THE STUDY
ON SUSTAINABLE GROUNDWATER DEVELOPMENT
FOR BOGOTA PLAIN
IN THE REPUBLIC OF COLOMBIA

FINAL REPORT
SUPPORTING REPORT

PART 4

DRILLING EXPLORATION

Final Report
(Supporting Report)

Part 4 Drilling Exploration
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PART - 4 DRILLING EXPLORATION

CHAPTER 1 Exploratory Drilling for Quaternary Formation

The Study Team carried out Quaternary exploratory drilling to know geological condition and to install groundwater level observation wells. The result of these drillings is summarized below.

(1) Location of Drilling

Location of six drilling is shown in Table-1.1 and Figure-1.1. In site selection, items below were examined. After intimate discussion with relating organizations, six sites were finally selected.

- To be suitable to know hydrogeological characteristics of Quaternary.
- To be suitable to know representative groundwater level of Quaternary.
- To be easy to get permission for drilling.

Table-1.1 Location of Quaternary Exploratory Drilling

Well No.		Coordinates	
		E	N
No.1	Gibraltar (Soacha)	988,439	1,005,845
No.2	Tisquesusa (Facatativa)	976,639	1,022,020
No.3	Siberia (Tabio)	991,462	1,017,974
No.4	Sopo (Sopo)	1,011,020	1,037,638
No.5	Diana	1,013,170	1,038,429
No.6	Choconta	1,049,874	1,067,343

(2) Well Structure

Total drilling depth of six wells is 1,022m, and average depth of each well is 200m. The final diameter of casing of six wells is 8 inch. After rotary drilling of wells, electrical logging and gamma logging were carried out to identify depth of aquifers. Screens were installed for location of aquifers, then pumping tests were carried out. Groundwater level recorders were installed for every well, which are protected by concrete boxes. After installation of the recorders, groundwater level is being automatically observed, it is scheduled to continue until the end of this Study. Six observation wells have multiple screen structure, which have screen for each sand and gravel aquifer distributing in clayey formation. Therefore, these wells show mixed groundwater level of different aquifers of Quaternary.

Result of Drilling

Result of drilling is shown in Table-1.2, and geologic columnar sections of wells are shown in Figure-1.2 to Figure-1.7. Pumping tests were carried out immediately after drilling completion. After pumping test of 48 hours pumping, recovery tests were carried out. For Gibraltar well, not pumping test but borehole permeability test was carried out because methane came out from ground water of wells.

Table-1.2 Result of Quaternary Exploration Drilling

	Well No. (Site)	No.1 (Gibraltar)	No.2 (Tisquesusa)	No.3 (Siberia)	No.4 (Sopo)	No.5 (Diana)	No.6 (Choconta)
	Well depth(m)	196	192	173	150	188	123
	Screen depth (GL-m)	73～75 85～121 132～136 149～152 163～166 (Total 48m)	117～120 128～146 152～158 162～186 (Total 51m)	80～92 95～119 124～127 134～137 143～155 (Total 54m)	25～47 57～65 (Total 30m)	41～53 73～82 96～105 126～132 144～147 (Total 39m)	41～60 65～73 120～144 154～175 (Total 72m)
	Casing Diameter	8 inch	8 inch	8 inch	8 inch	8 inch	8 inch
	Aquifer	Fine sand, sand and gravel (Sabana)	Fine sand (Sabana)	Fine sand (Sabana)	Sand and gravel (Sabana)	Fine sand, silty sand and gravel (Sabana)	Silty sand and gravel, silt (Tilata)
Pumping test	S.W.L[1)] (GL-m)	16.5	76.92	21.94	14.7	17.33	11.07
Pumping test	Yield (m^3/day)	-[4)]	317	432	605	586	533
Pumping test	Drawdown	-[4)]	6.43	16.69	5.37	6.99	3.89
Pumping test	D.W.L[2)] (GL-m)	- [4)]	83.35	38.63	20.07	24.32	14.96
Pumping test	Specific Capacity (m^3/day/m)	- [4)]	49	26	82	84	137
Pumping test	Transmissivity (m^2/day)	46	204	30	85	89	159
Pumping test	Conductivity (m/day)	0.96	4.0	0.56	2.8	2.3	2.2
Pumping test	Storativity	- [3)]	1.38×10^{-18}	6.82×10^{-2}	- [5)]	1.27×10^{-2}	7.61×10^{-2}

Note 1) S.W.L. :Static water level
2) D.G.L :Dynamic water level
3) Conductivity and storativity were analyzed by Jacob method and recovery method.
4) For Gibraltar well, not pumping test but borehole permeability test was carried out. Therefore, D.W.L, specific capacity, storativity are not calculated.
5) Storativity was not calculated for Sopo well, because drawdown was irregular during pumping test.

Geological condition

Geological columnar sections are shown for each well in Figure-1.2 to Figure-1.7. Five wells were drilled in Sabana Formation of Quaternary. The remaining one well of Choconta site were drilled in Tilata Formation of Quaternary. Sabana Formation is representative formation of Quaternary, which occupies upper half of Quaternary of the Study Area and distributes most of Bogotá Plain. Current pumping by flower companies is mainly from Sabana Formation. On the other hand, Tilata Formation occupies lower half of Quaternary of the Study Area, of which distribution is limited and still not fully known. As shown in Figure-1.2 to Figure-1.7, silty and clayey layers are dominant in Sabana Formation. In Sabana Formation, sand and gravel layers distribute separately in different depth. This situation corresponds to geological history of Bogotá Plain: Quaternary of Bogotá Plain consists of mainly lake deposits (clay and silt), among which several river sediments (sand and gravel) of different age distribute. Thickness of sand and gravel layers of the drilling points of the Study is 1m to 30m. This thickness is considered to be enough to provide sufficient groundwater to flower companies. These sand and gravel aquifers seem current main aquifers for wells of flower companies.

