Supporting-A   Geological Survey

SUPPORTING-A GEOLOGICAL SURVEY

1. GROUNDWATER

The study on groundwater development for Tegucigalpa City was conducted once by SANAA and C. Lotti & Associate in 1987.

SANAA has been using the groundwater for the source of domestic water supplying 16 colonies (refer to Table A.1.1, Figure A.1.1). It amounts to 1% of total water supply volume of SANAA. Private companies have also utilized groundwater for the commercial and industrial use. But, all data of production wells were lost and dispersed by the Hurricane "Mitch". Some of production wells were destroyed and others were damaged and production yield has changed. No organization can get the actual withdrawing volume of groundwater and nor can manage the groundwater source at present. The study result of Lotti is obsolete and it does not reflect the present hydrogeological condition. Groundwater is not the major source for the central water supply system in Tegucigalpa City, but it acts as local water source for the private or communal water use where SANAA cannot supply water by pipe. It is still an important water source, but is a limited source. Consequently, groundwater management plan should be established urgently and utilized continuously for the isolated areas in Tegucigalpa.

Geology in and around the Study Area is roughly divided into Basalt lava in Quaternary period, Padre Miguel Group and Matagalpa Formation in Tertiary Period, and Valle de Angeles Group in Cretaceous Period. The old basement rock of Cacaguapa Schist, Honduras Group, and Yojoa Group are not distributed in the Study Area. These consolidated basement rocks are principally impervious excluding weathered zones and fractured zones.

The basement rocks are covered by talus deposit, fluvial deposits of terrace deposit and river deposit of Quaternary period. Talus deposit mainly consists of clay, silt, sand, and gravel. Fluvial deposit mainly consists of sand and gravel that are expected to be an aquifer. But, these fluvial deposits are distributed locally and they are not expected extensive exploitation for groundwater.

There are four type of geological unites from the hydrogeological point of view in the Study Area as follows:

- Volcanic tuff of the Padre Miguel Group including Matagalpa Formation,
- Sedimentary reddish beds of the Valle de Angeles Group,
- Quaternary basalt, and
- Shallow Quaternary alluvial deposits.

1.1 AQUIFER TYPE

There are two types of hydrogeological units that are expected to be an aquifer in the Study Area as follows.

- Intergranular aquifer: it is an aquifer with intergranular flow in the Quaternary deposit of river deposit and terrace deposit. They are local aquifers and have poor productivity of groundwater.
- Fissure aquifer: it is an aquifer in the fractured zones of basement rocks of Quaternary basalt, volcanics of the Padre Miguel Group, Matagalpa Formation, and Valle de Angeles Group. They are local aquifers and have poor to moderate productivity of groundwater.

(1) Intergranular Aquifer

Quaternary formations of alluvial fan, terrace and recent river are mainly composed of permeable deposits such as sand and gravel. Judging from the production well and other surveys, this intergranular aquifer is classified into unconfined aquifer. It is reported that pumping yield in Zamorano village is less than 5 liter per second with better water quality comparing with the fissure aquifer (refer to Figure A.1.2)

The potential of the groundwater varies depending on the extent and thickness of the quaternary deposits, particle size of deposits and precipitation, etc. Quaternary formations are distributed locally in the Study Area. Consequently, extensive development of groundwater is not expected. Small scale private and community uses are expected.

(2) Fissure Aquifer in the Basement Rocks

Padre Miguel Group, Matagalpa Formation, and Valle de Angeles Group are mainly composed of volcanic rocks which are compact, hard and practically impermeable with poor porosity. These formations are considered to be the basement rock from the hydrogeological point of view.

Many geological data of these formations, however, show the development of joints and fractures formed by weathering and tectonic movements. Moreover, the results of the field reconnaissance, interpretation of topographic map, and aerial-photographs point out the existence of lineaments that correspond to fault and fractured zones in the mountain area.

The potential of the groundwater varies depending on the width and length of fractured zone. Fractured zones are distributed locally in the Study Area. Consequently, extensive development of groundwater is not expected. Small scale private or community use are expected.

1.2 HYDROGEOLOGICAL CHARACTERISTICS

(1) Alluvium

Aquifer transmissivity of fluvial deposit ranges from 60 to 290m^2/day and specific capacity from 0.03 to 5.0 l/s/m (liter per second per meter) in Zamorano village. The electric conductivity (hereinafter referred to as "EC") is less than 250 μS/cm. Therefore the dissolved ion is comparatively low and quality is generally good.

(2) Quaternary Basalt

It occurrs as sheet lava flows on higher ground in north and west of Tegucigalpa and these form discontinuous perched aquifers of limited extent. However this fissure aquifer is not developed in the Study Area.

In other area, it is reported that water well yields reach up to 8 l/s (liter per second) in highly fractured zones.

(3) Padre Miguel Group

Approximately 50% of the Study Area are covered by the extensive sequence of upper Tertiary volcanics. It reaches up to 400 meters in thickness and mainly consists of rhyolitic ignimbrite, stratified volcanic sediments, pyroclastics, and water deposited tuffs. The fissure aquifer in this group is developed in the Study Area and the yields of average production is 3.25 l/s (refer to Table A.1.1). It range 0.5 to 4 l/s in the west of Tegucigalpa, such as Los Laureles and La

Cuesta. But, at some well located at the southeastern part of Tegucigalpa, it reaches up to 25 l/s exceptionally. EC is around 650 μs/cm that the dissolved ion is comparatively high and it is classified into hard water.

(4) Matagalpa Formation

These lower Tertiary andesitic and basaltic rocks are of limited extent between the communities of Santa Cruz and La Cuesta immediately northwest of Tegucigalpa. Consequently, the fissure aquifer in this formation is not exploited in the Study Area.

In the other area, it is reported that water wells yield from 1 to 6l/s. Higher permeability zones are found in the upper 10 to 20 meters in the weathered horizontal of lava flows and fractured zones. Normally, undisturbed and hard andesitic lava flows behave as aquiclude (no productive aquifer).

(5) Valle de Angeles Group

This group is distributed extensively in the eastern part of Tegucigalpa City and the fissure aquifer of this group is exploited for private use in spite of hard water.

Valle de Angeles Group is divided into two formations of the lower Villa Nueva Formation of conglomerates and upper Rio Chiquito Formation of sandstone, siltstone, mudstone, and limestone.

Transmissivity of the Villa Nueva conglomerates are very low ranging from 1 to 5 m^2/d and water well yields are less than 3 l/s. On the one hand, the Rio Chiquito Formation is characterized by relatively high porosity and high secondary permeability due to the formation of fractures. The transmissivity of it ranges from 10 to 500 m^2/d and well yield rages from 2 to 8 l/s with an average of about 6.0 l/s (refer to Table A.1.1). Groundwater quality of aquifer in this formation is generally hard and high in sulfates. It proves that this groundwater has stayed long in the underground with a few recharging.

1.3 POSSIBILITY OF THE GROUNDWATER DEVELOPMENT FOR WATER SUPPLY

The following four elements shall be considered for the groundwater development:

- extent of the basin in the intergranular aquifer, or
  the size of fractured zone in the fissure aquifer,
- internal factor of permeability, transmissivity etc.,
- external factor of precipitation, river discharge that are related to the recharge condition, and
- water quality.

For the consideration of above-mentioned four elements, there are not suitable aquifers for the source of central water supply system in the Study Area.

(1) Intergranular Aquifer

This aquifer is easy to survey the extent of basin and to investigate the internal factor, and water quality may be better than fissure aquifer. But, these unconsolidated deposits of river deposit and terrace deposit are locally distributed in the Study Area. Accordingly, this aquifer is not suitable for the source of central water supply system and local water supply system.

(2) Fissure Aquifer

This type of aquifer is difficult to investigate the extent and size of fractured zone which regulate the withdrawal volume of groundwater. The well yield is not so high of 1 to 5 l/s and water quality is hard. Generally, it is not a suitable water source for the central water supply system. But, basement rock which may bears fissure aquifer is distributed in the Study Area. Accordingly, there is some possibility for the water source of the private use or communal use without the geological investigation.

1.4 RECOMMENDATION

(1) Establishment for the Groundwater Management

It is strongly recommended that hydrogeological investigation shall be conducted urgently and the Lotti's study shall be revised to establish the groundwater management for the sustainable development and the preservation of the environment.

(2) Investigation for New Water Source

Generally, it is reported in the Circum-Pacific Volcanic Belt that lava flow bears groundwater in its cavity, tunnel, and porous chilled-margin. It shall be considered to investigate the groundwater in the basalt or andesite lava, or the mountain foot of lava.

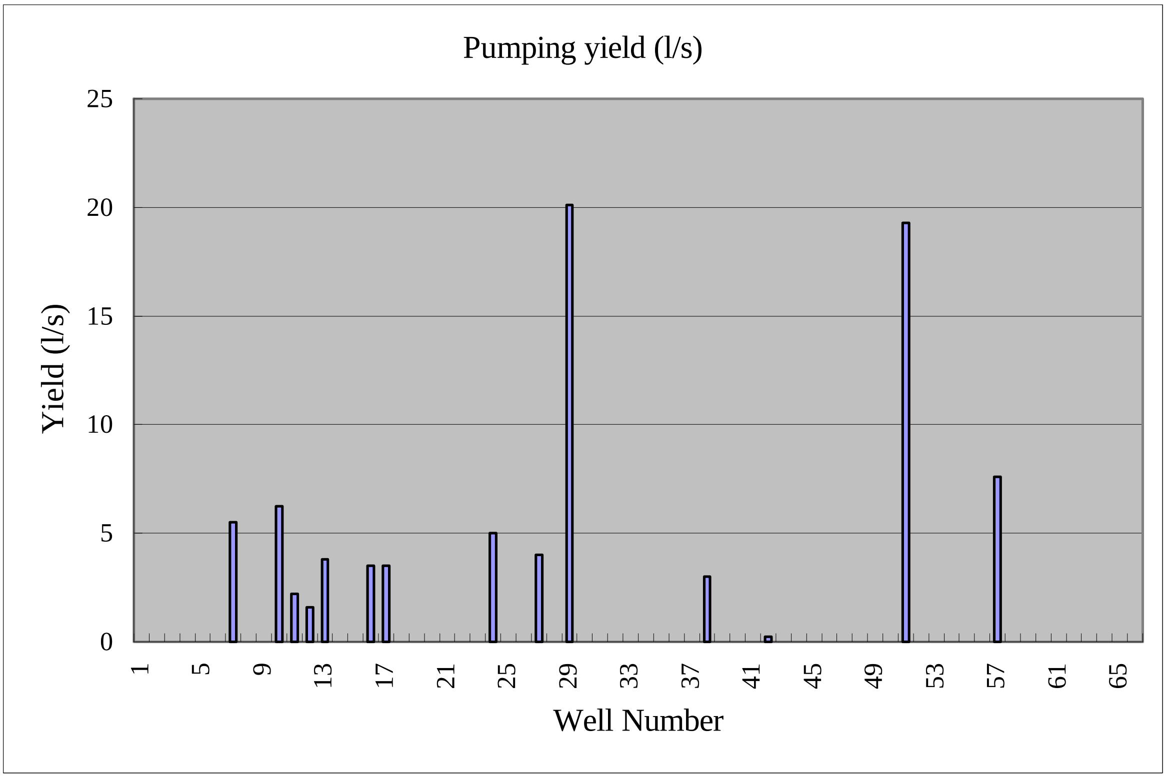
Table A.1.1 Well Inventory in Tegucigalpa Managed by SANAA

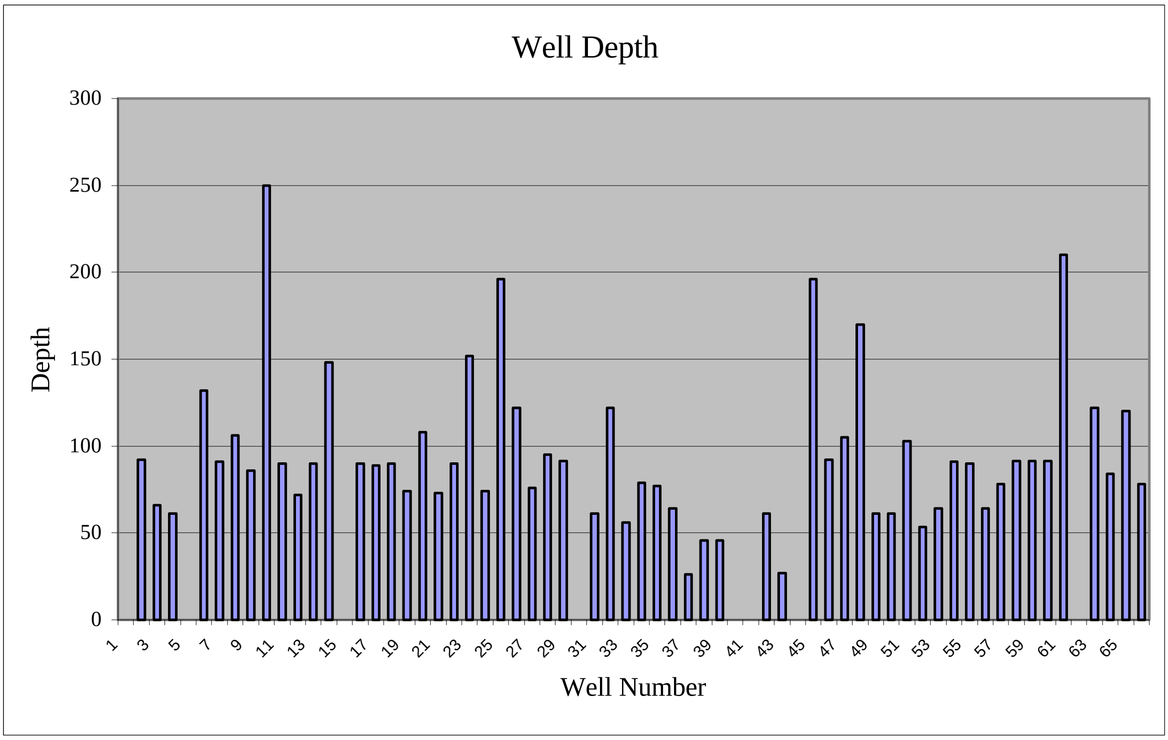
No	Location	Depth	El.	Coordinates		Construction Year	Pumping yield	Geology
		(m)	(m)	x	y	y/m/d	(l/s)	
1	Residencial San Angel		1000	48101	155527	85/2/11		
2	Col. 21 de Febrero	92	1100	47490	155698	87/3/1		
3	Kinder san Geronimo,P13	66	1200	47427	155949	87/12/10		
4	Hacienda El Sitio	61	1155	48385	156026			
5	Hacienda El Sitio		1155	48390	156030			
6	La Burrera	132	1000	47706	155547	87/8/30		
7	La Travesia	91		48347	155860		5.52	Kv
8	Aldea Villa Nueva	106	1400	48420	155256	87/6/3		
9	Summer Hill School	86		47733	155310			
10	Quebrada Aserradera 1	250		48687	156153		6.25	
11	Col Satelite	90	1100	47749	155290		2.2	Tpm
12	El Chimbo No 1	72	1400	48684	156228		1.6	
13	Col Satelite	90	1100	47755	155290		3.8	Tpm
14	El Chimbo No 2	148	1400	48684	156241			
15	Col. Satelite		1100	47742	155299			
16	La Fuente	90	1100	47399	155705		3.5	Tpm
17	Residencial La Fuente	89	1100	47365	155706		3.5	Tpm
18	Plantel Columbus	90	1100	47387	155853			
19	Colonia El Manantial	74		47376	155969			
20	Aldea Jacaleapa	108		48053	155311	1987		
21	Col. 21 de Octubre	73	1100	48151	155943			
22	Col.21 de Octubre	90	1100	48150	155950			
23	Colonia Mayangle	152	1100	47554	155768	1987		
24	Col. Los Girasoles	74		48104	155925		5	Kv
25	Colonia Mayangle Pz 5	196		47557	155764			
26	Prados Hills de Espinosa	122		48183	155970			
27	Mills	76		48185	155971		4	
28	Bo El Chile P11	95	1100	47727	155531	1987		
29	CASA, Hato de En Medio	91.47		48101	1555531		20.1	Tpm
30	Instituto Luis Bogran 5		1200	47420	155932			
31	Escuela de Enfermeria	61		47865	155733			
32	Col. 21 de Febrero No 3	122	1100			1990		
33	Hospital Materno Infantil	56	1100	47860	155743			
34	Hospital Materno Infantil	79	1100	47850	155725			
35	Hospital Neurosiquiatrico	77	1100	47846	155732			
36	Instituto Luis Bogran 6	64	1200	47423	155927	1992		
37	Nuevos Horizontes 1	26.2		47370	155980	1990		
38	Guasil 1	45.72		47620	153020	1985	3	
39	Guasil 2	45.72		47620	153017			
40	Cementerio 1		1000	47140	152490			
41	Cementerio 2		1000	47150	152500			
42	San Jose	61	1100	47290	152750	1967	0.23	Tpm
43	Apacinagua	27		47090	152560			
44	Col Las Torres		1100			1986		
45	Las Torres P9	196	1100	47532	155457			

