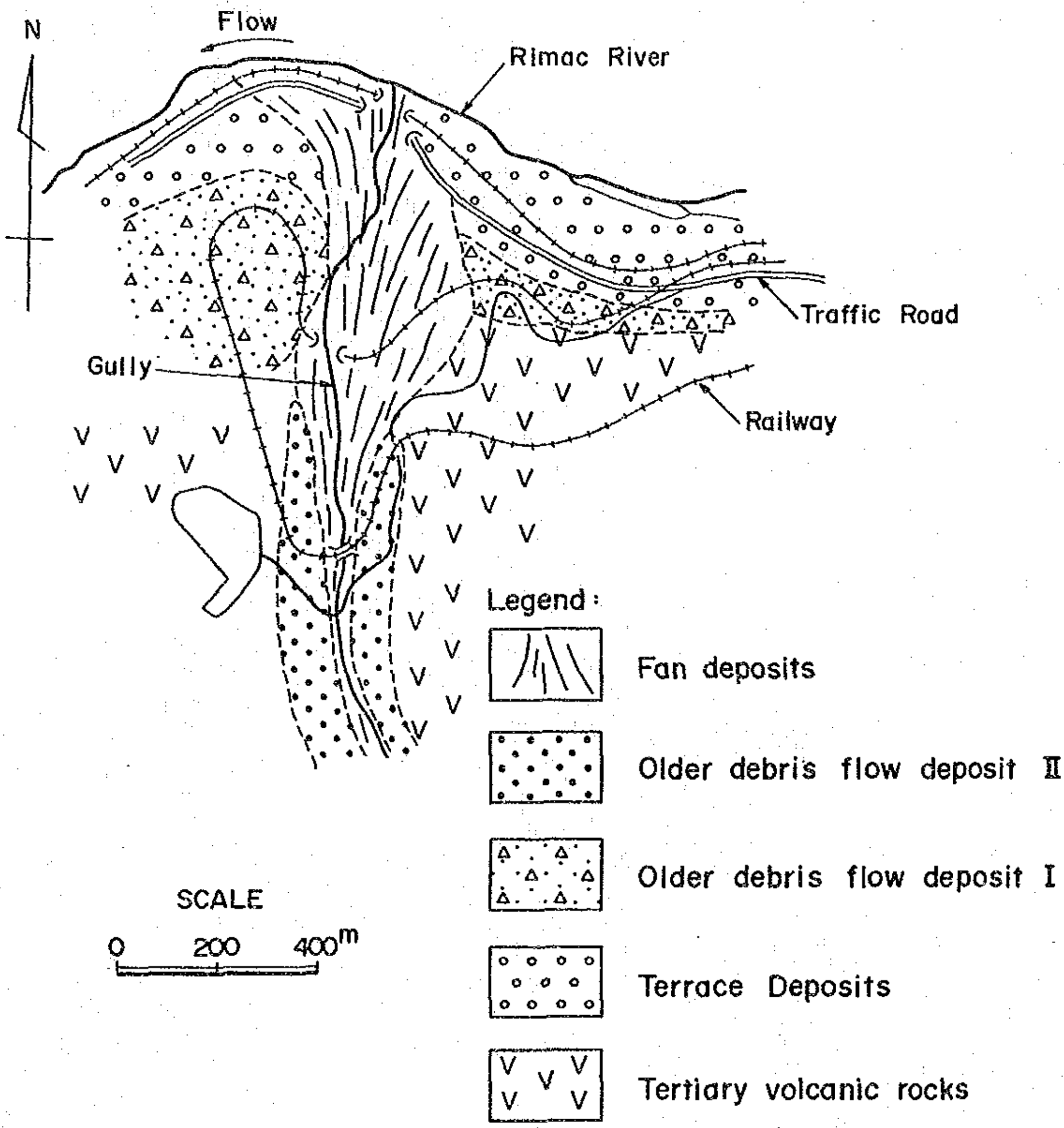

Fig.I-3-3 Distribution of Unconsolidated Materials in Qda.Rio Seco