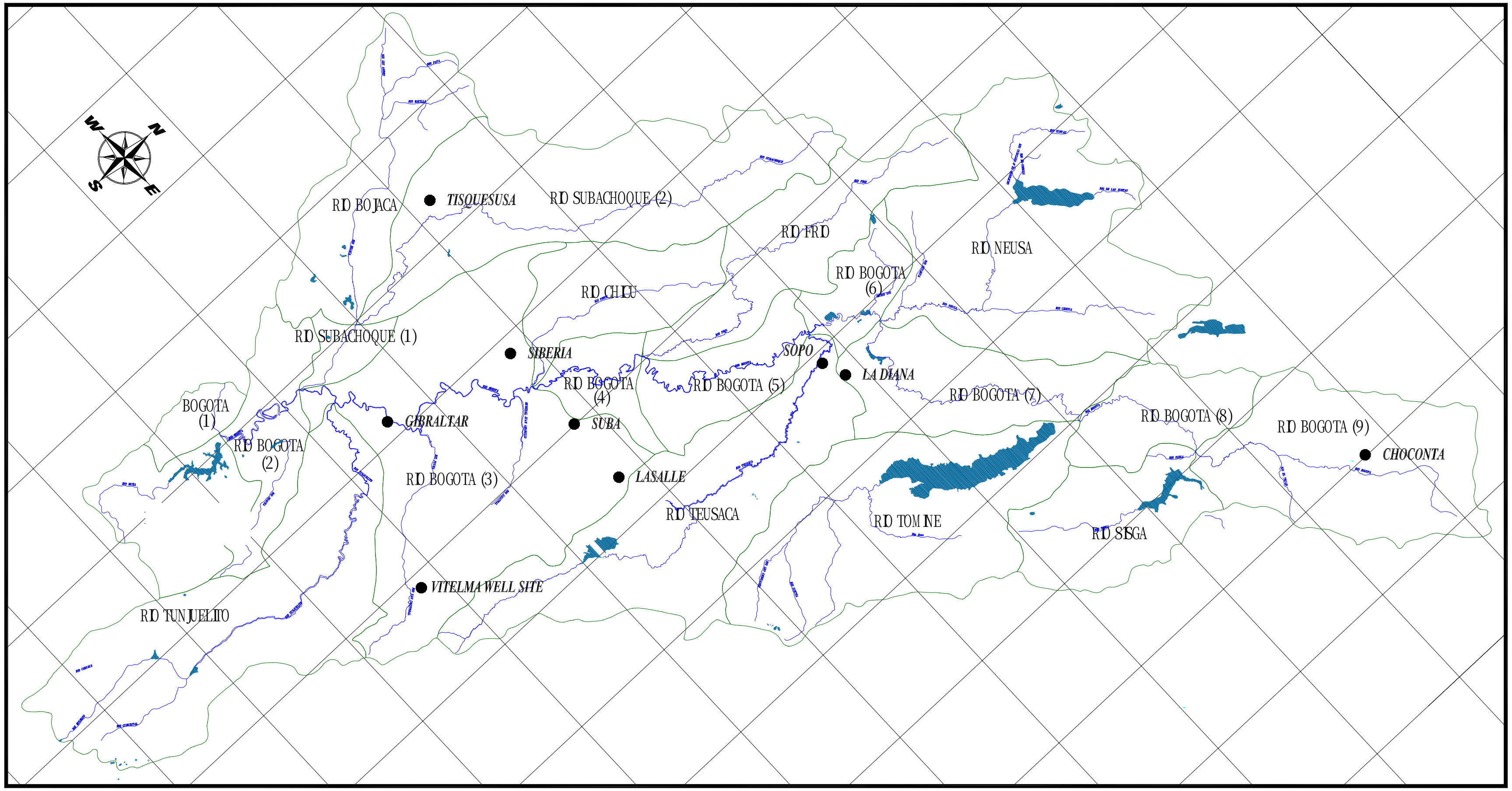


Figure-1.1 Sites of Exploratory Drilling of Quaternary and Cretaceous

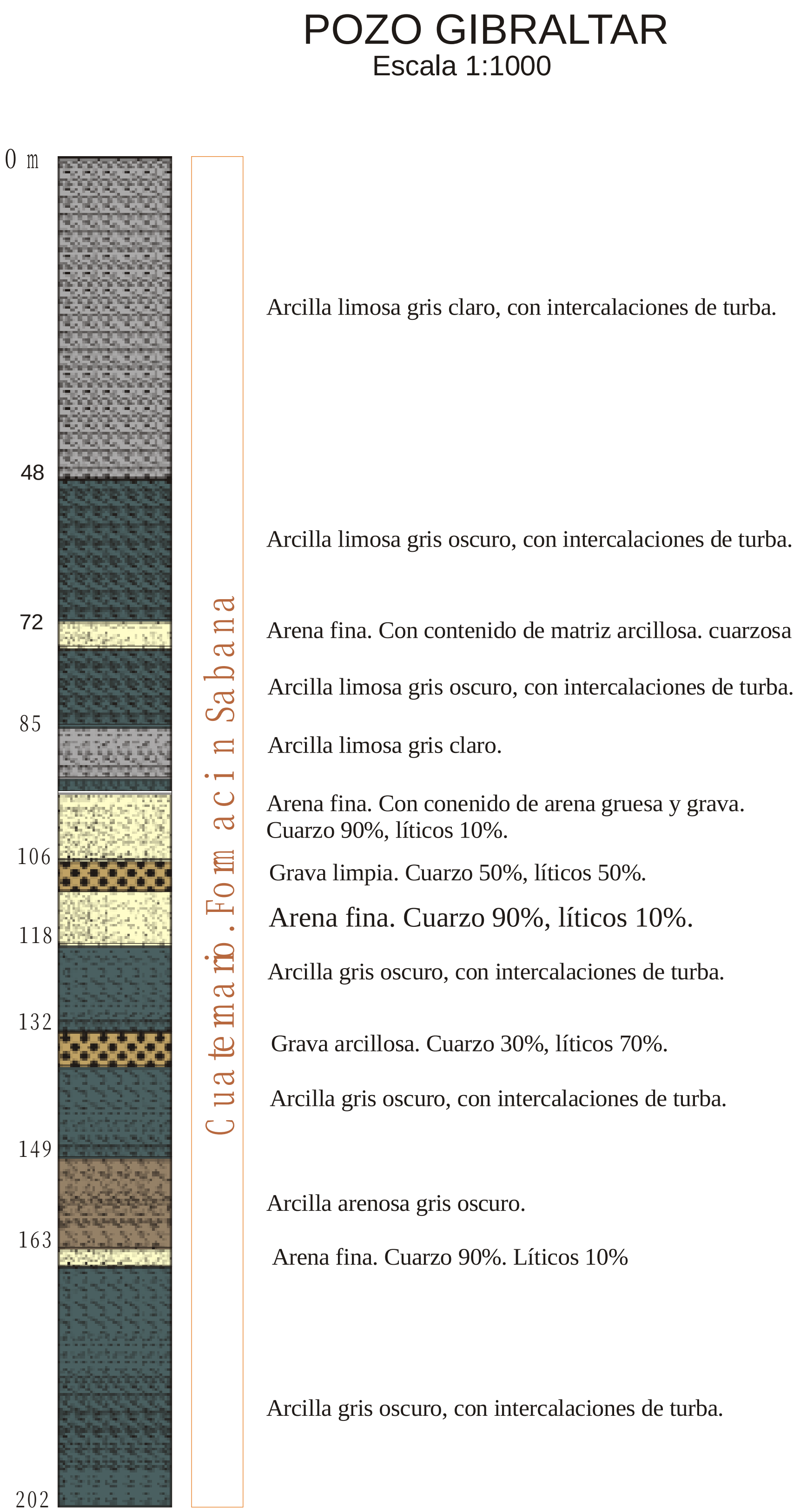


Figure-1.2 Geological Columnar of Quaternary Drilling (No.1 Gibraltar)