46	Los Domos	92		47955	155727	1987		
47	Col. 15 de Septiembre	105	1100	47595	155396			
48	Escuela Superior Pz 2	170		47972	155585	1987		
49	Manantial 3	61		47370	155980			
50	Altos de Loarque	61		4760	15520	1991		
51	Escuela Sup Prof. Pz2	103		47977	15585	1987	19.3	Tpm
52	Altos de Loarque No 2	53.35		47637	155233	1991		
53	Xausique	64.02		47870	15621	1991		
54	Pani 1	91		48035	155891			
55	Pani 2	90		48018	155892			
56	Smith No 1	64	1100	47480	155962	1992		
57	Pani Ave. Los Proceres	78		48019	155896		7.6	Kv
58	Smith No 2	91.5	1100	47480	155962	1992		
59	El Lolo Unicef	91.4		47310	156190	1990		
60	Luis Bogran No 7	91.5	1200	47418	155929			
61	Colegio de Ingenieros	210	1000	48060	155712			
62	Hac. Holanda			46120	157120			
63	Hato de En Medio	122		48098	155570			
64	Col 15 de Septiembre	84	1100	47599	155406			
65	Villa Los Laureles Pz 7	120	1100	47504	155537	1987		
66	Villa Los Laureles Pz 7	78	1100	47502	155536	1987		
	Total	5485.9					85.6	
	Number	59					14	
	Average	92.98					6.11	
	Weighted Average	90.41	n=55 wells				3.85	n=12 wells
						* Tpm=3.25 l/s, Kv=6.0 l/s		

* Tpm: Padre Miguel Group, Kv: Valle de Angeles Group

Figure A.1.1 Pumping yield and Depth





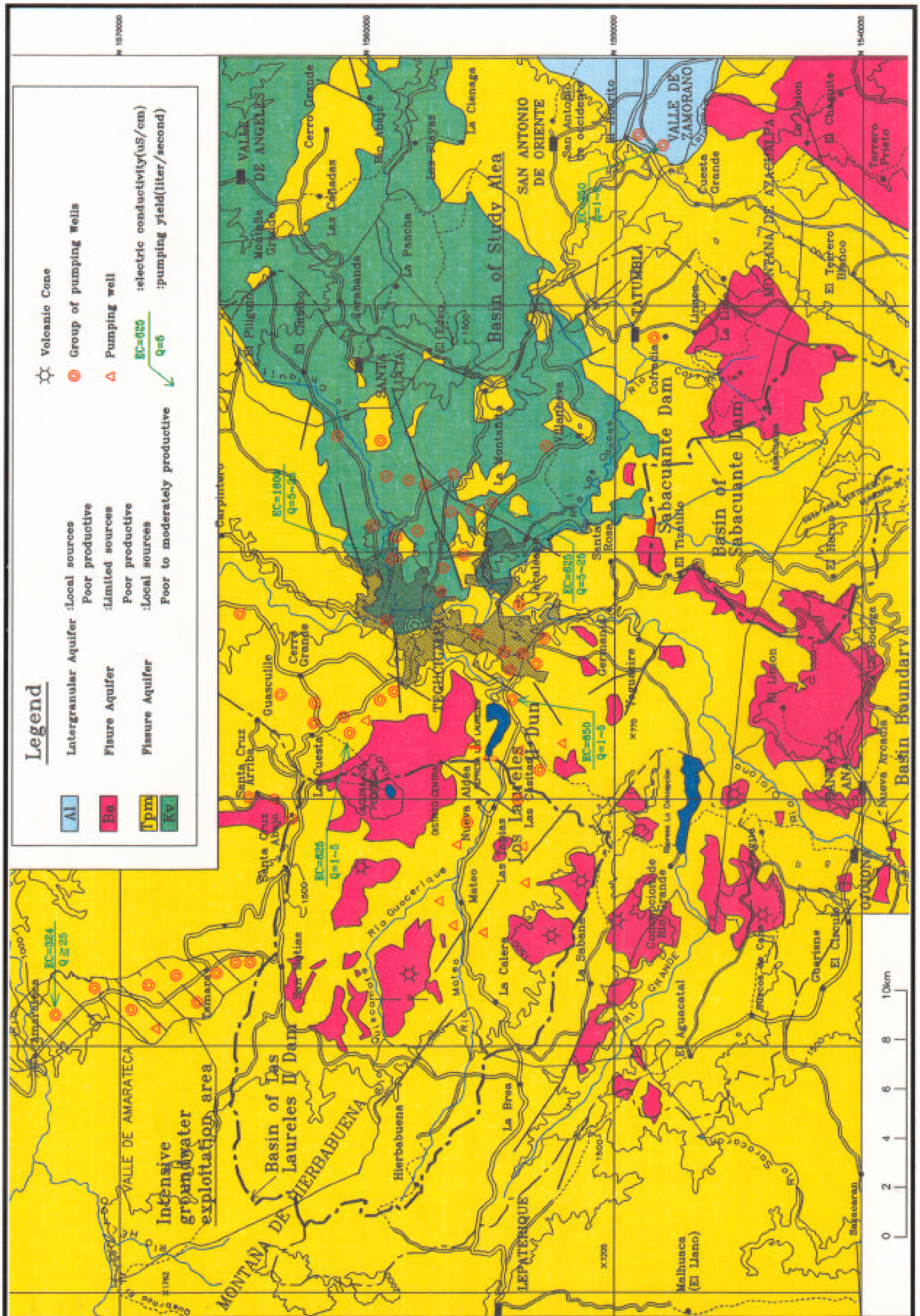


Figure A.1.2	Hydrogeological Map in the Study Area

2. GEOLOGY

2.1 REGIONAL GEOLOGY

2.1.1 GENERAL

Geology in and around the Study Area is roughly divided into three of Padre Miguel Group, Matagalpa Formation in Tertiary Period, and Valle de Angeles Group in Cretaceous Period. The other basement rocks of Cacaguapa Schist, Honduras Group, and Yojoa Group are not distributed in the Study Area. Figure A.2.1 shows the regional geology.

Basalt lava cover Padre Miguel Group and Matagalpa Formation in early Quaternary period. These consolidated basement rocks are covered by terrace deposit, talus deposit, and river deposit in Quaternary period.

Table A.2.1 Geology in and around the Study Area

Era	Period	Epoch	Sym-bol	Name Formation	Lithology
Cenozoic	0	Holocene	Qal	River, flood plain dt.	sand and gravel with clay
			Qc	Talus dt.	clay, sand, and gravel
	Quaternary	|	Qt	Terrace dt.	sand and gravel with clay
	2	Pleistocene	Qb	Basalt	basalt (lava flow)
		Pliocene		*Formation Gracias*	
				Padre Miguel Group	
			Tpmy	young volcanics	rhyolitic ignimbrite
		Miocene	Tep	Periodista Member	tuffaceous sandstone with gravel
			Tpmt	Tenampua Mem.	local deposit, ash fall
	Tertiary Ceno-zoic	|	Tpmi	ignimbrite	Vitric rhyolitic ignimbrite
			Tpmn	Nueva Aldea Mem.	well sorted tuff with locally pumice
		Oligocene	Tpmp	Puerta de Golpe Mem.	tuffaceous shale , calcareous shale, limestone
			Tcg	Cerro Grande Mem.	ignimbrite
		Eocene - Paleocene		Matagalpa Formation	
	65		Tm		andesite with hydrothermal alteration
Mesozoic				Valle de Angeles Group	
	Cretaceous	Upper	Krc	Rio Chiquito Form.	reddish-brown sandstone, siltstone, mudstone with lens of limestone
			Kvac		
		143	Kvn	Villa Nueva Form.	conglomerate
		Lower	*Ky*	*Yojoa Group*	*limestone, mudstone*
	Jurassic 247*		*Jkhg*	*Honduras Group*	*shale and sandstone with volcanic rocks*
Paleozoic			*Pzm*	*Cacaguapa Schist*	*mica-schist, quartzite with marble, meta-diabese*

Source: Geological map of Tegucigalpa, Lepaterique, and San Vuenabentura (1/50,000)

Note: *Italic groups and formations are not distributed in the Study Area.*

247*: geologic age (before present) x 10^6

2.1.2 STRATIGRAPHY

(1) Valle de Angeles Group

Valle de Angeles Group consists of two formations of Villa Nueva Formation and Rio Chiquito Formation and is distributed in the eastern half of the Tegucigalpa Basin.

Villa Nueva Formation is found in the southeast and Rio Chiquito Formation in the northeast of the basin. Villa Nueva Formation is characterized by the red beds of conglomerate.

Rio Chiquito Formation is reddish-brown uniformly bedded sandstones, siltstones, and mudstones, with lenses of limestone and quartz.

(2) Padre Miguel Group

Padre Miguel Group consists of various layers of Matagalpa Formation (Tm), Cerro Grande Menber (Tcg), Pueta de Golpe (Tpmp), Nueva Aldea (Tpmn), widespread Ignimbrite (Tpm), Tenampua Member (Tpmt), and youngest Volcanic rocks (Tpmy) that are generated by the volcanic activity in Oligocene to Miocene epoch of Tertiary period.

Matagalpa Formation of Palaeocene to Mid-Miocene Epoch is distributed in the north of Tegucigalpa. This Formation consists of andesite and basalt lava flow with interbedded pyroclastics and volcanic sediments.

This group of predominantly acidic pyroclastic volcanics is widely distributed in the Study Area. It comprises a lower succession of Miocene ignimbrites interbedded with fluviatile and lacustrine pumiceous sediment. Younger Miocene – Pliocene ignimbrite sheets are associated with interbedded mafic lavas, lahars, and volcanic sediments.

(3) Quaternary Volcanics

These Volcanics that erupted immediately west and northwest of Tegucigalpa deposited olivine-bearing tholeiitic basalts as dispersed lava mounds.

The most conspicuous valcano is El Pedregal located immediately west of the Tegucigalpa City that is located north of the proposed dam site of Los Laureles II. It forms basaltic plateau with the area of about 20 km^2. There are also distributed basaltic lava in and around the Study Area with lava plateau.

(4) Quaternary Unconsolidated Deposits

Unconsolidated deposits of talus deposit, flood plain deposit, terrace deposit, and recent river deposit are locally distributed in the Study Area. They do not play major role in the study from the geological viewpoint.

2.1.2 REGIONAL GEOLOGICAL STRUCTURE

It is necessary to realize the regional geological condition for understanding the local geology of the Study Area.

Cacaguapa schist formed in Paleozoic era is the lowest basement rock in the Honduras that are distributed locally at the northeast of Tegucigalpa City, distributed widely in the northeast part of Honduras, and north seacoast and not distributed in the Study Area. Movements of Cocos plate and Caribbean plate in the Mesozoic created the international boundary of Honduras and basin. Cretaceous sediments of limestone, dolomite, shale, and Valle de Angeles red beds are formed in this basin. In the Oligocene epoch of Tertiary period, most land of Central America was emerged and most of sediments have been faulted and folded in an east-west anticline.

During the Tertiary period, Honduras has continued moving towards the east up to the present position. Volcanic activities were generated during the plate movement, and its created the huge volcanic rocks of lave, ignimbrite, and tuff that are distributed western part and southern part of Honduras and widely distributed in the Study Area. These volcanic rocks are named as the Padre Miguel Group. They deposited on land in some cases and in water of lake in other cases. They covered the old basement rocks and older volcanic rocks in an unconformity. During the Tertiary and early Quaternary period, geo-structural movements formed the northwest-southeast faults mainly and northeast-southwest faults in the Study Area. These faults displaced the Valle de Angeles red beds and volcanic rocks of the padre Miguel Group. But they do not displace the recent geological beds in Holocene epoch (less than 10 thousand years ago) that are called “Active Fault”.

2.2 SEISMICITY

According to the data from 1900 to 1996 yeas, many earthquakes have occurred along the sea coast of Pacific Ocean where the Cocos plate has been slipping under the Caribbean Plate at the Guatemala trench. The magnitude of most earthquakes were less than 4.5 of Richter scale. The earthquakes occurred at the border of Guatemala (Magnitude 7.5) in 1976. But, no big damage are happened for Tegucigalpa City. Small earthquakes and a few epicenter are only distributed near the Study Area (refer to Figure A.2.2 and Table A.2.3).

A study in 1999 by U.N.A.H. (Universidad National Autonoma Honduras) Geophysic Section analyzed the historic seismic record and calculated the expectation of the acceleration by earthquake in major cities in Honduras. Table A.2.2 shows the calculation result.

Table A.2.2 Expected Peak Acceleration for the Ground

Unit: m/sec^2

City	Latitude	Longitude	Return Period (year)				
			100	200	500	1000	5000
Tegucigalpa	14,084	87,157	0.753	0.926	1.184	1.455	2.276
Santa Rosa de Copan	14,750	88,720	1.150	1.456	1.956	2.516	4.114
Santa Barbara	14,900	88,250	0.939	1.160	1.491	1.848	2.877
Choluteca	13,300	87,270	1.329	1.644	2.145	2.667	4.110
Trujillo	15,920	85,950	0.829	1.131	1.627	2.245	4.310
San Pedro Sula	15,481	88,040	1.144	1.549	2.265	3.040	5.518
La Ceiba	15,667	86,833	0.912	1.245	1.826	2.531	4.865
Puerto Cortez	15,850	88,000	1.262	1.782	2.710	3.724	7.128
Amapala	13,310	87,620	2.300	2.931	3.891	4.957	7.984
El Cajon	14,950	87,750	1.051	1.360	1.875	2.469	4.075
Roatan	16,330	86,504	1.276	1.813	2.764	3.800	7.242

Source: La Amenaza Sismica de 11 Lugares Importantes en Honduras by U.N.A.H.