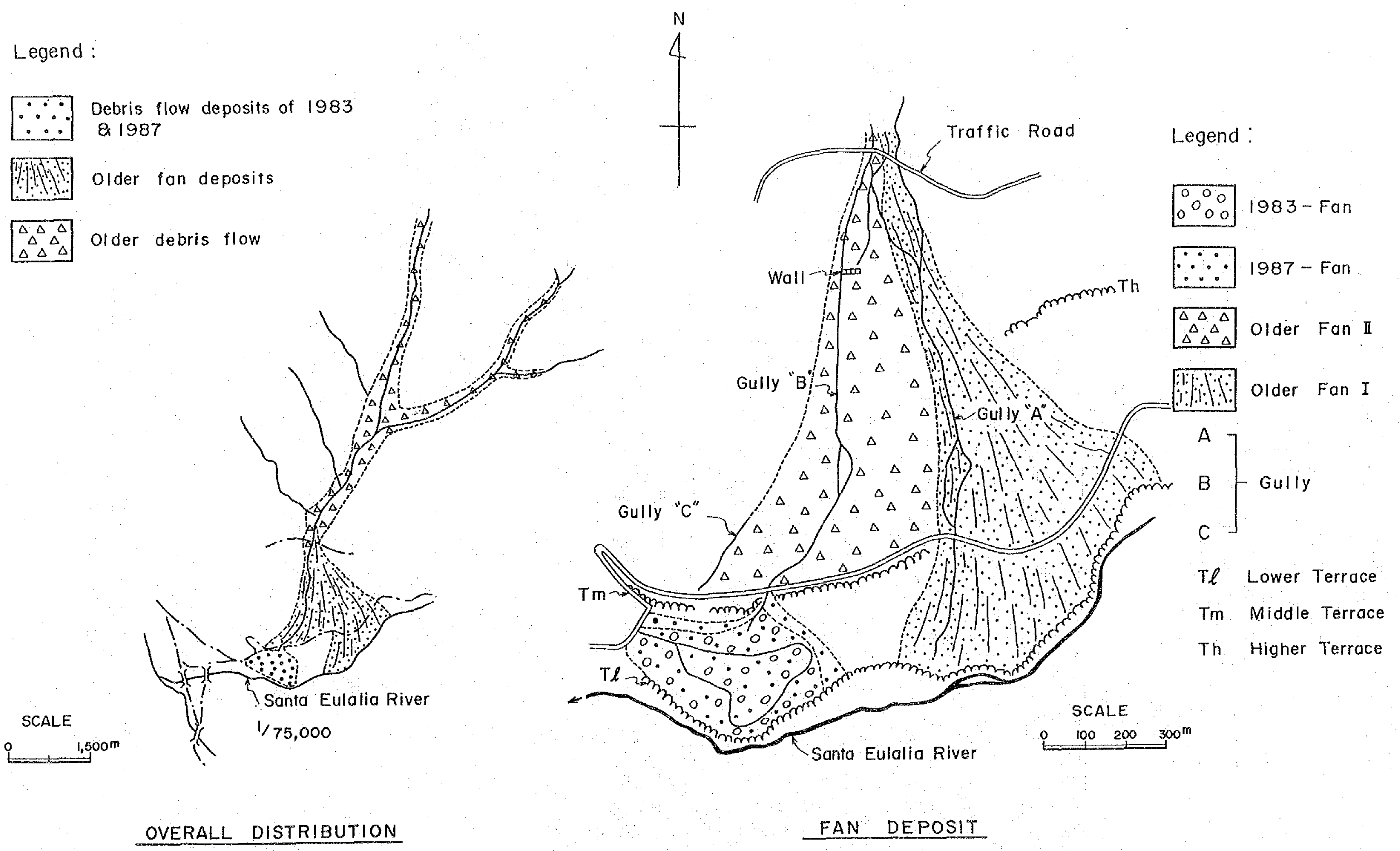

Fig.I-3-4 Distribution of Unconsolidated Materials in Qda.Cashahuacra