POZO TISQUESUSA
Escala 1:1000

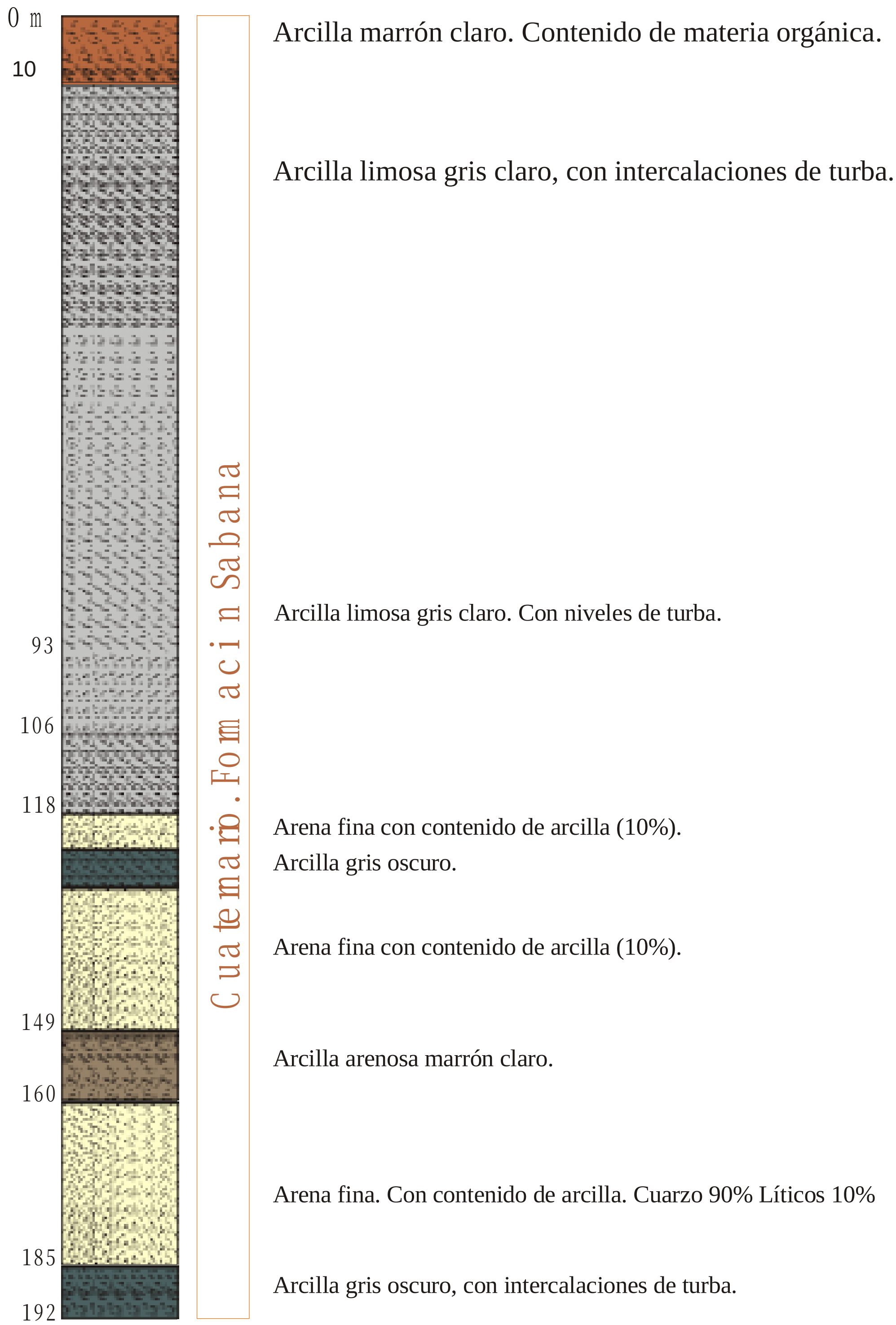


Figure-1.3 Geological Columnar of Quaternary Drilling (No.2 Tisquesusa)