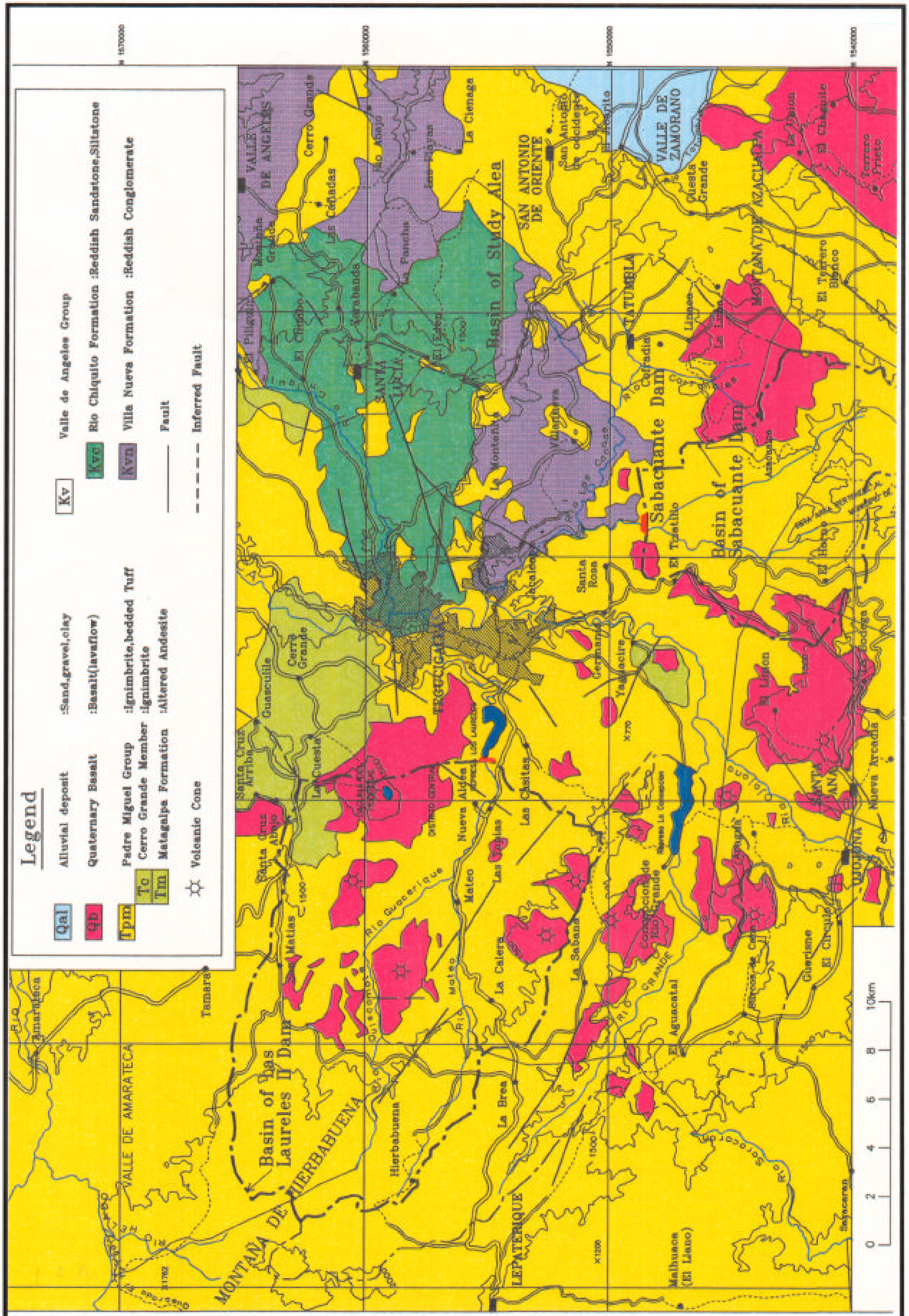
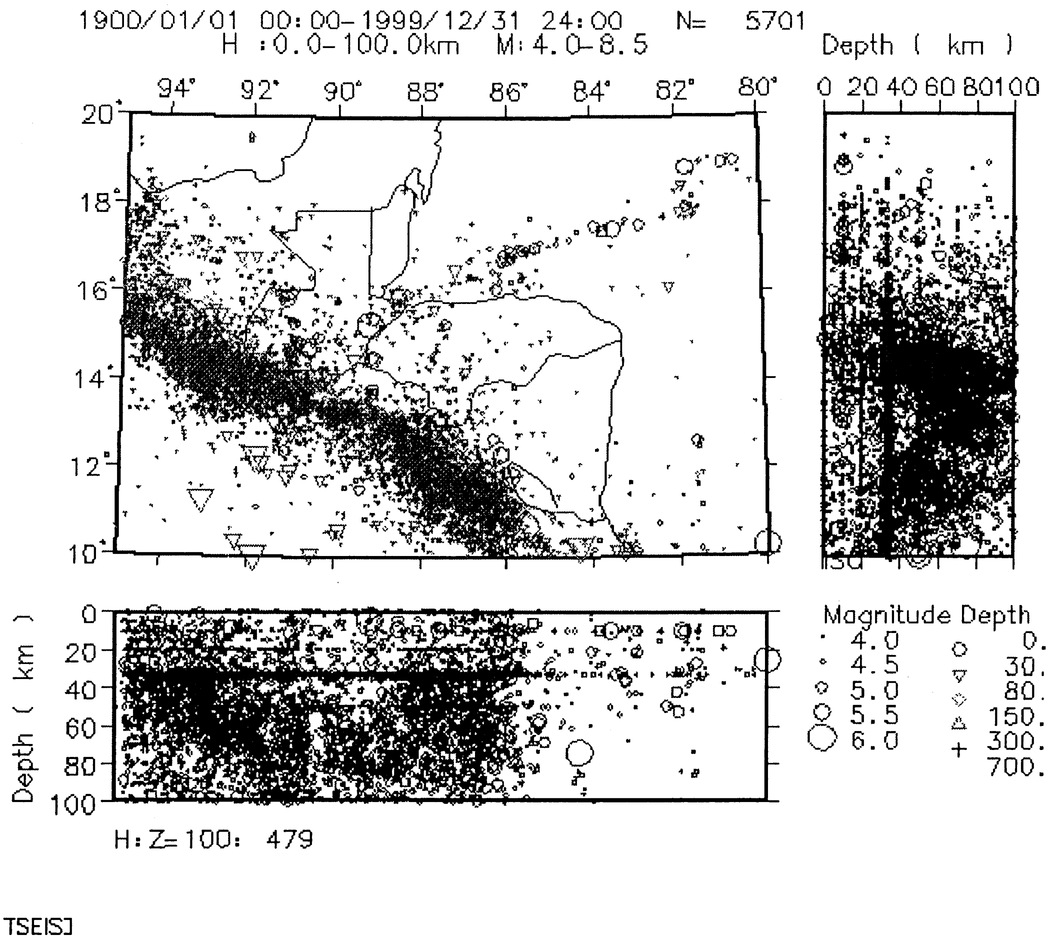


Figure A.2.1 Geological Map in the Study Area



PARAMETER

TM1:	1900/01/01
TM2:	1999/12/31
RGN:	-95/10/-80/20
DEP:	0.0/100
MAG:	4.0/8.5

Figure A.2.2	**Distribution Map of the Earthquakes in the Central America**

Table A.2.3 Chronology of the Earthquakes and Volcanic Activities in Honduras (1/3)

Date	Place	Mercali Intensity	Richter Scale Magnitude	Phenomenon and Damages
1522	Fonseca Gulf			Eruption
24/11/1539	All Honduras			Violent earthquake, with a radius of 160 kms (from Cape Higueras)
22/03/1610	Comayagua and All Honduras			Earthquake and tremor. Damage to the Cathedral of Comayagua
1630	Olancho el Viejo (San Jorge)			It is argued whether it was flood or earthquake. The mountain area was destroyed due to tremendous violence, the village was destroyed by the rainfall of rocks, stones and ashes.
1724	Comauagua			Tremor
1750	Comauagya			Tremor
07/1764	Trujillo	VII	6.50	This earthquake had destroyed 108 houses n the port and claimed various victims (According to the bishop, it was the eruption of the Monte Blanco, a volcano located to the east of Trujillo).
9/03/1773	Jicaramanl Yamaranguila Santiago Colosuca and Belén Gaulco			A lot of tremors had left churches in ruin and in danger. The church of Belen Gualcho was left with fissure and opening, to which was feared to be dropped.
16/09/1773	Omoa			A tremor followed by heavy rain and string wind that inundated a village.
14/10/1774	Gracias, Santa Rosa de Copán, Omoa, Tencoa, Ajuterique, La paz, Lajamaní and Comayagua			A big tremor was felt in Comayagua; in Lejamaní, a church and towers were ruined; in La Paz, many houses were damaged and greater majority silver mines in Gorra mountain was filled with earth; in Ajuterique, a church was opened and it rained some days when it had been heard resound; in Gracias, rivers water were increased and the wall of 3 churches and all houses of the village cracked.
16/12/1788	Gracias a Dios			Cyclone and seaquake (Tsunami)
1795	Comayagua			Tremor
20-23/7/1809	Comayagua and Tegucigalpa			An earthquake which was felt throughout Honduras. In Comayagua, the cathedral was suffered from damage, and in Teguigalpa, the San Miguel Parish Church.
19-20/1809	Tegucigalpa	VIII		An earthquake which was felt throughout Honduras. In Tegucigalpa, the San Sebastián church was destroyed.
19/10/1820	Villa de Omoa and San Pedro Sula		5.5	A strong earthquake which destroyed Villa de Osomoa, and in San Pedro Sula various houses and churches were fallen and there were some victims.
2/1825	Roatán	VII		Seismic movement
20-25/1/1835	Puerto del Tigre			An eruption of the Volcano Cosiguina (the Gulf of Fonseca, Nicaragua). 20-25/January, at 11 am, it got dark during two days for the majority of time. In the Island of Tigre, or in the sea, it was found dead birds, mice, bats and any kinds of reptiles. Other reports indicated that sand was fallen in Jamaica, Santa Fe de Bogotá and Oaxaca, Mexico over the area more than 1,500 miles of diameter. The explosion was heard 800 miles; and one vessel navigated until 50 leguas (about 200 km) among mass stones which covered sea surface.
22-23/6/1836	Omoa and Various Places in Central America			Tremor
1839	La Mosquitia			A strong tremor which continued about 5 seconds and it was followed by other tremors and dark storm cloud which covered the sun.
15/2/1848	Islands of the Bay			Earthquake
1/2/1848	Gulf of Honduras and Trujillo			Tremors

Table A.2.3 Chronology of the Earthquakes and Volcanic Activities in Honduras (2/3)

Date	Place	Mercali Intensity	Richter Scale Magnitude	Phenomenon and Damages
27/10/1849	Honduras, Nicaragua and El Salvador	VIII	6-7	A tremor which caused land movement during a minute and had horizontal vibration for 30 seconds.
8,18/7/1851	Trujillo and inside Honduras			Tremor
8,18/8/1851	Trujillo	VI	a) 5.50 b) 4.50	2 tremors
1/9/1851	Almost all Honduras			Tremors
11-14/11/1851	Tegucigalpa, Trujillo	VI		Tremor
3/1852	All Honduras			Tremor. Appeared a crack near the bridge and landslides en Barrio El Jazmin.
9/2/1853	Guatamala and Trujillo	VI	6-7	A strong horizontal and vertical tremor.
26/8-3/12/1853	Guatemala and Trujillo			During various months, lands were shaked in Trujillo causing many damages and destroying a bridge.
15/4/1854	Omoa, Trujillo	IX		Seismic movement
16/8/1854	Omoa, Trujillo and Gracias		7-8	Strong tremors destroyed buildings in small fragments. In those days, a violent earthquake destroyed San Salvador.
25/9-9/10/1855	Trujillo	VII	6.50	Vertical seismic movements with 15 seconds which left the village seriously damaged.
5/5/1856	Omoa	VI	7-8	Violent earthquake
4-27/8/1856	All the Coast and Carribean Sea and Olancho	X	7-8	Omoa became complete ruins because of Tsunami. The port was completely destroyed. During 8 days, there were 108 seismic movements in Omoa and Trujillo. It was felt even in Ocotepeque.
7/9/1856	Omoa and Comayagua			Strong Tremor
4/11/1867	Central Zone	VIII		Seismic movement. Produced breakdown in Tegucigalpa. It was the largest earthquake in the central zone.
25/8-3/9/1859	Isla del Tigre and Amapala	VIII	6.50	Various land movements caused many damages. At the same time, it was reported a Tsunami. 6 seismic movements taken from the Volcano Cosiguina.
8/12/1859	South and Central Zones and Comayagua	XI	8	A strong tremor which was felt in Guatemala and el Salvador. The Volcano Izalco had new movements.
28/12/1859	Trujillo			Tremor
19/12/1861	All Honduras		6.50	Tremor
19/12/1862	All Honduras	X		Seismic movement
13/1/1867	All Honduras			Tremor
12/7/1870	Santa Rosa de Copán	VIII		A strong tremor which had caused many damages.
22/2/1873	Gracias	IX		Seismic movement
9/10/1873-20/4/1874	All Honduras, Santa Bárbara			Strong tremors which destroyed houses and buildings
21/12/1876	Santa Rosa de Copán			Strong Tremor
26/3/1878	Santa Rosa de Copán			Earthquake
23/4/1881	Gulf of Honduras	VII		Seismic movement
28/3/1881	Tegucigalpa, Trujillo and Belice			Seismic movement
19/4/1882	Trujillo, Olancho,Gracias a Dios			Seismic movement
19/9/1883	Trujillo	VII		Seismic movement

Table A.2.3 Chronology of the Earthquakes and Volcanic Activities in Honduras (3/3)

Date	Place	Mercali Intensity	Richter Scale Magnitude	Phenomenon and Damages
14/7/1888	All Honduras			Storms
5/7/1893	La Mosquitia			A tremor which devastated all the houses and various buildings.
7/1897	Northeast and Central Area of Honduras	VII	5-6	Seismic movement which caused many damaged in buildings.
28/9/1898	La Ceiba			A strong tremor but fortunately no misfortune was reported.
10/6/1899	Tegucigalpa and other regions of the Republic			A strong earthquake which continued about 4 seconds and brought about slight damages to some houses.
29/4/1913	San Marcos de Colón			Tremor. It was said just after the phenomenon, snow fell on the mountain..
26/12//1915	Gracias			A tremor which destroyed completely a city.
29/12/1915	Trujillo		6.3	An earthquake which produced victims in Trujillo.
10/11/1916	San Pedro Sula			Tremors, but no misfortune was reported.
17/8/1918	Cedros, Juticalpa and Guaimaca			Tremors
15/2/1933	Yoro			Tremor
18/3/1933	La Ceiba			Tremors accompanied by hurricane.
19/3/1933	Olanchito			Tremor
23/3/1933	San Pedro Sula			Tremor
19/6/1933	San Francisco de Atlántida			Tremor
4-6/10/1933				It was reported that in the west, specially in the Department of Gracias, seismic movement was felt. Source: Magazine "Hablemos Claro", 1-7, Dic/1998, Newspaper Diario Comercial, San Pedro Sula,5,6/10,1993.
2,3,8/12/1934	Tegucigalpa, Copán Intibucá and Ocotepeque		6.1	Tremors which caused damages over ruins in Copan and in Santa Rosa de Copan. It was felt all the central regions including Tegucigalpa. The damages covered the western part of the country.
25/2/1969	Honduras, Guatemala and El Salvador			An earthquake felt in various area of these countries.
4/2/1976	Puerto Cortés, San Pedro Sula, Guatemala		7.5	The epicenter was in Guatemala City. An earthquake originated from the fault in Motaguo, nearer to Puerto Cortés than to Guatemala City. The largest earthquake of the century in Honduras. Many damages were reported in Puerto Cortés, San Pedro Sula and bordering zone with Guatemala.
12/1/1982	Gulf of Fonseca		6.0	An earthquake which had origin in the Gulf of Fonseca. Two persons were injured and some were affected.
29/9/1982	Ocotepeque		6.2	An earthquake in Ocotepeque. Two persons were died, 60 were injured and about 400 were affected.

Source: 1)"Cronología de las Catástroferas en Honduras", Francisco A. Andino, Revista Geográfica, IGN, SOPTRAVI, Dic. 1996. Sntesisñ Nancy Guitérrez, Rivera (August/1998), 2) Terremotos Hisóricos más Relevantes, Diario La Prensa, Aiméc Cárcamo, 27 Dic. 1998

Note: Most of telluric movements have affected the north coast, specially, Trujillo, and have had their origin in the interaction of the panel of Caribbean Sea and that of North America and, at the same time, that in small fault in the Atlantic Coast.

3. GEOLOGICAL STUDY FOR DAM

3.1 GEOLOGICAL INVESTIGATION

Geological investigation was conducted at Los Laureles II Dam Site in Guacerique River and Sabacuante Dam Site in Sabacuante River as follows:

Table A.3.1 Contents of Geological Investigation

No.	Site	Location	Depth (m)	Lugeon Test	S.P.T.	Laboratory test
Bg-1	Site 1	Left bank	60	11	5	
Bg-2	Site 1	Left bank	60	11		5
Bg-3	Site 1	River bed	40	7		5
Bg-4	Site 1	Right bank	60	11		
Bg-5	Site 1	Right bank	60	11		
Bg-6	Site 1	River bed	30	5		
Bg-7	Site 1	River bed	30	5		
Bg-8	Site 1	Spillway	40	7		
Bg-9	Site 1	Reservoir	30	5	4	
Bg-10	Site 1	Reservoir	30	5	5	
		subtotal	440	78	14	10
Bs-1	Site 2	Left bank	80	15	4	
Bs-2	Site 2	Left bank	80	15		5
Bs-3	Site 2	River bed	80	15		5
Bs-4	Site 2	Right bank	80	15		
Bs-5	Site 2	River bed	40	7		
		subtotal	360	67	4	10
		Total	800	145	18	20

Site 1: Los Laureles II Dam, Site 2: Sabacuante Dam
S.P.T.: Standard Penetration Test
Contents of laboratory test: Specific gravity and Water absorption, Unit weight, Pulse velocity, and Compression test

Table A.3.2 Seismic Exploration

Line	Site	Location	Length
1	site 1	Dam axis, left bank	120m
2	site 1	Dam axis, left bank	120m
3	site 1	River bed	*60m
4	site 1	Dam axis, right bank	120m
		subtotal	420m
1	site 2	Right bank	120m
2	site 2	Dam axis, right bank	*60m
3	site 2	River bed	*60m
4	site 2	River bed	*60m
5	site 2	Left bank	120m
6	site 2	Dam axis, left bank	120m
		subtotal	540m
		Total	960m

Site 1: Los Laureles II Dam, Site 2: Sabacuante Dam
Pickup space: normal; 10m, *; 5m

3.2 LOS LAUREлES II DAM

3.2.1 GEOLOGY IN THE RESERVOIR

(1) Outline of the basin

The basin of the Los Laureles II Dam is characterized by the mountainous topography with an altitude of about 1000 to 1900 meters from the lower reach to the upper reach. The lower part of the basin is utilized as for the cultivated and pasture land. Fifty percents of the land are covered by the grass in this area. On the other hand, eighty percents of the upper part from the junction of Guacerique River and Mateo River are covered by a forest that acts as the preservation of the water source. But, these areas are urbanized recently, especially along the Mateo River. It is generating a water pollution and it is recommended to preserve the forest and to mitigate the water pollution from a domestic and industrial drainage (refer to Figure A.3.1).

(2) Topography

Guacerique River flows roughly from the northwest to the southeast to the vicinity of Nueva Aldea Village with a slightly meandering. Mateo River joins it and flows roughly from the west to the east. Tributaries are developed excluding the distribution area of the Quaternary basalt that is fresh and hard enough to resist the weathering and erosion. Guacerique River forms a flood plain in the downstream stretch from the junction with Mateo River.

(3) Stratigraphy

Ignimbrite and various tuffs of Padre Miguel Group are extensively distributed in and around the reservoir. These basement rocks are covered by the talus deposit in the hilly region, terrace deposits on the flood plain, and Alluvial deposit in the river in the age of Quaternary period (refer to Figure A.3.2).

<u>Ignimbrite</u>

It consists of a rhyolitic welded tuff, low welded tuff, and pyroclastic flow of white, red green crystals, feldspar, biotite, pumice fragment, and reddish gravel of Valle de Angelles Group.