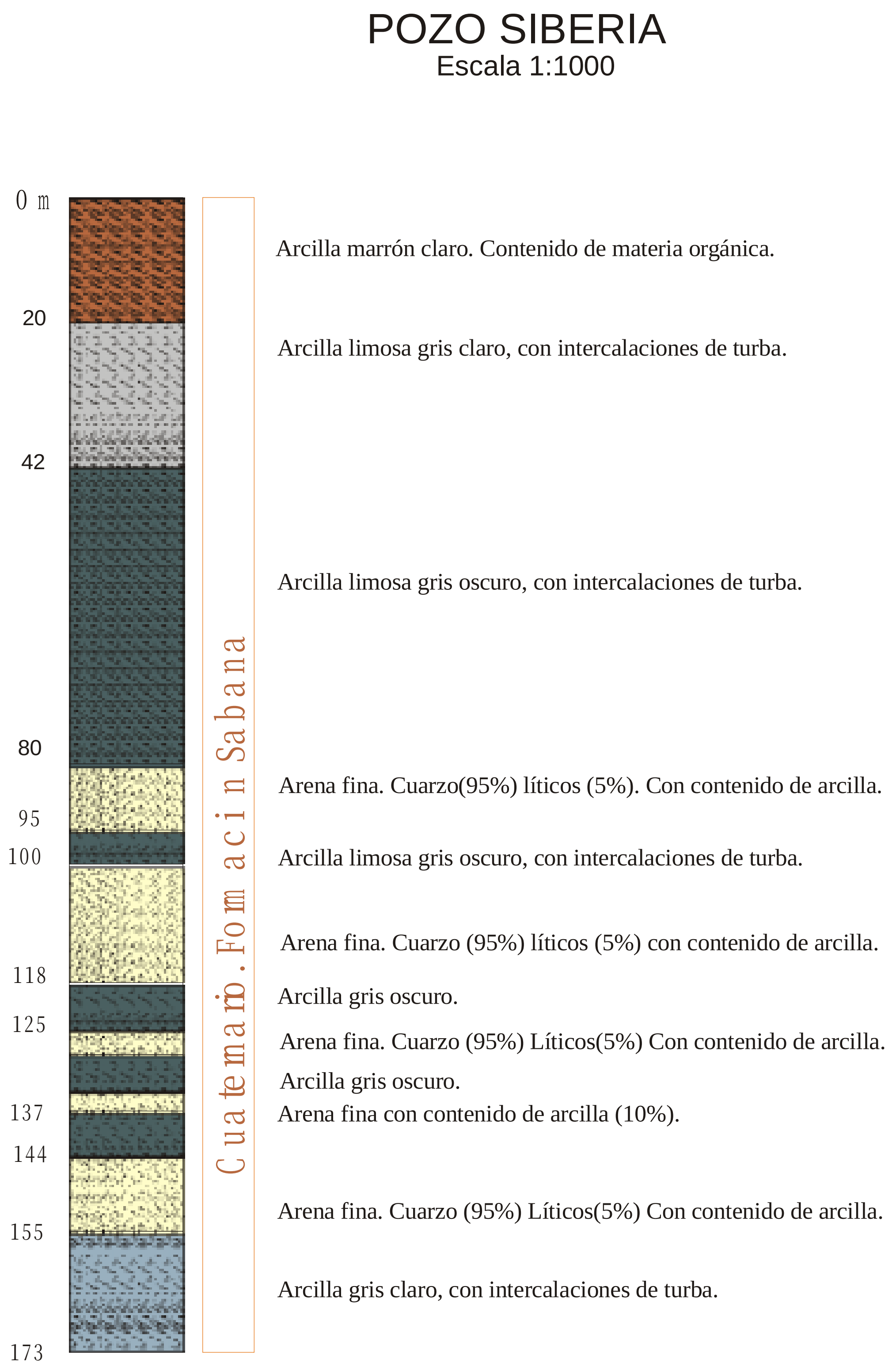


Figure-1.4 Geological Columnar of Quaternary Drilling （No.3 Siberia）

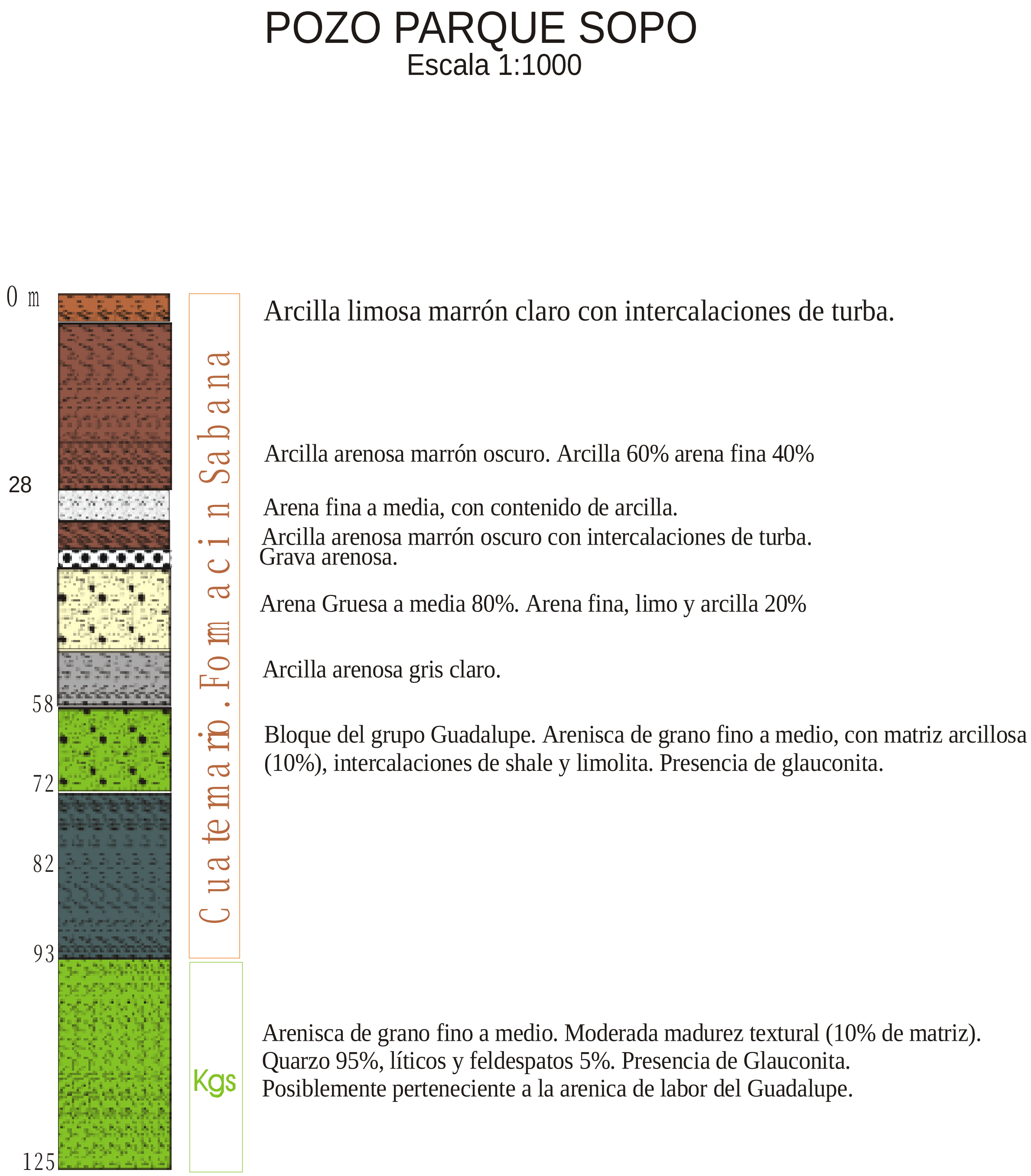


Figure-1.5 Geological Columnar of Quaternary Drilling （No.4 Sopo）

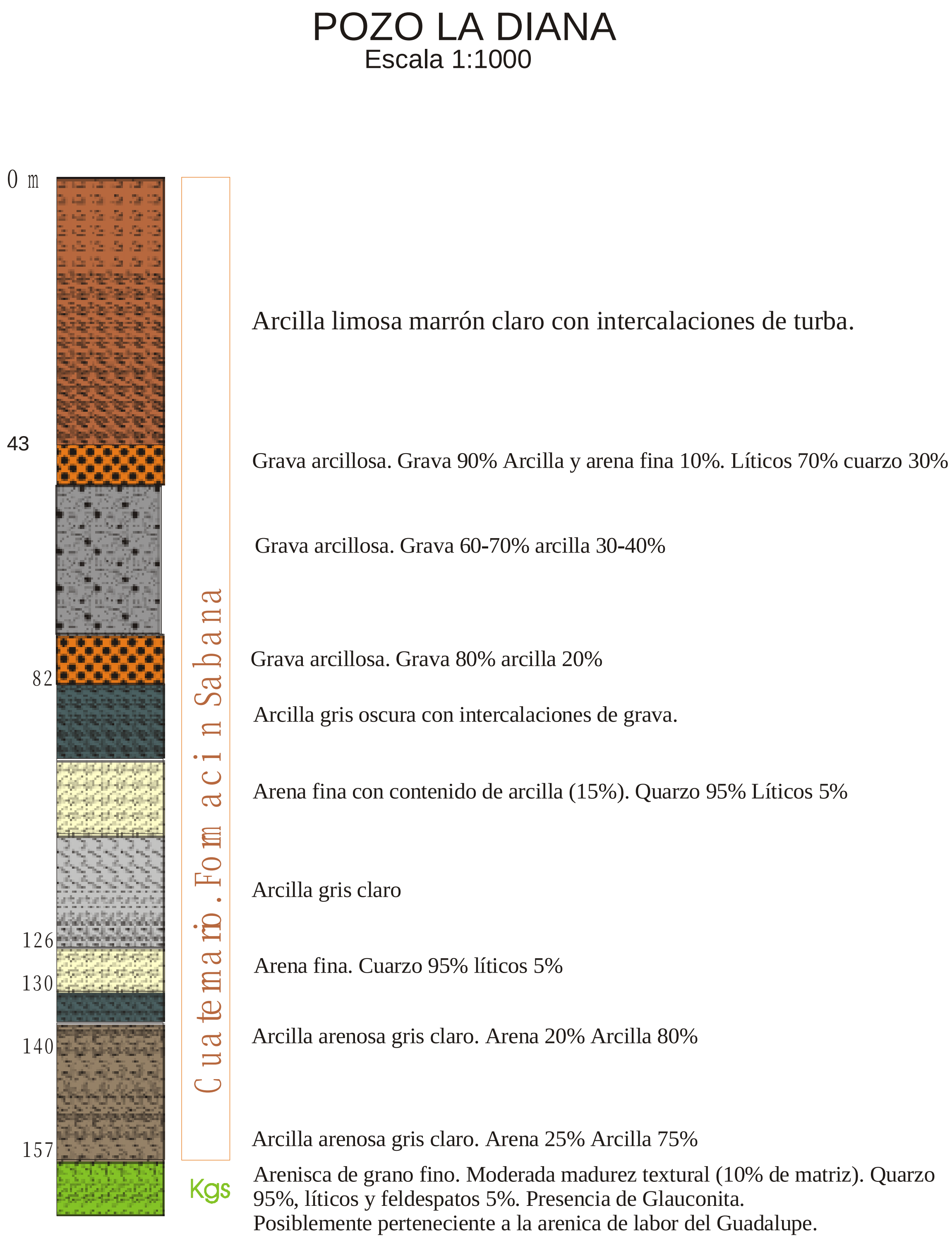


Figure-1.6 Geological Columnar of Quaternary Drilling (No.5 Diana)

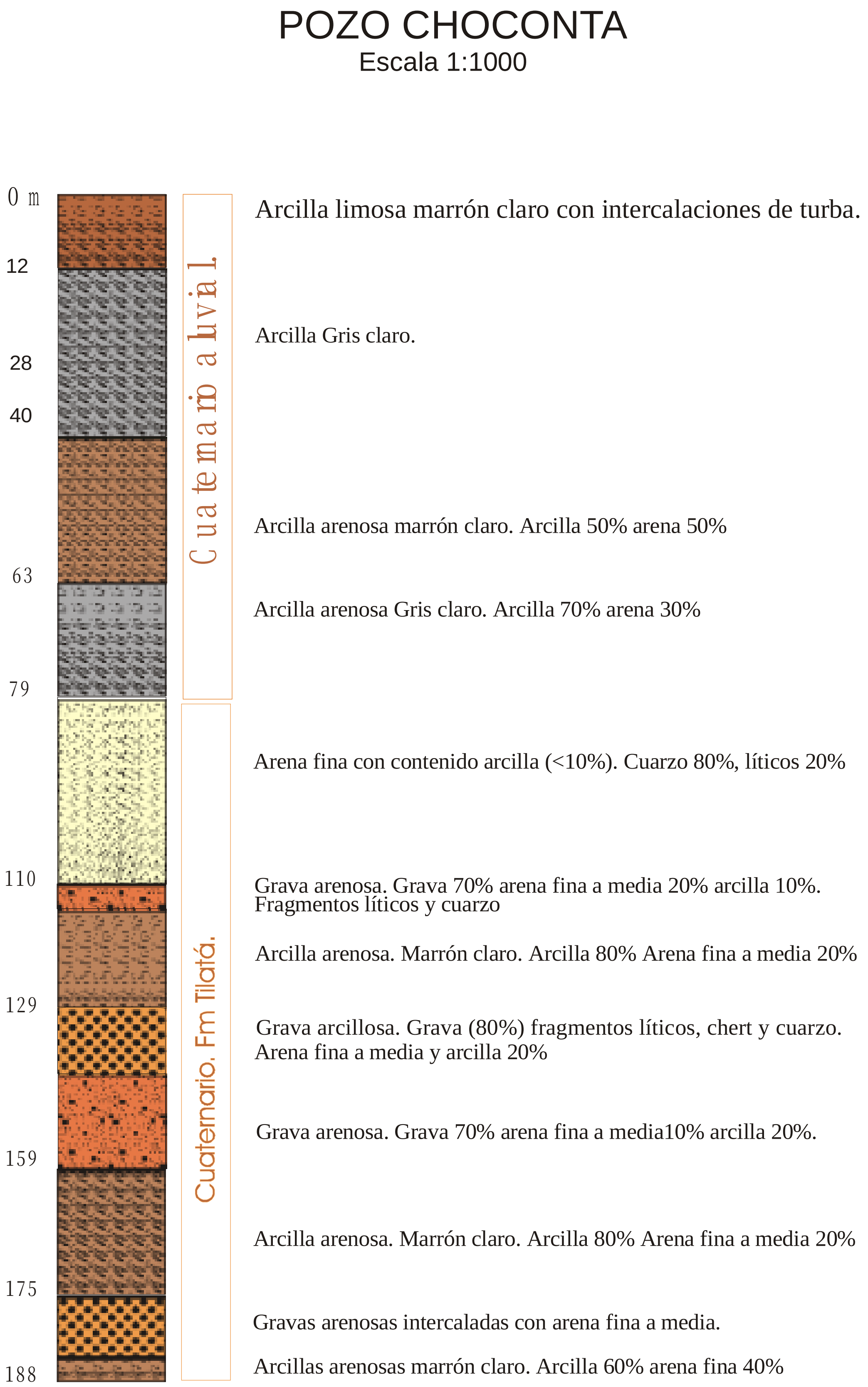


Figure-1.7 Geological Columnar of Quaternary Drilling （No.6 Choconta）

Groundwater level

Groundwater level of drilled six wells is from GL-16m to GL-22m, corresponding to general groundwater level of Quaternary aquifer in Bogotá Plain. On the other hand, groundwater level of Tisquesusa well is GL-76.92m, which is much deeper than the other wells. There are many wells concentrated in this area. Currently it is said that groundwater level of this area is deeper than the other area. The drilling result proved this situation.

Specific yield of wells

Specific yield of drilled six wells is $26m^3$～$84m^3$/day/m, and its average is 60 m^3/day/m. Therefore, 1m drawdown by pumping produces yield of $60m^3$/day, and 10m drawdown by pumping produces yield of 600 m^3/s/day. This value is not small, and it means that huge amount of wells drilled by flower companies take huge amount of groundwater from Sabana Formation.

Conductivity

Conductivity of six wells of Quaternary is 0.96～4.0m/day (1.1×10^{-3}～4.6×10^{-3}cm/s), and its average is 2.1m/day (2.4×10^{-3}cm/s). It seems reasonable value because aquifers consist of fine sand, and conductivity of aquifers is concluded favorable. On the other hand, average conductivity of Quaternary calculated for the total well length is 2.0×10^{-4}～1.5×10^{-3} cm/s, and its average is 7.3×10^{-4} cm/s. Conductivity may be said not high but not low for entire Quaternary in the drilling sites.

Storativity

Storativity of drilled six wells shows 10^{-2} order. This value is a little higher than existing result. On the other hand, Tisquesusa well shows extremely low Storativity of 10^{-18}. Generally, calculated storativity has low accuracy than calculated transmissivity. In addition to this, pumping test by the Study did not have observation wells. These effects should be considered in evaluation of resultant storativity. Generally, storativity of unconfined aquifer is nearly the same as effective porosity of aquifer. Storativity becomes smaller as aquifer becomes more confined. From the analyzed storativity, sand and gravel aquifer of Quaternary in the Study Area seems to be between confined and unconfined condition. Sand and gravel aquifers are confined by overlying and underlying low- permeable layers, but not completely confined. Groundwater of sand and gravel layers has connection of vertical flow though intermediate low permeable layers. It means that deep aquifer has connection with shallow aquifer of near ground surface.

Characteristics of Quaternary Aquifer

According to result of exploratory drilling, Sabana and Tilata Formation consist of mainly clayey sediments, and sand and gravel layers are not so many. Only sand and gravel layers become aquifers in Quaternary, which distribute separately in different depth between thick and low-permeable layers. In drilling sites, sand and gravel aquifers are at most 30m in thickness. Thicker aquifers have high continuity to horizontal side, but thinner aquifers have low continuity and soon disappear. As the results of drilling exploration of Quaternary, it is concluded: Quaternary aquifer consists of sand and gravel layers, which distribute irregularly in different depth and places. These permeable sand and gravel layers and low-permeable silty and clayey layers form "one" Quaternary aquifer system as a whole. Within this system, groundwater of sand and gravel layers has connection of vertical flow though intermediate low-permeable layers.

CHAPTER 2 Exploratory Drilling for Cretaceous Formation

EAAB carried out four of Cretaceous Exploratory Drilling during this Study. The result of the drilling is summarized below.

(1) Location of Drilling

Drilling sites of five wells are sown in Figure-1.1. No.1 well is located in the foot of Eastern Hills where groundwater is recharge to Cretaceous Formation. No.2 well is located near Suba Hill. La Salle well and Suba well are arranged on the assumed fault line. No.3 and No.4 wells are located in Vitelma Intake Site of EAAB in the Eastern Hills. No3 well is for artificial recharge and No.4 is for observation. No. 5 corresponds to Mariscal Sucre drilled in the plain side near Suba well.

(2) Well Structure

Drilling depth of La Salle well is 270m, Suba well is 389m, Vitelma recharge well is 300m and Vitelma observation well is 280m and Mariscal Sucre well is 304 m. Final casing diameter is 8 inch for both wells. After rotary drilling, electrical-logging and gamma-logging were carried out to identify the location of aquifer for screen installation. Location of screen installation was decided after consideration of items below.

- Layers with extremely low and high electric resistivity are not aquifer. Layers with resistivity of around 500Ωm seem aquifer.
- Layers with low density by gamma logging seem aquifer.
- layers where groundwater spring into well or drilling water flow away from the wells seems aquifer.

After installation of screen, pumping test was carried out for the five wells. Then automatic groundwater level recorder was installed with protection box for Suba well. Groundwater level observation is now on going and continues till the end of this Study. The five wells have screens separately in different depth of Cretaceous Guadalupe Formation.

(3) Drilling Result

Result of two drilling is shown in Table-2.1, and geological columnar sections are shown in Figure-2.1 to Figure-2.2.

Table-2.1 Result of Cretaceous Exploratory Drilling (1)

		No.1 (La Salle)		No.2 (Suba)		No.3 (Mariscal Sucre)	
Well No. (Site)		No.1 (La Salle)		No.2 (Suba)		No.3 (Mariscal Sucre)	
Coordinate of Wells		E:1,006,063/N:1,017,517		E:999,911/N:1,017,839		E: 999. 214/N: 1.019.352	
Well depth(m)		270		389		304m	
Screen depth (GL-m)		60～65、69～75、82～85、87～90、97～106、113～119、134～140、148～151、153～156、172～175、179～188、195～198、202～205、221～224、229～238、248～254、258～261 (Total 84m)		145～148、150～159、166～175、190～199、213～222、228～234、240～246、258～267、283～286、322～325、329～335、341～344、349～355、377～380 (Total 84m)		124, 136, 164, 195, 200, 215, 220, 240, 264, 284, 288,	
Casing Diameter		8 inch		8 inch		8 – 6 inch	
Aquifer		Sandstone and shale		－23.92m		Sandstone	
Pumping Test	S.W.L 1) (GL-m)	+1.75m		-23.92		20.09	
	Yield (m3/day)	1,944		1,987		4,320	
	Drawdown	35.01		5.07		3.91	
	D.W.L 2) (GL-m)	33.26		18.85		24	
	Specific Capacity (m^3/day/m)	56		392		1,104	
	Transmissivity (m^2/day)	160-192		651		1,729	
	Conductivity (m/day)	1.9-2.3 (0.59～0.71)		7.8 (1.67)		-	
	Storativity	1.44×10^{-11}		1.53×10^{-4}		2.3×10-3	
step Down	1 step yield / drawdown	636 m^3/day	4.18m	758 m^3/day	0.87m	1,520 m^3/day	0.88m
	2 step yield / drawdown	968 m^3/day	8.33m	1,165 m^3/day	1.73m	1,763 m^3/day	1.06m
	3 step yield / drawdown	1,158 m^3/day	11.10m	1,486 m^3/day	2.60m	2,065 m^3/day	1.28m
	4 step yield / drawdown	1,495 m^3/day	18.40m	1,970 m^3/day	4.39m	-	-
	5 step yield / drawdown	1,944 m^3/day	35.01m	-	-	-	-

Note 1) Conductivity and storativity were analyzed by Jacob method and recovery method
2) Two types of conductivity are shown. The first one is (Transmissivity / total screen length), and second one is (Transmissivity / total well length).