<u>Tuff</u>

The stratified tuff consists of green sandy tuff, lapilli tuff, and tuff breccia that are distributed at the low altitude in the reservoir and high altitude in the left bank of dam site. The layer is horizontal at the left bank of dam site and has N50W to N85E of strike and 5 to 10 degrees of dip in the reservoir.

(4) Geologic Structure

Ignimbrite including pyroclastic flow covers unconformablly the stratified tuffs. The stratified tuffs have the structure of horizontal to 10 degrees of dip toward the downstream. The sandstone and siltstone of lake deposit are distributed between them. The boundary of them has the auto-brecciated or chilled-margine part in the ignimbrite and the weathered zone in the tuffs.

(5) Slope Stability

The unconsolidated deposits of talus deposit and terrace deposit are distributed in the reservoir. But the normal water level (N.W.L.) of 1053m covers completely these deposits or reaches only the bottom of these deposits. The basement rock of ignimbrite is permeable layer and rain water will be carried away immediately from the underground. Accordingly, the reservoir water does not affect on the slope stability.

The existing report pointed out the distribution of landslide near the military base (conducted by Dressv & Mckee International Inc.,1987). JICA Study Team conducted the field reconnaissance and two drillings to investigate it. The result is shown in the Figure A.3.3. It became clear the distribution of heavily weathered zones of stratified tuff, permeable talus deposit, and permeable basement rocks. It has also become clear that talus deposit has sufficient strength from the result of standard penetration test (N-value: 30 to more than 50). The sound rocks are exposed and slope feature is stable. Accordingly, this slope will be stable while the heavily weathered zone is distributed. It is also supported that this slope was stable when the Hurricane “Mitch” attacked because of the distribution of permeable layer and good slope feature. In conclusion, the reservoir water does not affect on the stability of this slope.

3.2.2 GEOLOGY AT DAM SITE

(1) Topography

Los Laureles II dam is proposed at the upstream end of the reservoir of existing Los Laureles Dam near Las Tapias and Campo de Balampie Village. Guacerique River in the vicinity of the proposed dam has a channel on a roughly straight line in the W-E direction with a stretch of approximately 600 meters, while the upstream is meandered. Guacerique River forms gorge with sound ignimbrite only around the proposed dam site, while the river forms flood plain and gentle geographical feature in the upper reach that gives the effective storage for the reservoir. The river bed elevation at the proposed dam axis is 1032m with the width of about 18 meters. The gradient of the abutment is approximately 45 degree from the riverbed to EL.1053m of Normal Water Level (N.W.L) in the left bank and 40 degree in the right bank. The gorge width is 64 meters at EL.1053m , and the ratio between height and valley width at EL. 1053 m is approximately 1:3.2.

(2) Geology

The basement rock at the proposed dam site is composed of the pumice tuff, lapilli tuff, thin layer of lake deposit of sandstone and siltstone, pyroclastic flow in water, rhyolitic ignimbrite. There are two types of ignimbrite of strongly welded and medium to low welded (refer to Figure A.3.4, A.3.5, A.3.6).

Alluvial deposit composed of sand and gravel covers the basement rock with the thickness of about 3 to 6 meters at the river bed. Talus deposit is distributed on the bank with the thickness of about 0.5 to 3 meters.

Joints of ignimbrite are not developed but a few joints are loosed and opened. Vertical joints are dominant.

(3) Engineering Geology

The weathering of foundation rocks of ignimbrite and tuff is low excluding the lapilli taff located at the left high bank. Consequently, the strength and soundness of the foundation rocks are determined by the rock consolidation considering with the development of faults and joints. The fresh ignimbrite is stronger than tuffs. The result is compiled as the map of rock soundness (see Figure A.3.7).

Detailed values regarding the ignimbrite are unknown since the foundation rock tests have not been carried out, but based on the results of laboratory test, seismic exploration, and field reconnaissance, it is considered to have sufficient soundness for the construction of a concrete gravity dam of the height of about 30 meters.

The standard of Rock Soundness Classification applied is as follows:

Table A. 3. 3 Rock Soundness Classification for Pyroclastics

Class	Description
A	Very fresh and very hard, no weathering and alteration, joints are extremely tight.
B	Fresh and hard, mineral and grain are partly weathered or altered. Joints are tight.
CH	Solid, mineral and grain are partly weathered or altered except quartz. The cohesion of joints is slightly decreased with limonite
CM	Comparatively solid. Mineral and grain are somewhat softened by weathering except quartz. The cohesion of joints is slightly decreased with limonite and clay.
CL	Soft, the rock piece is broken by the soft hammer blow.
D	Very soft, clayey, the rock piece is easily broken by the soft hammer blow.

The result of laboratory test

The laboratory test was conducted to make clear the strength of the ignimbrite. These test pieces are classified as CM class.

Item	Number of test	Unit	Result	Mean value
Specific gravity	10	-	2.01-2.07	2.05
Water absorption	10	%	14.1-18.3	16.0
Unit weight (wet)	10	g/cm^3	1.76-1.79	1.78
Compressive strength	10	kg/cm^2	128.6-193.5	163.1
Pulse velocity	10	m/s	1400-2500	2250

Abnormal value are neglected in the mean value

Each value harmonizes with other test item and they are within the general Tertiary volcanic rocks.

The result of seismic exploration

The seismic exploration were conducted along the dam axis and river bed. The result is compiled in Figure A.3.7. Two velocity layer are classified as follows:

Layer	Velocity (m/s)	Mean velocity (m/s)	Depth (m)	Geology
1st layer on the left bank	501- 654	578	0.1-8.0	Top soil and talus deposit
1st layer on the right bank	455-521	488	1.0-4.0	Top soil and weathered rock
2nd layer on the bank	1875-2188	1988	-	Fresh rock

The longitudinal wave velocity (Vp) of fresh rock is within the general velocity of Tertiary ignimbrite and tuff of about 1700 m/s to 2600 m/s.

Shear strength

The shear strength will be estimated on the basis of above-mentioned results as follows:

Ignimbrite; τ_0=80-120 t/m^2 (CM)
Pyroclastic flow; τ_0=60-80 t/m^2 (CL)
Tuff; τ_0=60 t/m^2 (CL)
Siltstone, sandstone, weathered rock; τ_0<60 t/m^2 (D)

(4) Permeability

Lugeon test was conducted to make clear the permeability of the basement rocks.

Table A.3.4 The Result of Lugeon Test at Los Laureles II Dam

Depth	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60
BG-1	6	18	1	11	0	0	33	23	2	11	8
BG-2	3	19	4	1	0	1	1	0	0	0	0
BG-3	0	0	0	0	0	0	0				
BG-4	17	4	12	14	1	4	0	2	0	2	24
BG-5	27	15	22	24	21	23	0	3	14	22	23
BG-6	0	0	0	0	1						
BG-7	-	5	3	0	1						
BG-8	17	7	0	18	19	15	1				
BG-9	*	*	*	*	0						
BG-10	*	*	*	*	25						

* : seepage from the top of the hole

Watertightness depends on the distribution and property of joints. The permeability of ignimbrite is not high in general but high in local where joints existed judging from the field reconnaissance and lugeon test. For example, the rocks of BG-5 are fresh and comparatively hard, but lugeon value is high because of the distribution of vertical joints at the location. The distribution of high lugeon values are reflected the looseness near the ground surface (See Figure A.3.8).

Groundwater measurement

According to the distribution of secondary clay in the joints, groundwater will be fluctuated between dry season and rainy season. Groundwater level in the drill holes shall be measured a few years continuously.

(5) Construction Material

Terrace deposit is widely distributed on the flood plain at the middle to upper reach of the river. It consists of the sand and gravel of hard andesite and basalt including the soft material of about 10 %. It may be possible to use for the construction material of concrete aggregate and or filter to transition materials for the rock fill dam. The basalt distributed in and around the reservoir may be possible to use for the concrete aggregate (see Figure A.3.1, A.3.2).

3.3 SABACUANTE DAM

3.3.1 GEOLOGY IN THE RESERVOIR

(1) Outline of the basin

The basin of the Sabacuante dam is characterized by a mountainous topography with an altitude of about 1000 to 1800 meters from the lower reach to the upper reach. Sixty to seventy percents of the basin are covered by the grass which are utilized as for the cultivated and pasture land. On the other hand, 30 to 40 percents of the basin are covered by a forest that acts as the preservation of the water source.

(2) Topography

Sabacuante River flows roughly from the southeast to the northwest with meandering. The Grande River flows roughly from the south to the north and joins the Sabacuante River at the just upstream of the proposed dam site. Sabacuante River forms a few terrace but comparatively a lot of talus topography and slope collapse here and there. The slope inclination is steeper and forest coverage is lower than the Guacerique River basin (refer to Figure A.3.9).

(3) Stratigraphy

The sandy tuff with conglomerate and the rhyolitic lava of the Padre Miguel Group are extensively distributed in the reservoir (refer to Figure A.3.10).

The sandy tuff are distributed below the altitude of about 1140 meters. The strike is about E-W which is almost parallel to the dam axis and the dip is around 10 degrees toward the downstream.

The rhyolite lava covers the sandy tuff. It has the horizontal structure.

(4) Geologic Structure

The rhyolite covers conformablly the sandy tuff. The sandy tuff has the structure of horizontal to 10 degrees of dip toward the downstream. The boundary of them is stuck together without the weathered zone. A fault is inferred at the left tributary that make the west part of rocks to rise and forms gentle geographical feature comparing with the other area in the reservoir. It does not affect the dam plan.

(5) Slope Stability

The unconsolidated deposits of talus deposit and terrace deposit are mostly distributed under the normal water level (N.W.L.) of 1122m that covers completely these deposits. It is not necessary to consider a landslide of these deposits. Two sites of slope collapse of the basement rock is distributed in the reservoir, but unstable unconsolidated material has already fallen down. Accordingly, the reservoir water does not affect the slope stability.

3.2.2 GEOLOGY AT DAM SITE

(1) Topography

Sabacuante dam is proposed just upstream of the Aguacate Village. Sabacuante River in the vicinity of the proposed dam has a channel on a roughly straight line in the S-N direction with a stretch of approximately 300 meters, while the upper reach and lower reach are meandered. Sabacuante River forms narrow gorge of sandy tuff and it make the reservoir storage small. The river bed elevation at the proposed dam axis is 1051 m with the width of about 10 meters. The slope gradient is approximately 50 degree from the riverbed to EL.1080m and 18 degrees up to EL.1122 meters of Normal Water Level (N.W.L) in the left bank and 40 degree in the right bank. The gorge width is 250 meters at EL.1122 meters, and the ratio between height and valley width at EL. 1122 meters is approximately 1:3.5.

(2) Geology

The basement rock in the proposed dam site is composed of the sandy tuff, rhyolite, and tuff breccia of Valle de Angeles Group.

Alluvial deposit composed of sand and gravel covers the basement rock with the thickness of about 2 meters at the river bed. Talus deposit is distributed on the bank with the thickness of about 2 to 5 meters (refer to Figure A.3.11, A.3.12).

Joints of the sandy tuff are not developed but a few joints are loosed and opened. The sheeting joints almost parallel to the bedding are dominant in the sandy tuff with a few vertical joints. A lot of sheeting joints are loose which may cause the seepage. The tuff breccia and rhyolite are not directly related to the dam foundation.

(3) Engineering Geology

The weathering of sandy tuff is low and the strength and soundness of the foundation rocks are determined by the rock consolidation considering with the development of faults and joints. The result is compiled as the map of rock soundness (see Figure A.3.13).

Detailed values regarding the sandy tuff are unknown since foundation rock tests have not been carried out, but the shear strength will be estimated on the basis of the results of laboratory test, seismic exploration, and field reconnaissance.

<u>The result of laboratory test</u>

The laboratory test was conducted to make clear the strength of the sandy tuff. These test pieces are classified as CL class.

River bed

Item	Number of test	Unit	Result	Mean value
Specific gravity	5		1.69-1.96	1.81
Water absorption	5	%	18.6-25.8	22.5
Unit weight (wet)	5	g/cm^3	1.30-1.81	1.52
Compressive strength	5	kg/cm^2	(17.7)-106.8	104.7
Pulse velocity	5	m/s	(360)-1600	1400

Abnormal value are neglected in the mean value

Left bank

Item	Number of test	Unit	Result	Mean value
Specific gravity	5		1.85-1.92	1.88
Water absorption	5	%	20.0-25.2	22.8
Unit weight (wet)	5	g/cm^3	1.46-1.70	1.54
Compressive strength	5	kg/cm^2	(16.27)-65.6	50.2
Pulse velocity	5	m/s	1200-1400	1330

Abnormal value are neglected in the mean value

Each value harmonizes with other test item and they are within the Tertiary tuffs.

<u>The result of seismic exploration</u>

The seismic exploration were conducted along the dam axis and river bed. Two velocity layer are classified as follows:

Layer	Velocity (m/s)	Mean velocity (m/s)	Depth (m)	Geology
1st layer on the river bed	875, 1481	1178	0.4-2.1	saturated alluvial deposit
1st layer on the bank	403-543	459	0.8-4.0	Top soil and talus deposit
2nd layer on the river	2063, 2258	2160	-	Fresh sandy tuff
2nd layer on the bank	1243-1402	1303	-	Loosened rock

The longitudinal wave velocity (Vp) of fresh rock is lower than the general velocity of Tertiary tuff of about 1700 m/s to 2600 m/s.

Shear strength

The shear strength will be estimated on the basis of above-mentioned results as follows:

Sandy tuff; τ_0=60-80 t/m^2 (CL)

Weathered rock τ_0<60 t/m^2 (<CL)

(4) Permeability

Lugeon test was conducted to make clear the permeability of the basement rocks.

Table A.3.5 The Result of Lugeon Test at Sabacuante Dam

Depth	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80
BS-1	3	6	3	1	4	12	15	48	22	16	2	9	1	1	1
BS-2	*	6	20	28	21	5	27	1	0	0	0	0	0	0	2
BS-3	0	0	0	3	0	0	0	0	-	0	0	0	0	0	0
BS-4	23	20	20	31	1	0	0	0	0	8	25	0	0	0	5
BS-5	2	5	0	2	0	0	0								

* : seepage from the top of the hole

Watertightness depends on the distribution and property of joints. The permeability of sandy tuff is not high in general but high in local where joints existed judging from the field reconnaissance and lugeon test.

There was leakage from the vertical joint and sheeting joint distributed at the left river wall when the lugeon test has been conducted at BS-2. There was also leakage from the sheeting joints at the right river wall when the lugeon test has been conducted at BS-4. The rocks of BS-2 and BS-4 are fresh and well consolidated, but lugeon value is high because of the distribution of joints at the location. The distribution of high lugeon values near the ground surface are reflected the looseness (See Figure A.3.14).

(5) Construction Material

The construction material such as aggregate for the concrete dam and materials for rock fill dam are not distributed in the vicinity of dam site. River bed deposit is rare in this reservoir. Basalt is distributed at the left high bank of dam site, but it is difficult to exploit. Rhyolite is also exposed above the elevation of 1140 meters, but it is also supposed to be difficult to exploit and there is a fear of the alkaline reaction with the cement because of it's content of the vitric material.