Table-2.2 Result of Cretaceous Exploratory Drilling (2)

Well No. (Site)	No.4 (Vitelma Recharge well)	No.5 (Vitelma obsevation well)
Coordinateso f Wells		
Well depth(m)	300 m	240 m
Screen depth (GL-m)	60～63、73～82、87～96、100～106、114～129、133～136、139～154、167～176、208～211、216～219、252～258、262～265、281～287 (Total length 90m)	113～140、148～151、173～179、199～202、205～208、216～222、233～236 (Total length 72m)
Casing Diameter	8 inch	4 inch
Aquifer	Sandstone, shale	Sandstone, shale
＜Pumping Test＞		
S.W.L (GL-m)	-6.63m	－6.84m
Yield (m3/day)	1,296	-
Drawdown	18.84	12.03
D.W.L (GL-m)	25.47	18.87
Specific Capacity (m^3/day/m)	69	-
Transmissivity (m^2/day)	62-	60
Conductivity (m/day)	0.70 (0.21)	0.68 (0.21)
Storativity	3.4×10^{-4}	3.4×10^{-4}

Note 1) Conductivity and storativity were analyzed by Jacob method and recovery method
2) Two types of conductivity are shown. The first one is (Transmissivity / total screen length), and second one is (Transmissivity / total well length).
3) S.W.L. of No.4 well is from ground level of No4 well.