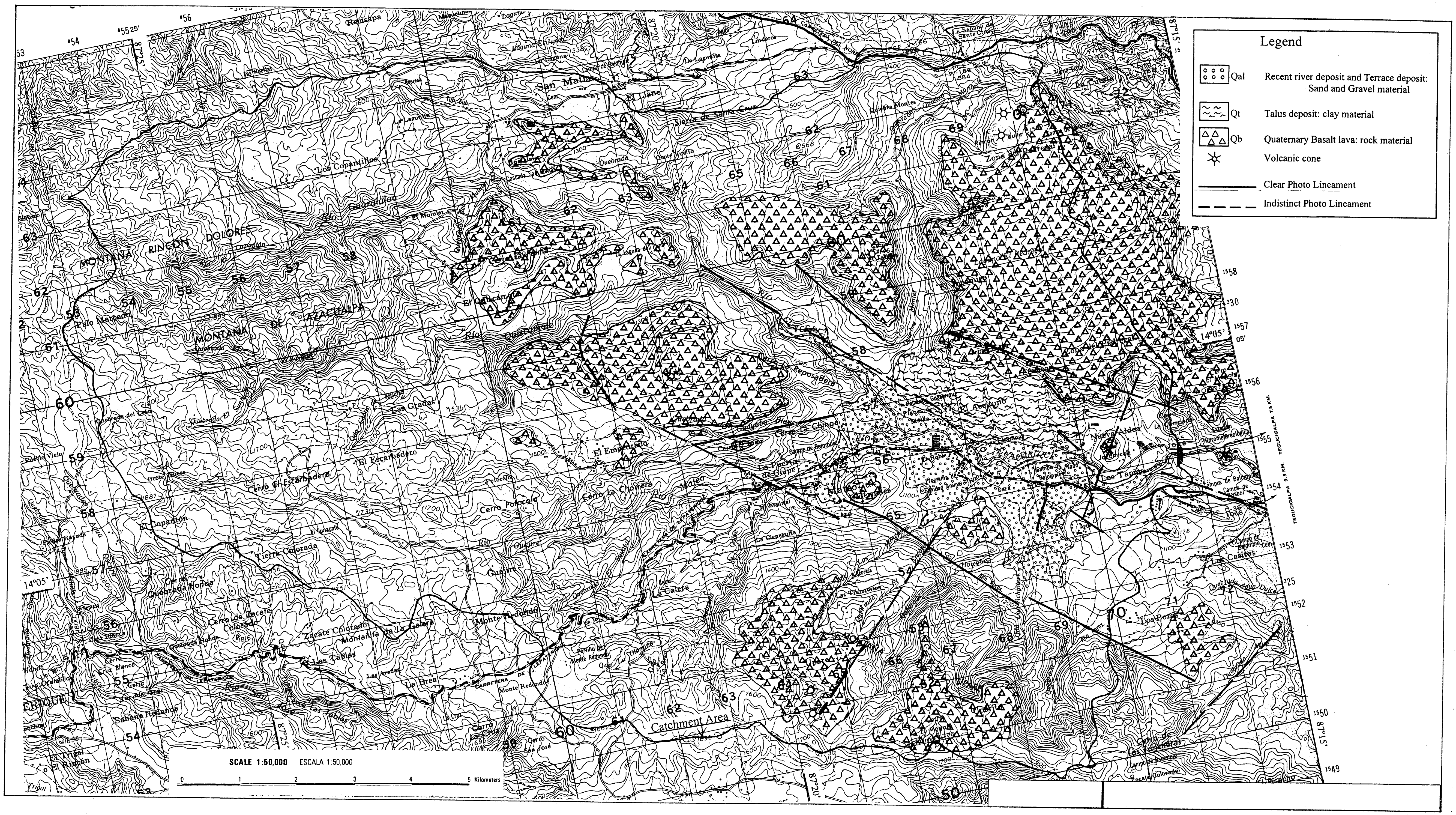


Figure A.3.1	Geological Information in the Basin of Los Laureles II Dam

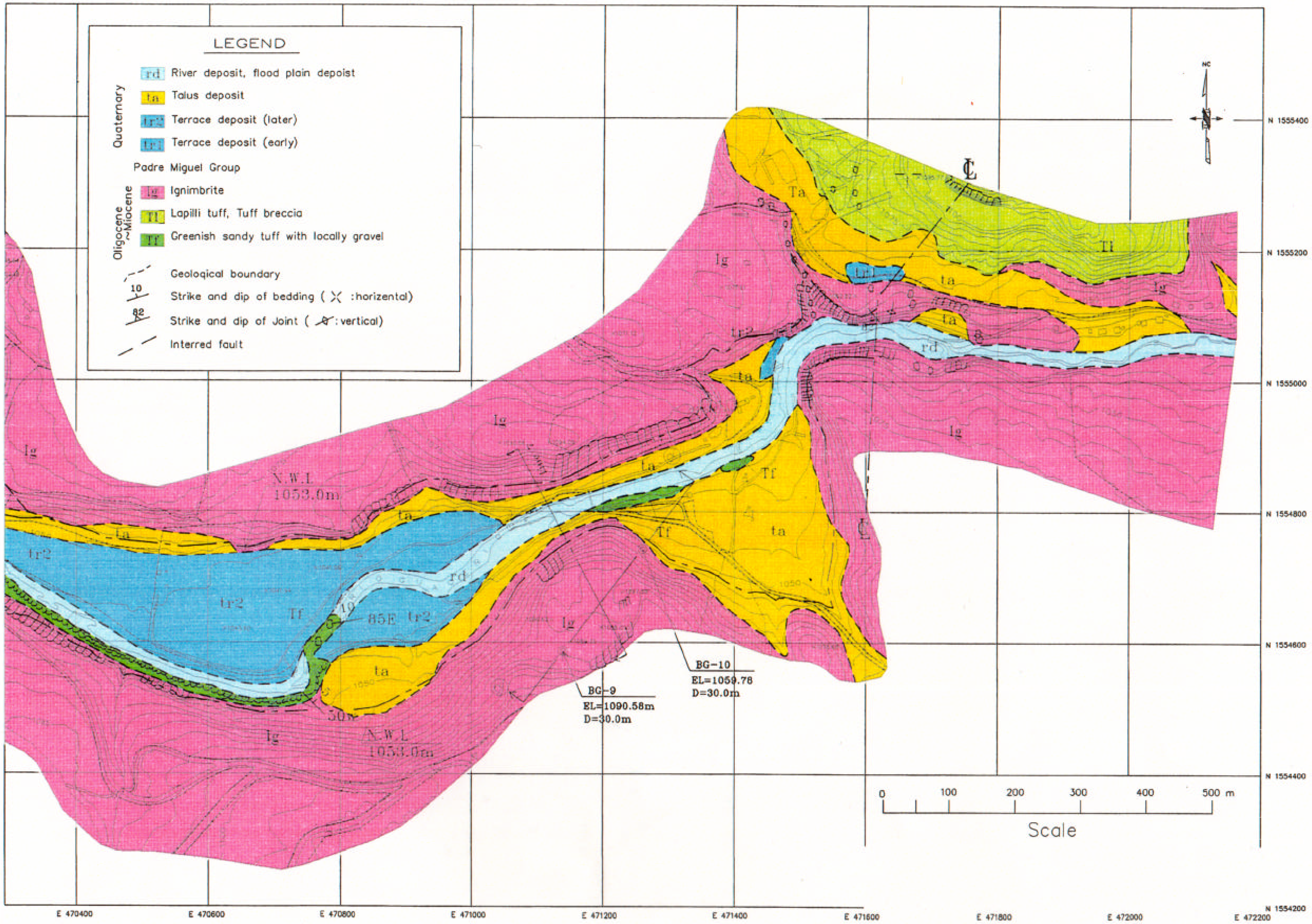


Figure A.3.2 (1/2)	Geological Map of the Los Laureles II Reservoir

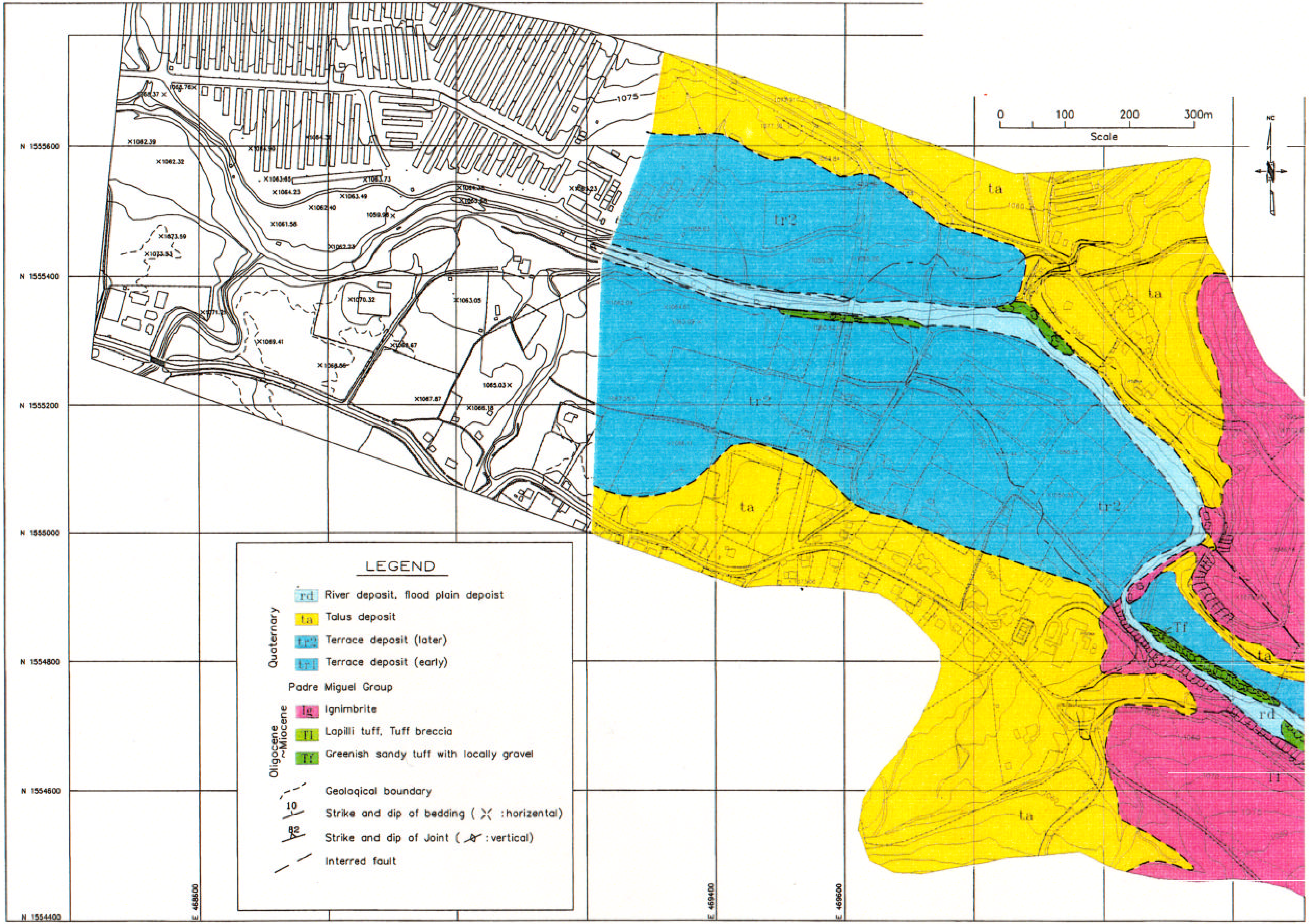


Figure A.3.2 (2/2) | Geological Map of the Los Laureles II Reservoir

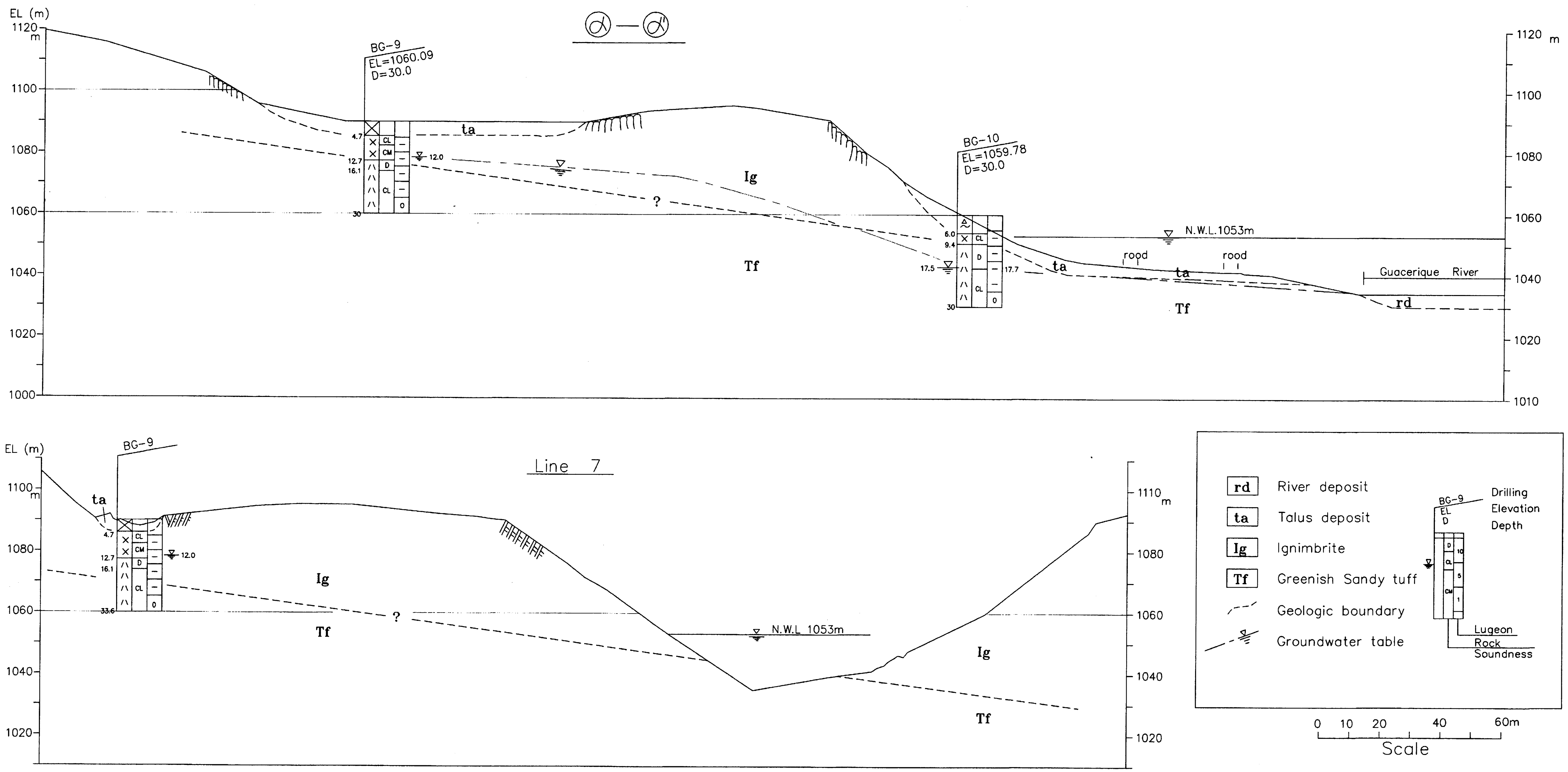


Figure A.3.3 | **Geological Profile of the Military Base**