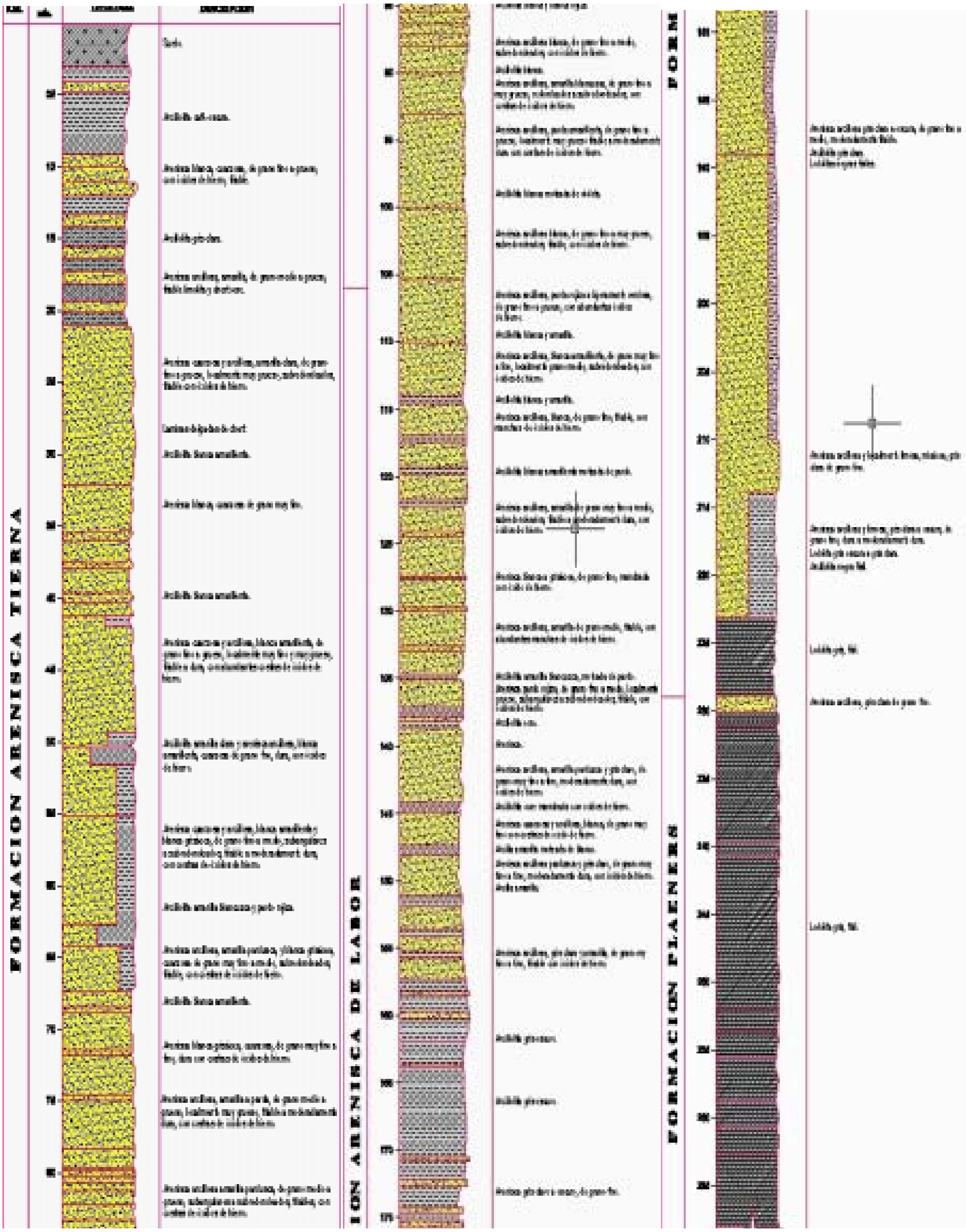


Figure-2.1 Geological Columnar of La Salle Well

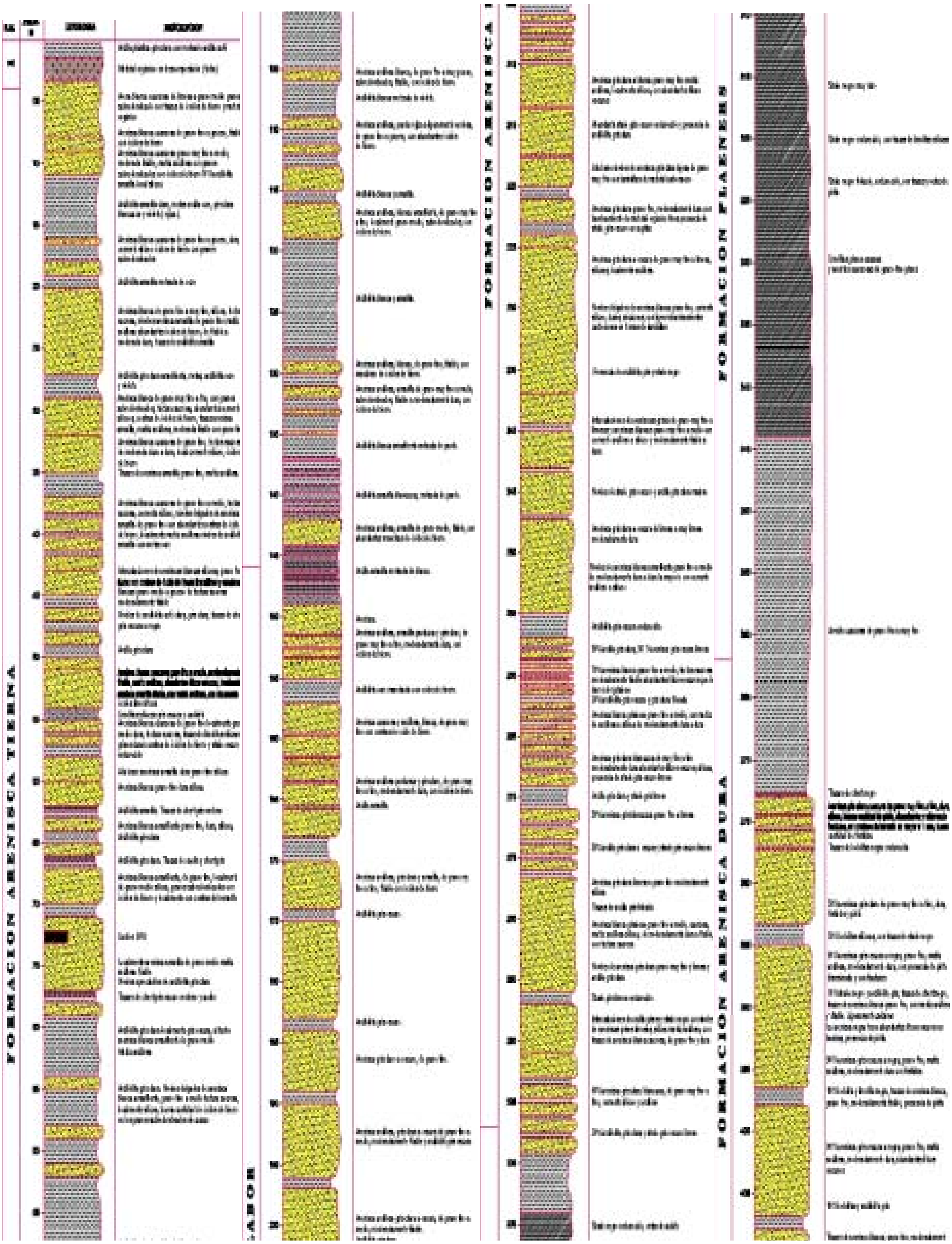
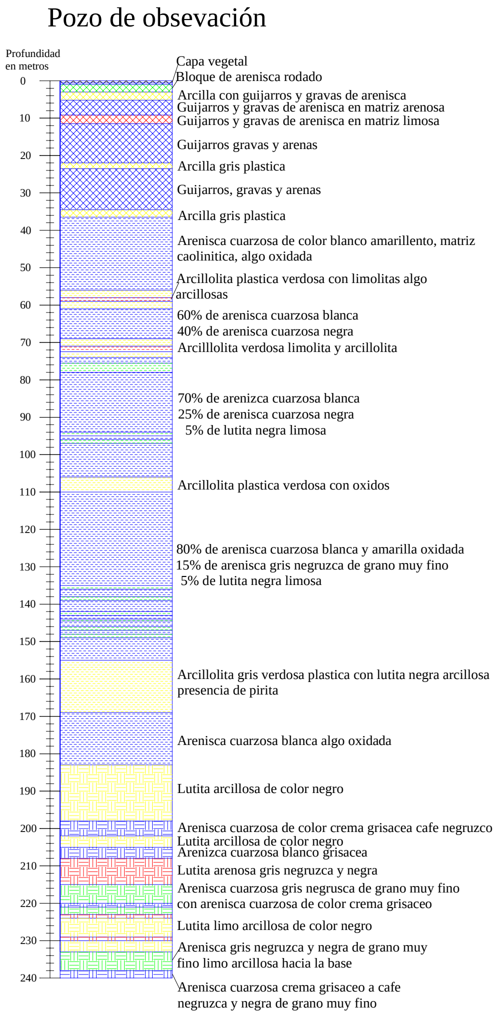
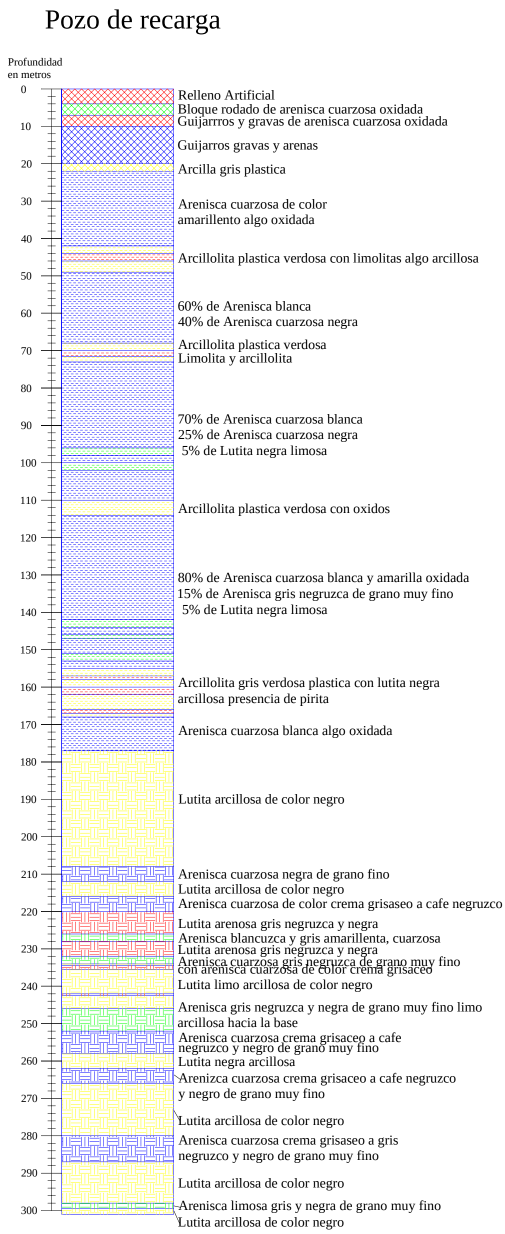


Figure-2.2 Geological Columnar of of Suba Well

Vitelma



(a) Monitoring Well



(a) Recharge Well

Figure-2.3 Geological Columnar of Vitelma Well

<u>Geological condition</u>

Geological columnar of La Salle, Suba and Vitelma wells is shown in Figure-2.1 and Figure-2.2, and geological condition is summarized in Table-2.3.

Table-2.3 Geological condition of Cretaceous Well

Well	Geology	Depth (m)	Rock face
La Salle	Colluvial deposit	0-11	Sand, silt, clay
	Tierna Formation	11-100	Sandstone dominant alternation of sandstone and shale
	Labor Formation	100-223	Sandstone dominant alternation of sandstone and shale
	Plaeners Formation	223-268	Shale, partly sandstone
Suba	Colluvial deposit	0-8	Sand, silt, clay
	Tierna Formation	8-77	Sandstone dominant alternation of sandstone and shale
	Labor Formation	77-300	Sandstone dominant alternation of sandstone and shale
	Plaeners Formation	300-365	Shale, partly sandstone
	Dura Formation	365-411	Sandstone dominant alternation of sandstone and shale
Vitelma (recharge well)	Colluvial deposit	0-22	Gravel, sand, silt
	Labor and Tierna Formation	22-180	Sandstone dominant alternation of sandstone and shale
	Chipaque Formation	180-300	Shale, partly sandstone
Vitelma (monitori ng well)	Colluvial deposit	0-36	Gravel, sand, silt
	Labor and Tierna Formation	36-188	Sandstone dominant alternation of sandstone and shale
	Chipaque Formation	288-240	Shale, partly sandstone
Mariscal Sucre	Colluvial deposits	0-48	Soil clay, organic deposits, silt.
	Tierna Formation	48-140	Sandstone white, fine and sorted grain size.
	Labor Formation	140-310	Sandstone gray, and black shale.
	Plaeners Formation	310-427	Silt and sand cracked shale, quartz of fine grain.
	Dura Formation	427-454	Sand fine grain, pyrite and shale.

<u>Groundwater Level</u>

< **La Salle Well** >

La Salle well is flowing well. Groundwater level of La Salle well is 1.75m from the ground surface at the time of pumping test. During drilling work, groundwater sprung into well at the depth of 185m, and this caused La Salle well to be flowing well. Groundwater level of La Salle well in December 2001 is almost the same as the groundwater level of the time of the pumping test.

< **Suba Well** >

Groundwater level of Suba well was GL-23.92m at the time of pumping test. During drilling work, drilling water flowed away from well at the depth of 147m. Existence of big fracture is expected at this depth.

<Mariscal Sucre Well>

Groundwater level of this well was 20.09 m, even though the well is relatively near to Suba Well this is towards the flat terrain, no water loss was registered during the drilling work. Therefore the well is far apart from the fractured zone,.

<Vitelma Wells>

Distance between Recharge Well and Observation Well in Vitelma is 122m, and the groundwater level of both wells is almost the same.

Specific capacity of well

Specific capacity is 56m^2/day in La Salle well, 392m^2/day in Suba well and 69 m^2/day in Vitelma well. Three wells show very high specific capacities. It proves that Guadalupe Group of the drilling sites has high aquifer capacity.