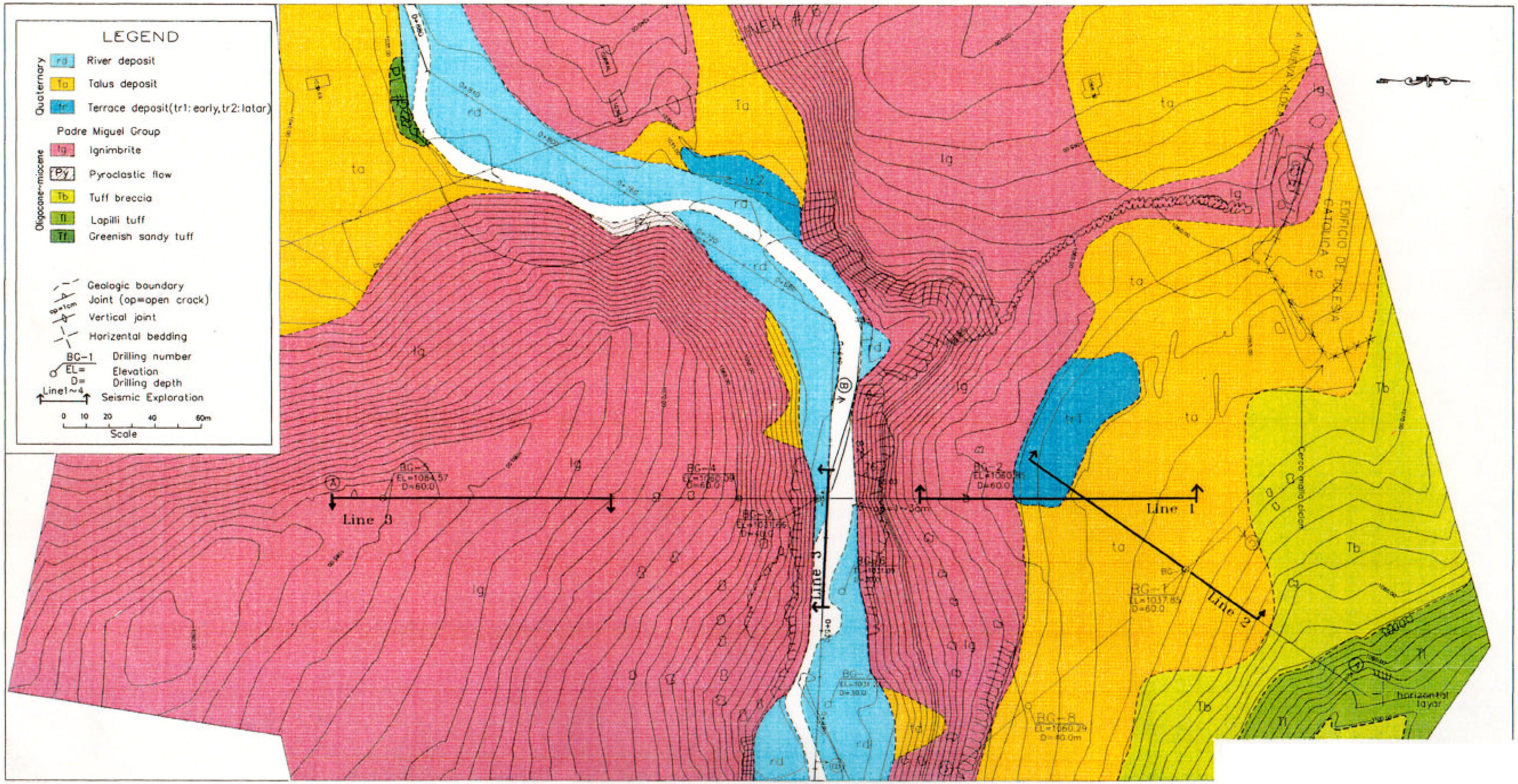


Figure A.3.4	Geological Map of the Los Laureles II Dam

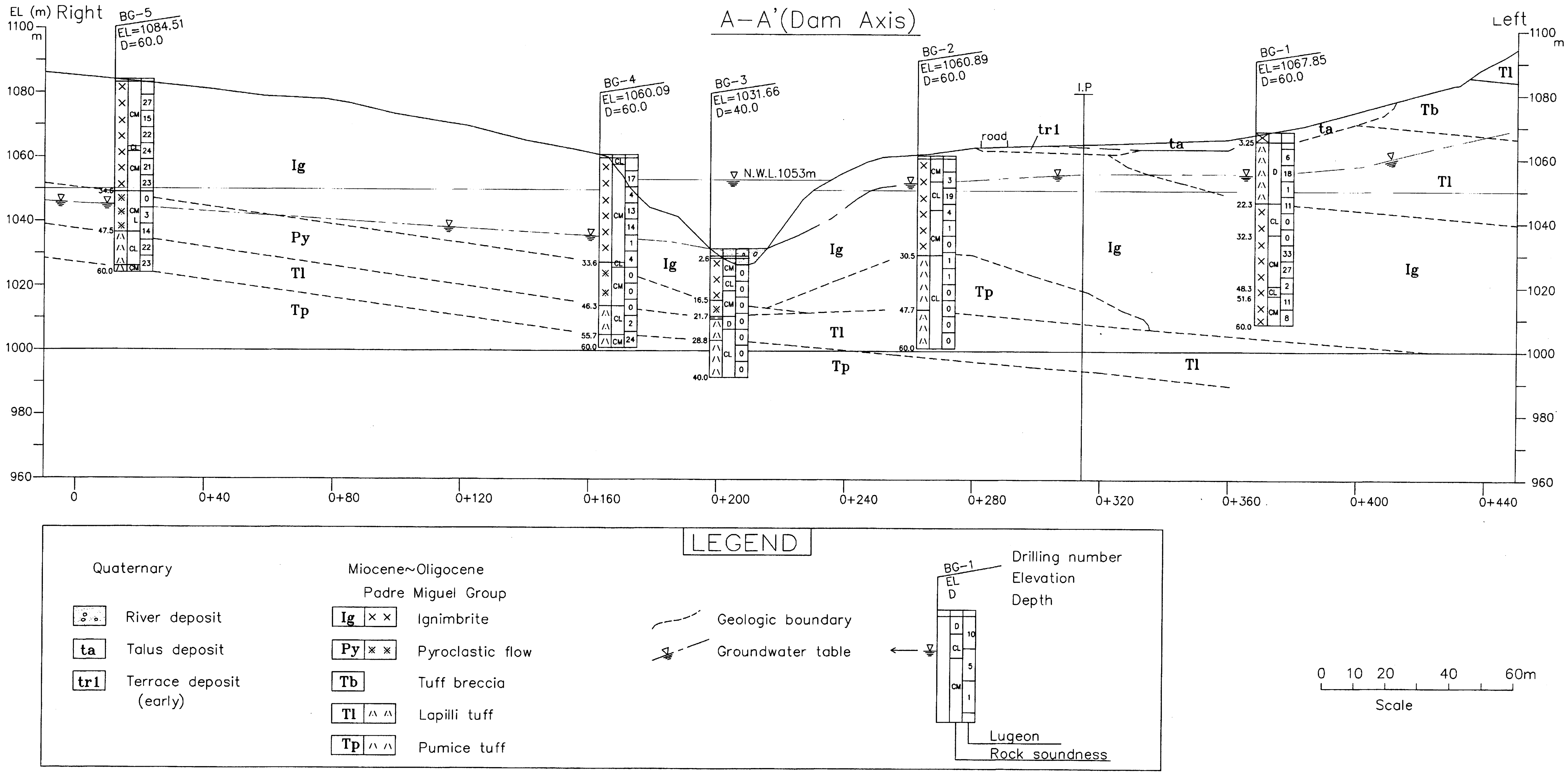


Figure A.3.5 Geological Section of the Los Laureles II Dam Axis (A-A')

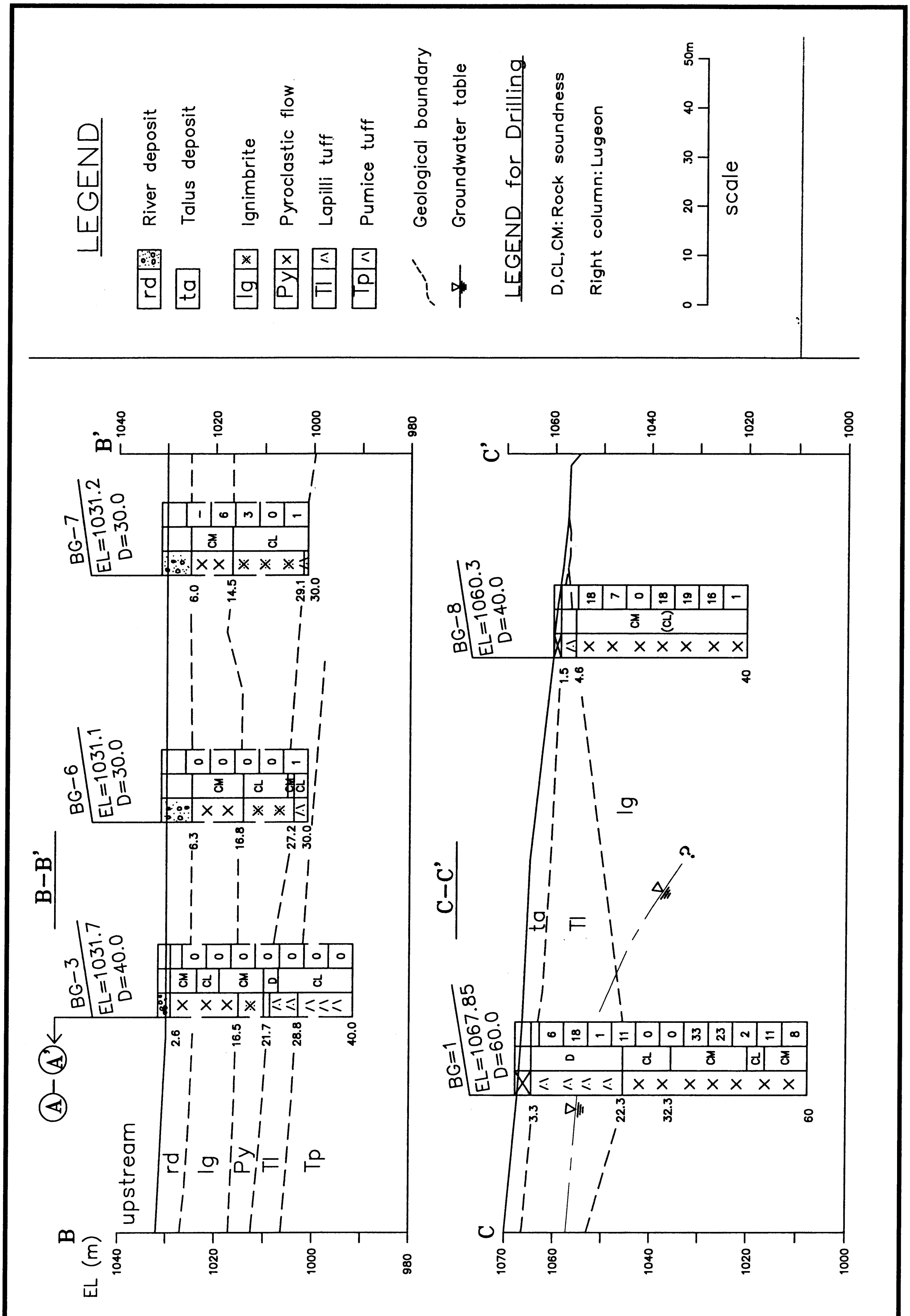


Figure A.3.6	Geological Profiles (B-B', C-C'), of the Los Laureles II Dam

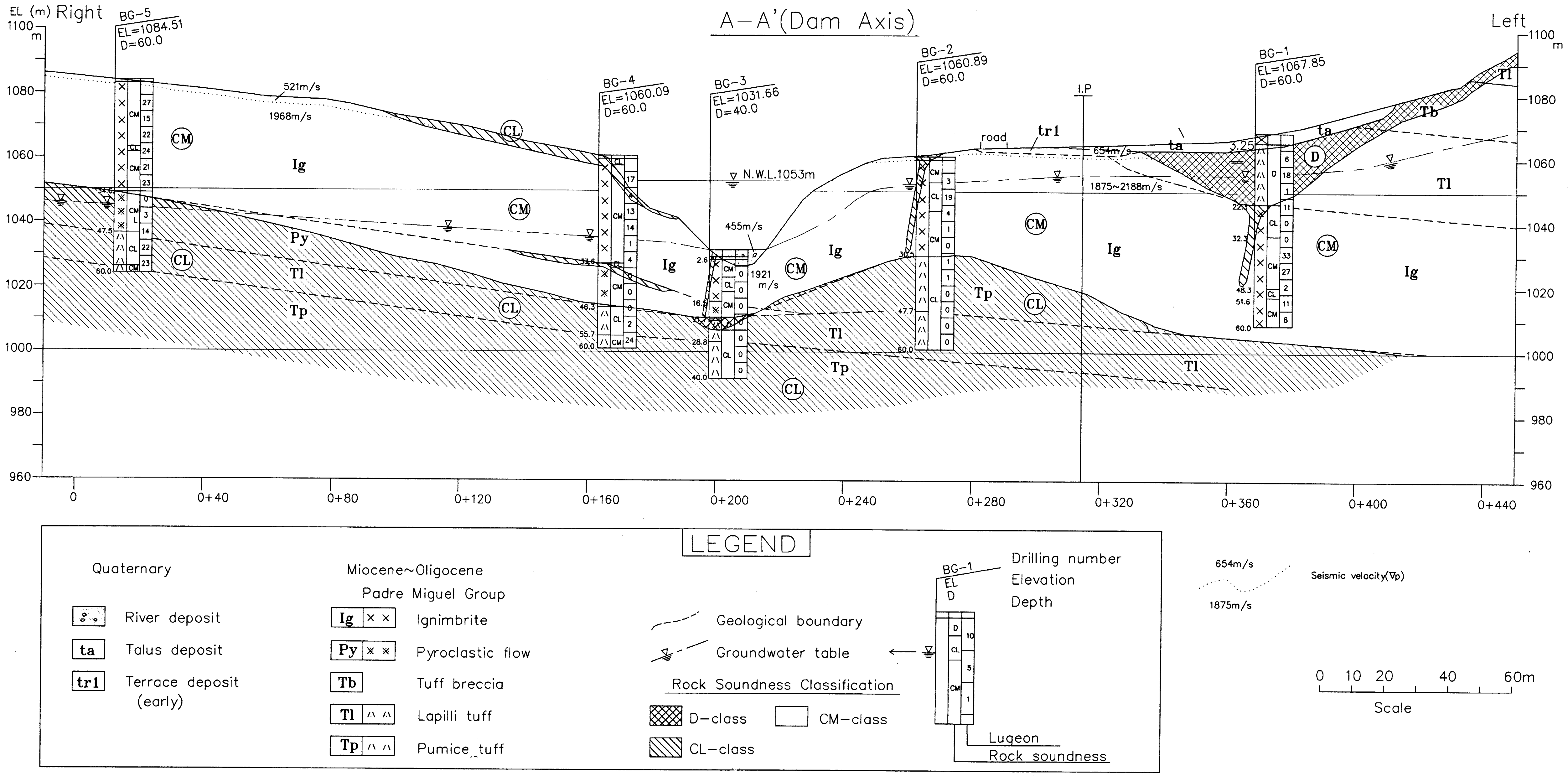


Figure A.3.7	Rock Soundness Classification map of the Los Laureles II Dam Axis (A-A')

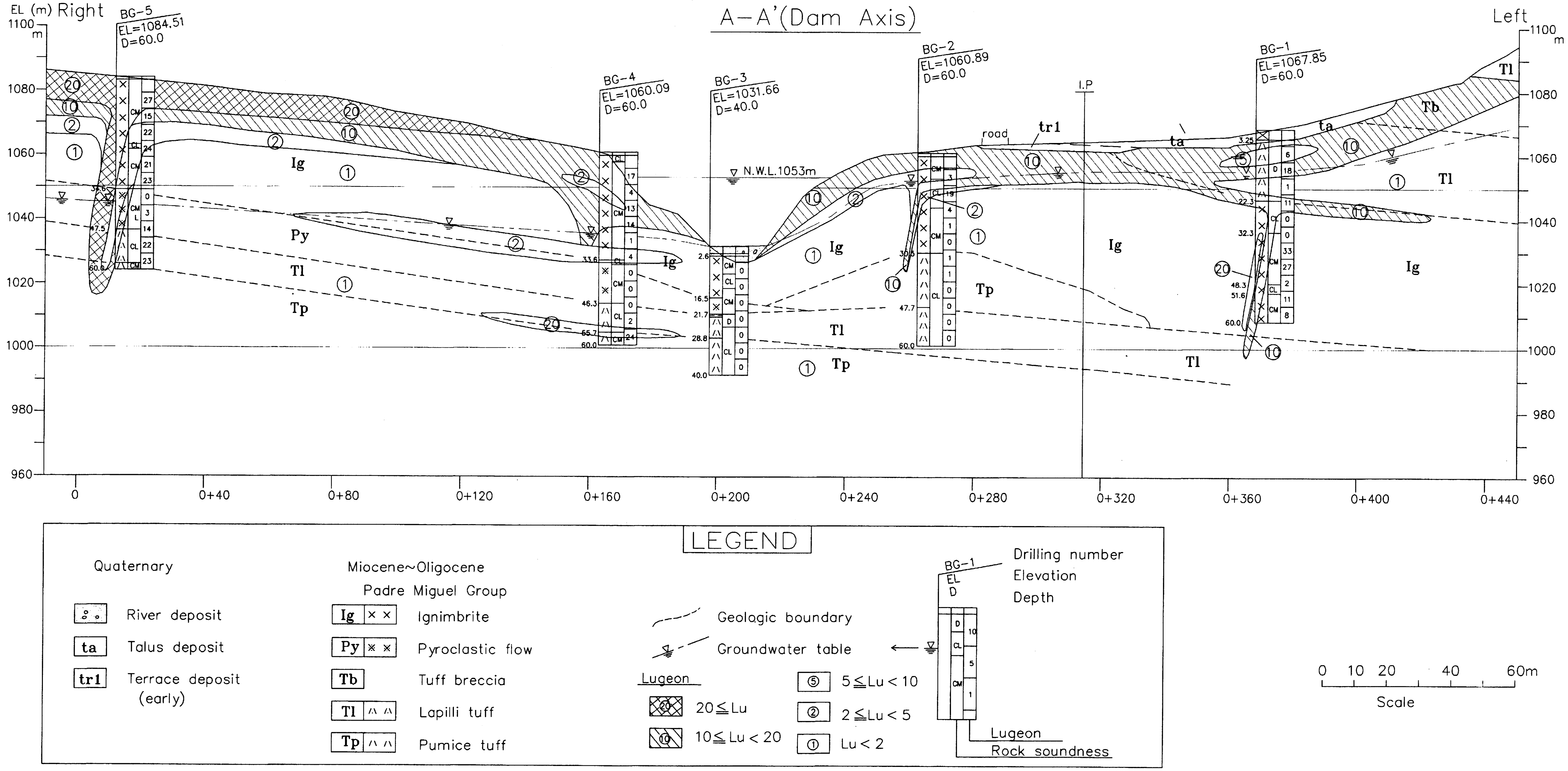


Figure A.3.8 | **Lugeon Map of the Los Laureles II Dam Axis (A-A')**

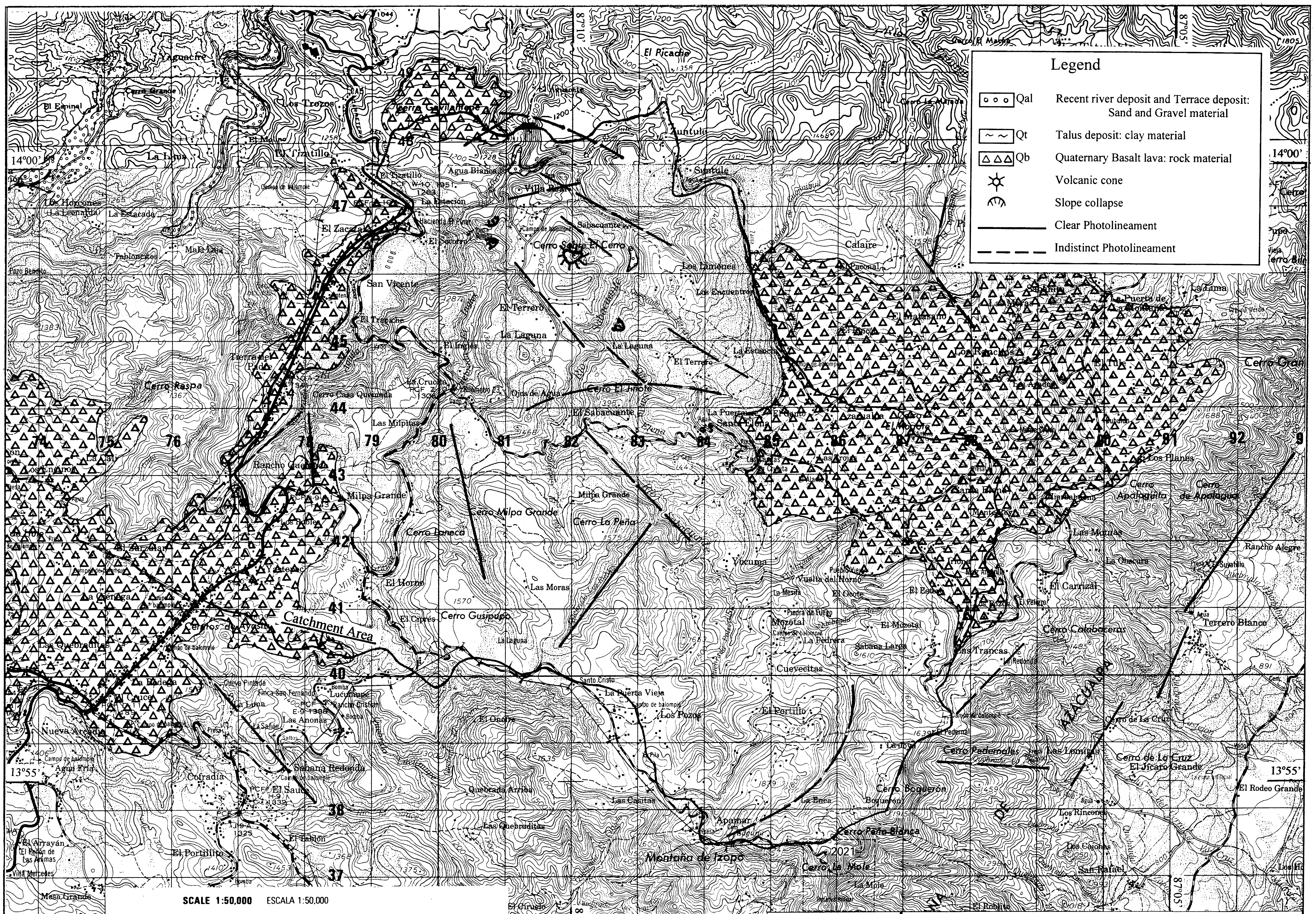


Figure A.3.9 **Geological Information in the Basin of Sabacuante Dam**

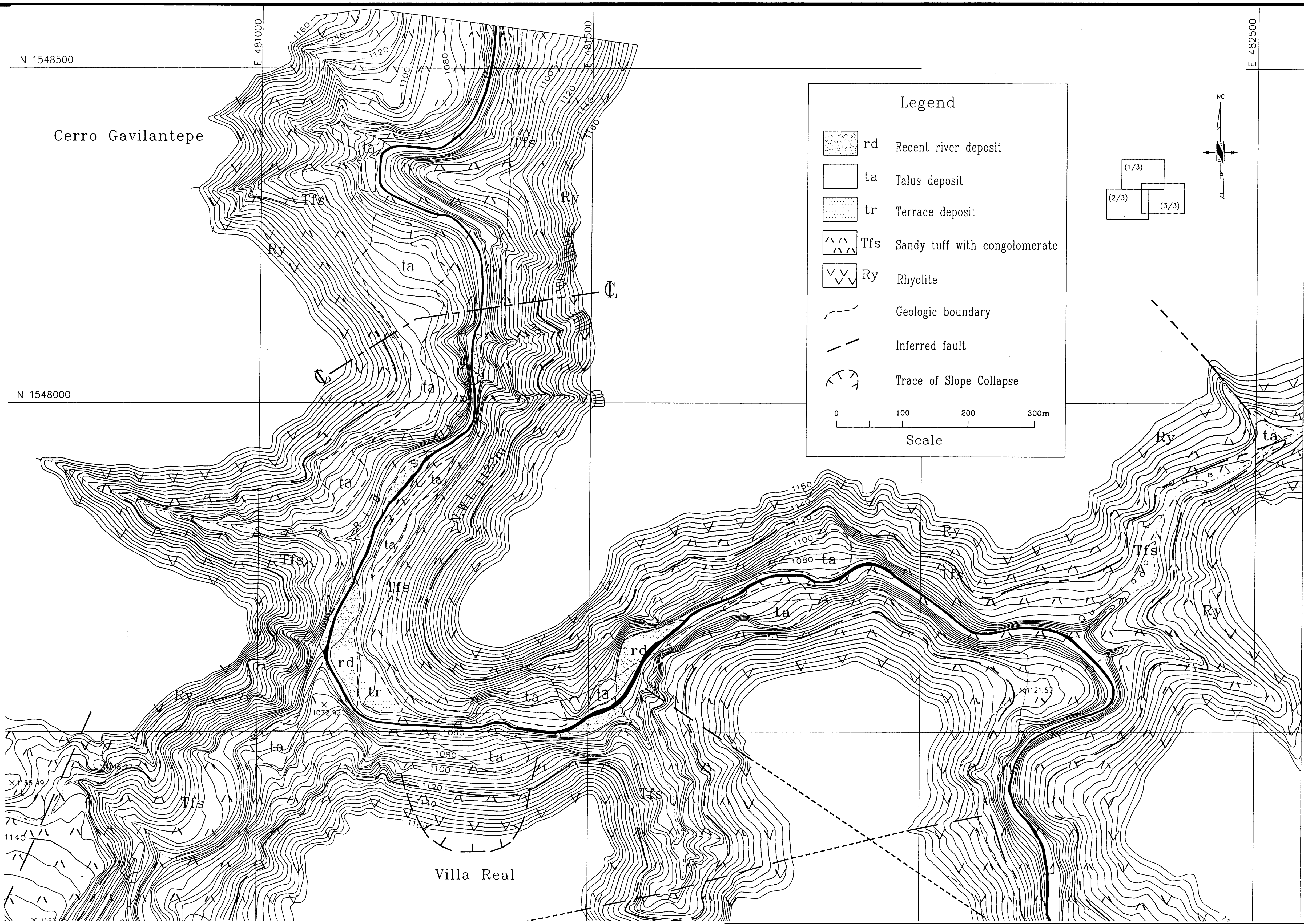


Figure A.3.10 (1/3)	Geological Map of the Los Laureles II Reservoir

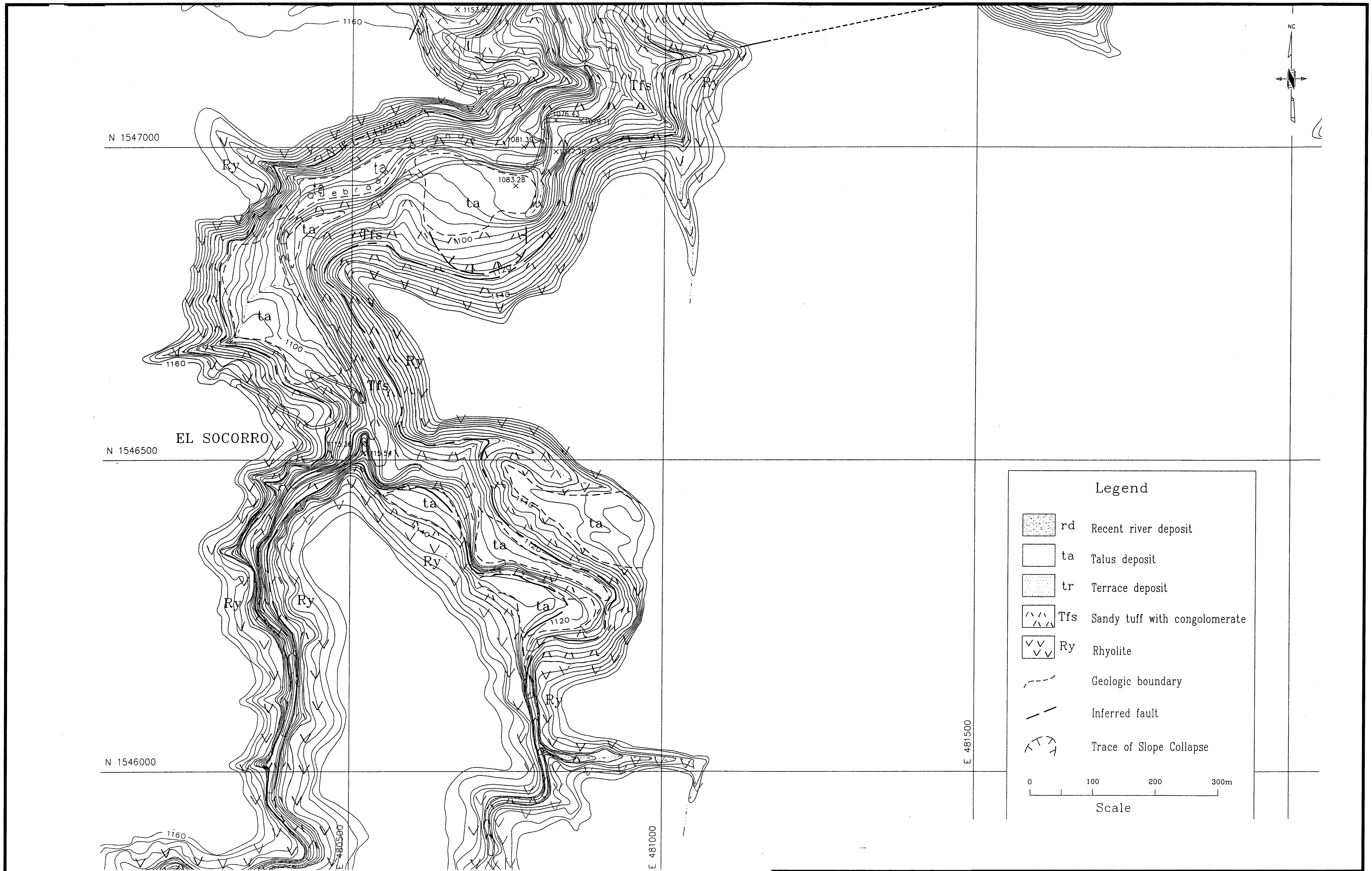


Figure A.3.10 (2/3) | **Geological Map of the Sabacuante Reservoir**

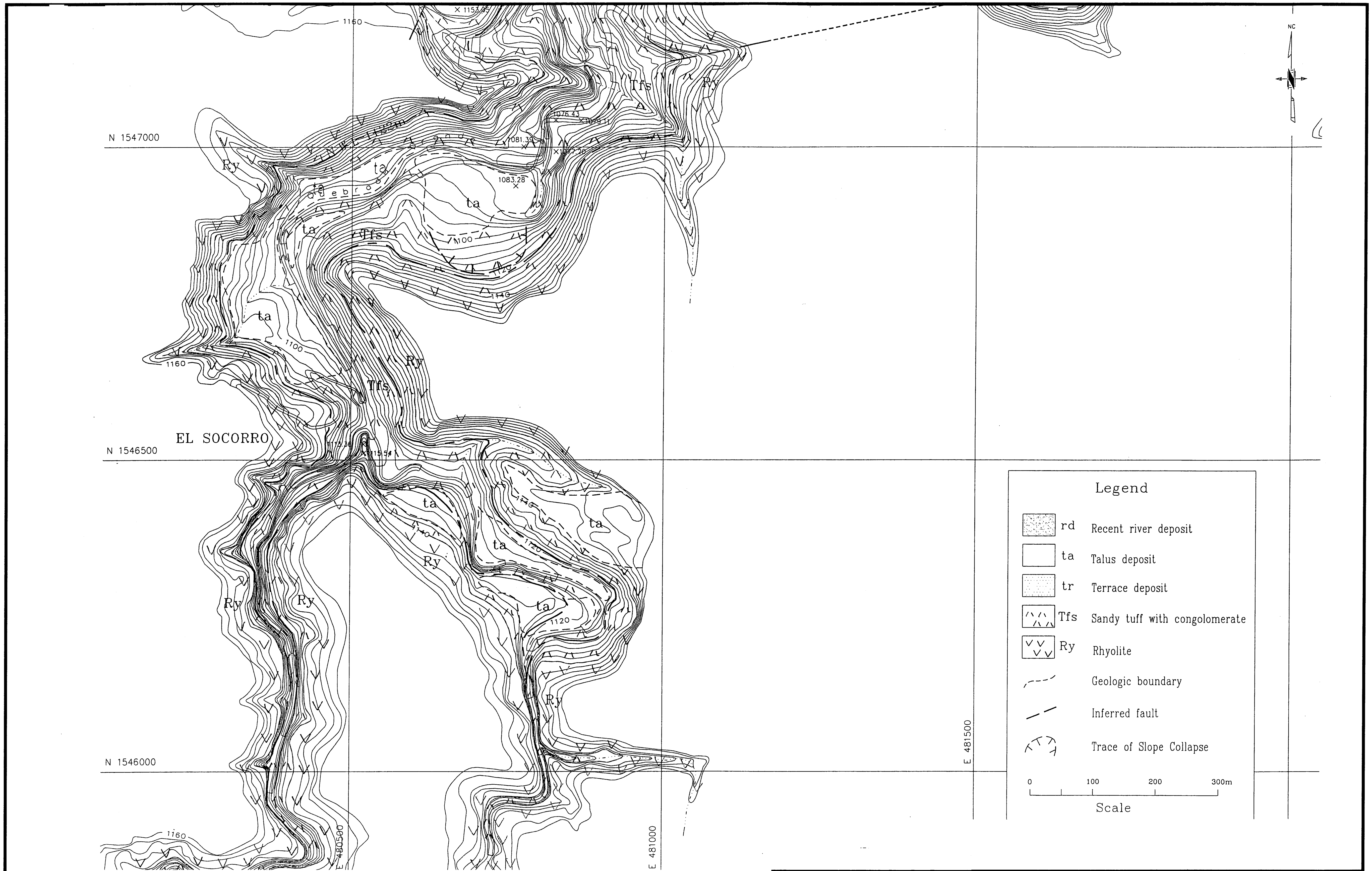


Figure A.3.10 (2/3) | Geological Map of the Sabacuante Reservoir