Permeability

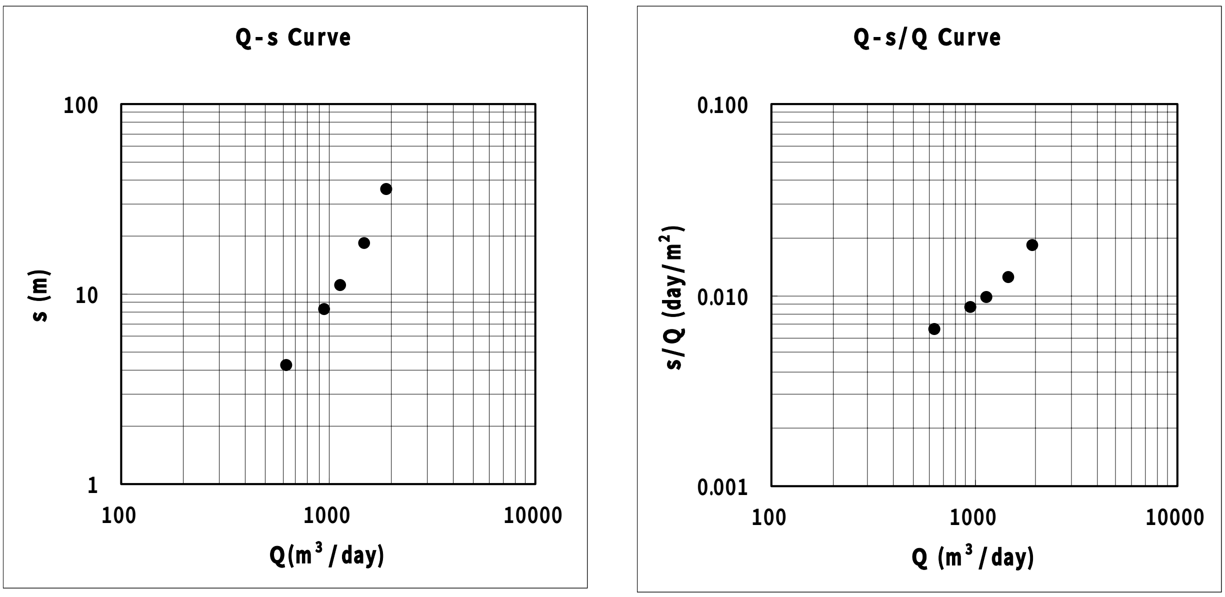
Permeability coefficient of screen part is 1.9 - 2.3m/day（2.2×10^{-3} - 2.7×10^{-3}cm/s） in La Salle well, 7.8m/day(9.0×10^{-3}cm/s)in Suba well, and 0.70m/day (8.1×10^{-4}cm/s) in Vitelma well. Permeability of both well is favorable. Permeability coefficient of entire well length is 0.59 - 0.71m/day（6.8×10^{-4} - 8.2×10^{-4}cm/s） in La Salle well, 1.67m/day (1.9×10^{-3}cm/s) in Suba well, and 0.21m/day (2.4×10^{-4}cm/s) in Vitelma well. This result means that Guadalupe Group of the drilling sites has high permeability.

Storativity

From pumping test result, storativity of the drilling site is 10^{-11} order in La Salle well, and 10^{-4} order in Suba, 0.25 x10^{-3} Mariscal Sucre and Vitelma well. Generally, calculated storativity has lower accuracy than calculated transmissivity. Little difference in analysis may cause big difference in result. In addition to this, pumping test by this Study did not have observation wells. These effects should be considered in evaluation of resultant storativity. Calculated storativity of three wells are a little different, but it may be suggested that actual storativity may be 10^{-5} - 10^{-6} order for three wells. This storativity means aquifers of three sites are confined condition.

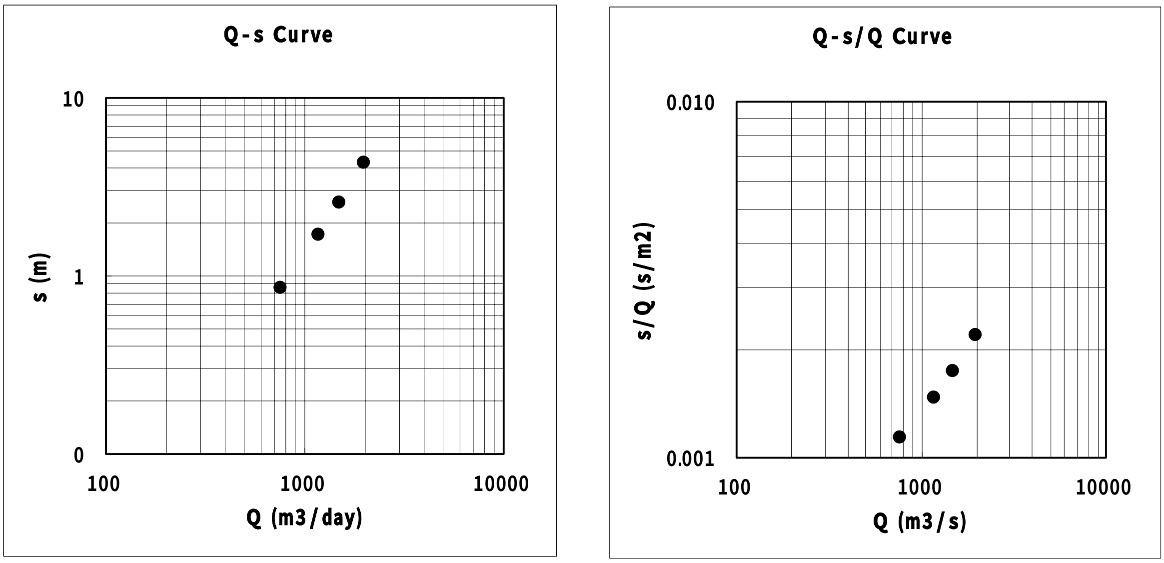
Step Drawdown Test

Step Drawdown test was carried out with five step yields in La Salle well. Pumping test continued until drawdown reached constant with 3 to 11 hours' pumping for each step. On the other hand, step drawdown test was carried out with four step yields in Suba well, three steps Mariscal Sucre. Pumping test continued until drawdown reached constant with 3.5 hours' pumping for each step. Result of step drawdown test is summarized in Table-2.1 and Figure-2.4 and Figure-2.5.



Note） s: Drawdown(m),Q: Yield(m^3/day) s: Drawdown(m),Q: Yield(m^3/day)

Figure-2.4 Result of Step Drawdown Test in La Salle



Note) s: Drawdown(m),Q: Yield(m^3/day) s: Drawdown(m),Q: Yield(m^3/day)

Figure-2.5　Result of Step Drawdown Test in Suba

As shown in Figure-2.4 and Figure-2.5, there was not big change in pumping situation during step drawdown test. From the pumping test result, relation between yield (Q) and drawdown (s) is approximated as shown below.

La Salle well: $s = 2.9 \times 10^{-3} \times Q + 7.8 \times 10^{-6} \times Q^2$

Suba well: $s = 4.5 \times 10^{-4} \times Q + 9.1 \times 10^{-7} \times Q^2$

Mariscal Sucre well: $s = 3.9 \times 10^{-2} \times Q + 6.5 \times 10^{-4} \times Q^2$

Where,

s : Drawdown (m)

Q : Yield (m^3/day)

Characteristics of Cretaceous aquifer

From the drilling result, main aquifer of Cretaceous Group in La Salle, Suba, Mariscal Sucre and Vitelma drilling sites is Labor y Tierna Formation. Labor y Tierna Formation consists of mainly sandstone, of which more porous and fractured parts becomes aquifer. Such sandstone distributes in different depths within Labor y Tierna Formation, and it is difficult to predict the depth of aquifers before drilling. There was notable groundwater jetting at the depth of 185m of La Salle well, which causes La Salle well to be flowing well. On the other hand, there was big fracture at the depth of 147m of Suba well, and this fracture seems one of main aquifer of this well. As explained above, notable fractured zones are developed in Labor y Tierna Formation, and such fractured zones sometimes form excellent aquifer.