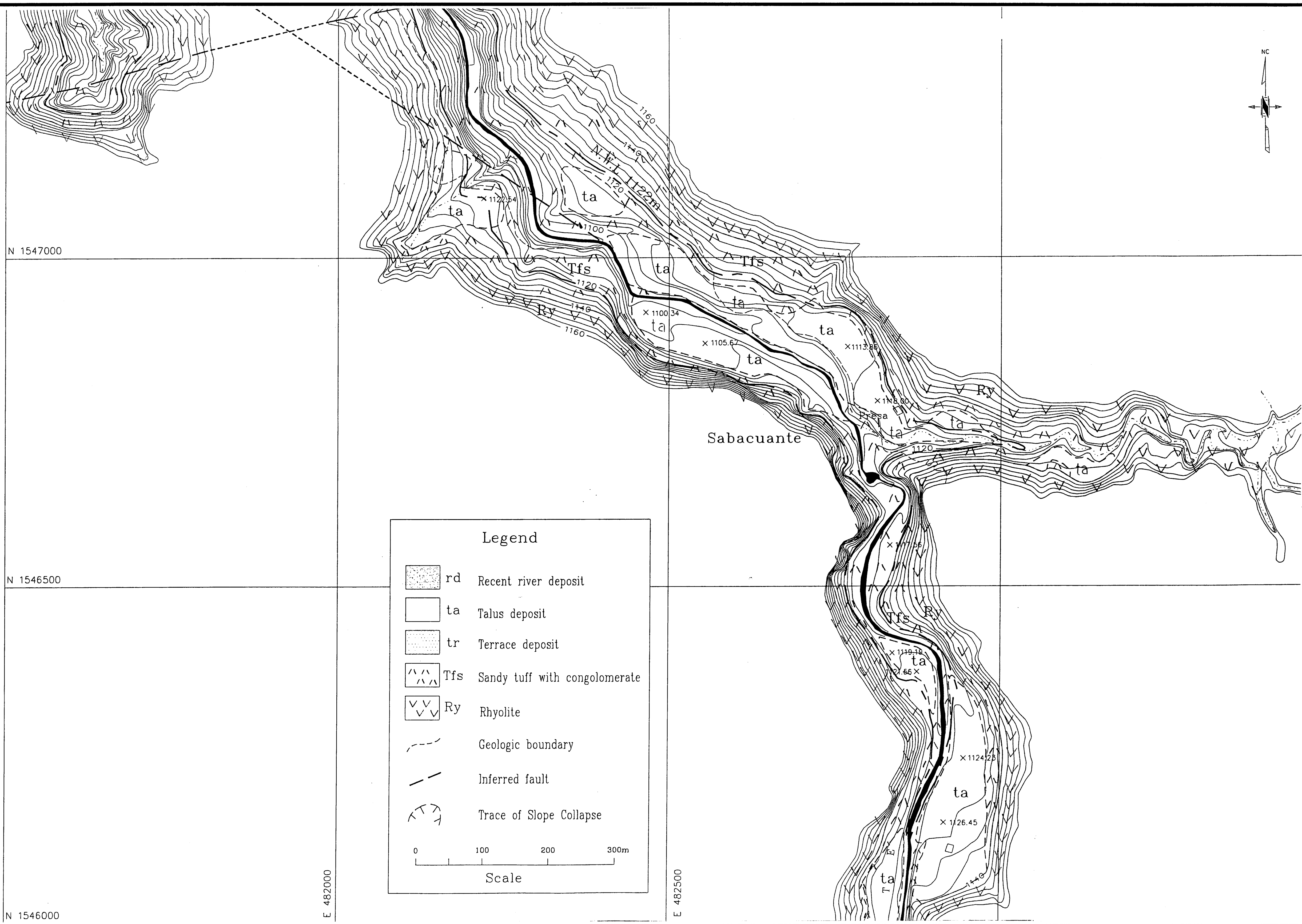


Figure A.3.10 (3/3)	Geological Map of the Sabacuante Reservoir

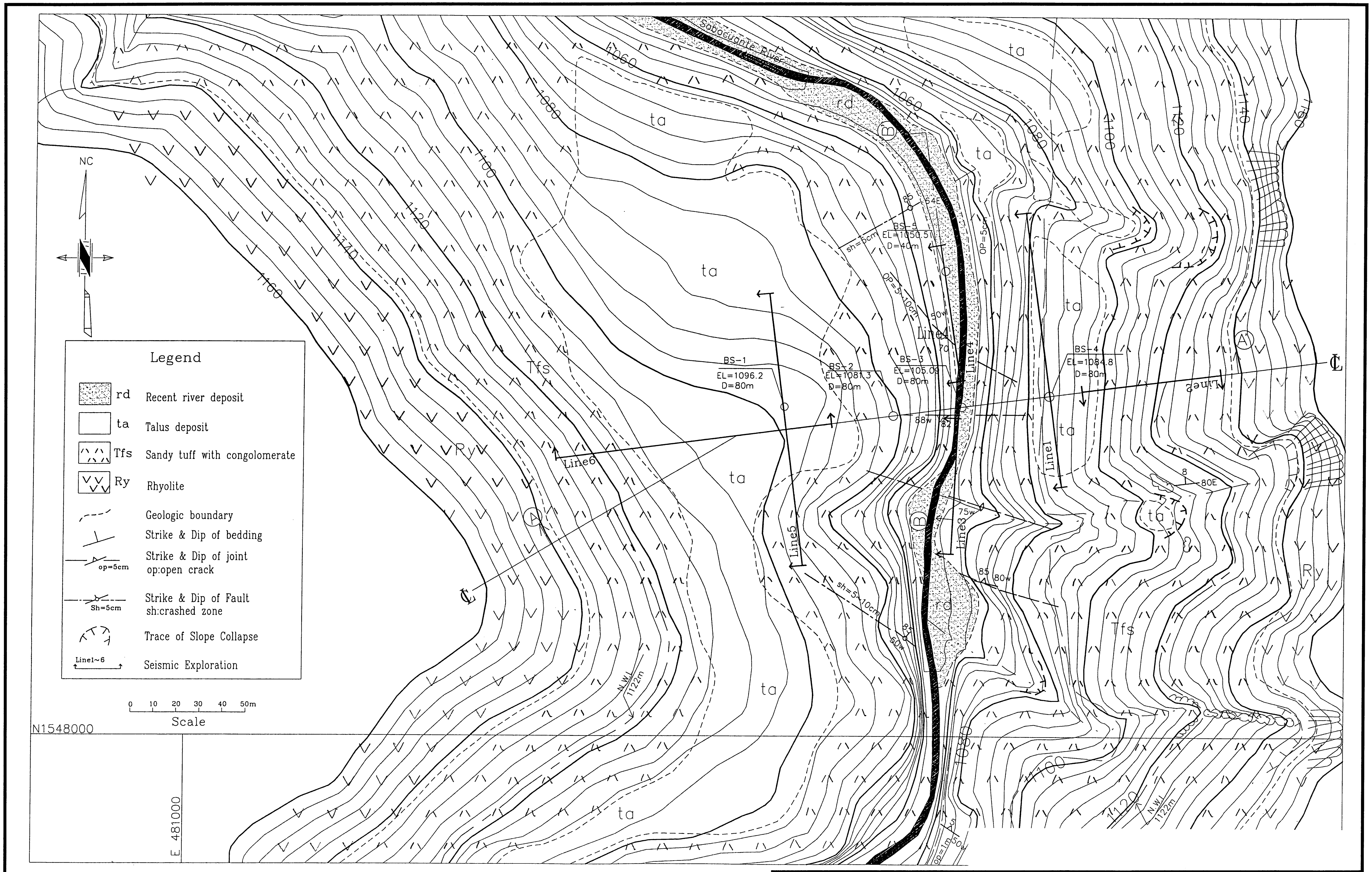


Figure A.3.11	Geological Map of the Sabacuante Dam

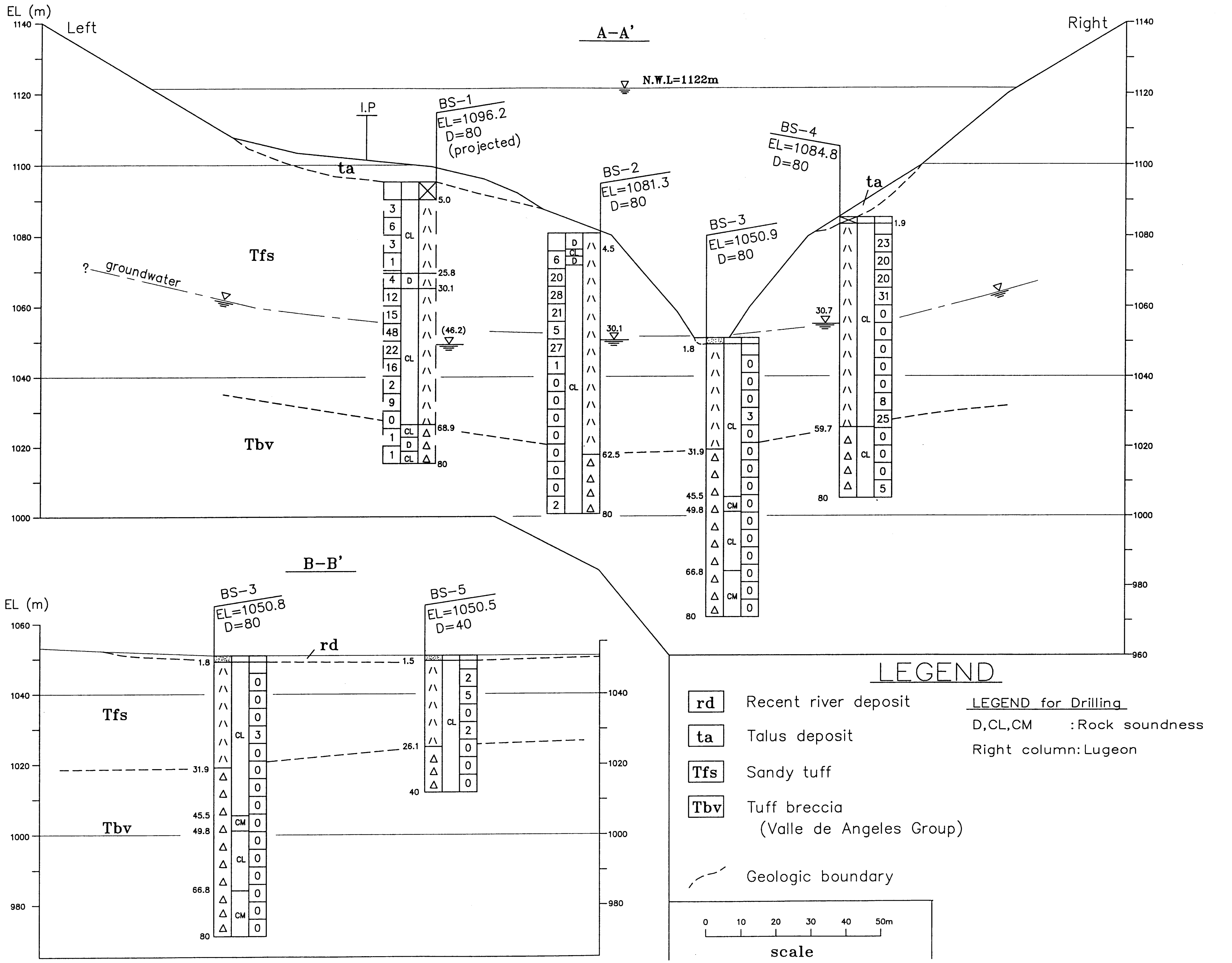


Figure A.3.12	Geological Section of the Sabacuante Dam Axis (A-A') and Profile (B-B')

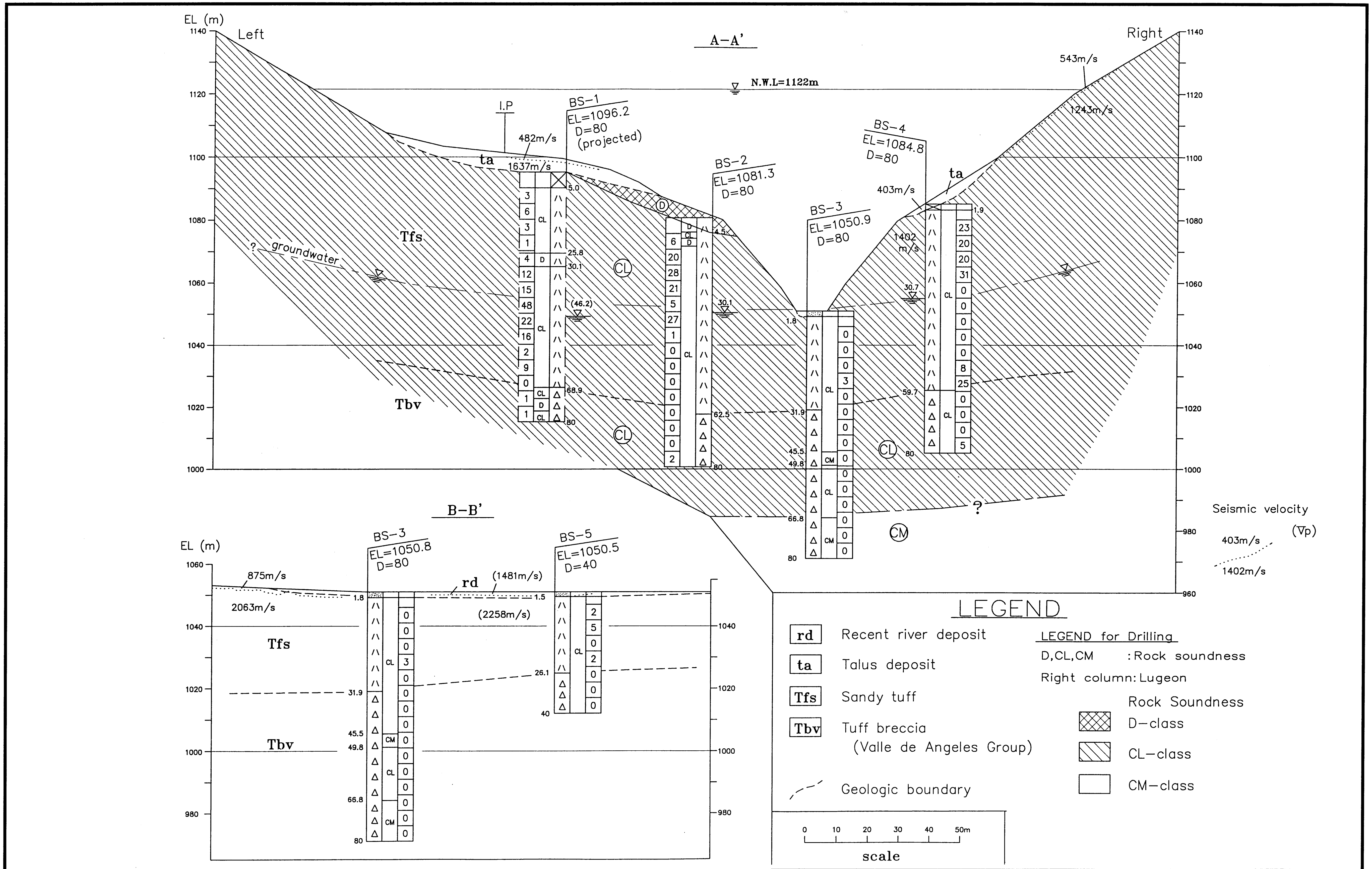


Figure A.3.13 Rock Soundness Classification map of the Sabacuante Dam Axis (A-A')

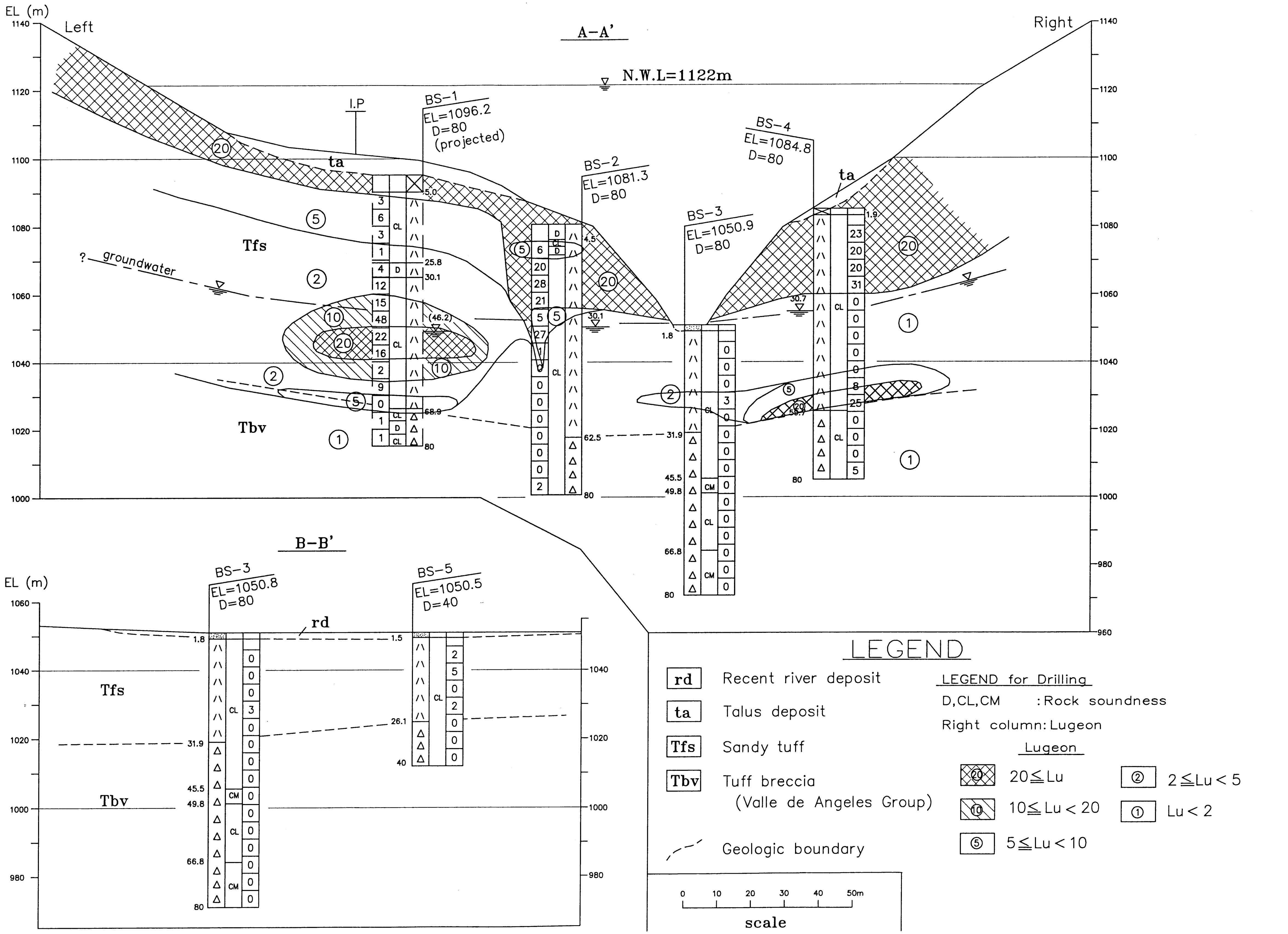


Figure A.3.14 | **Lugeon Map of the Sabacuante Dam Axis (A-A')**