INGENIERÍA CIVIL

Programa de Doctorado en Ingeniería

Línea de Investigación

INGENIERÍA DEL AGUA Y DEL AMBIENTE

50 AÑOS POSGRADOS INGENIERÍA CIVIL

Área Curricular de Ingeniería Civil y Agrícola
Facultad de Ingeniería
Sede Bogotá

UNIVERSIDAD NACIONAL DE COLOMBIA

HYDROGEOCHEMICAL PROCESSES AND ISOTOPES ANALYSIS.
Case of study: “La Línea Tunnel”, Colombia

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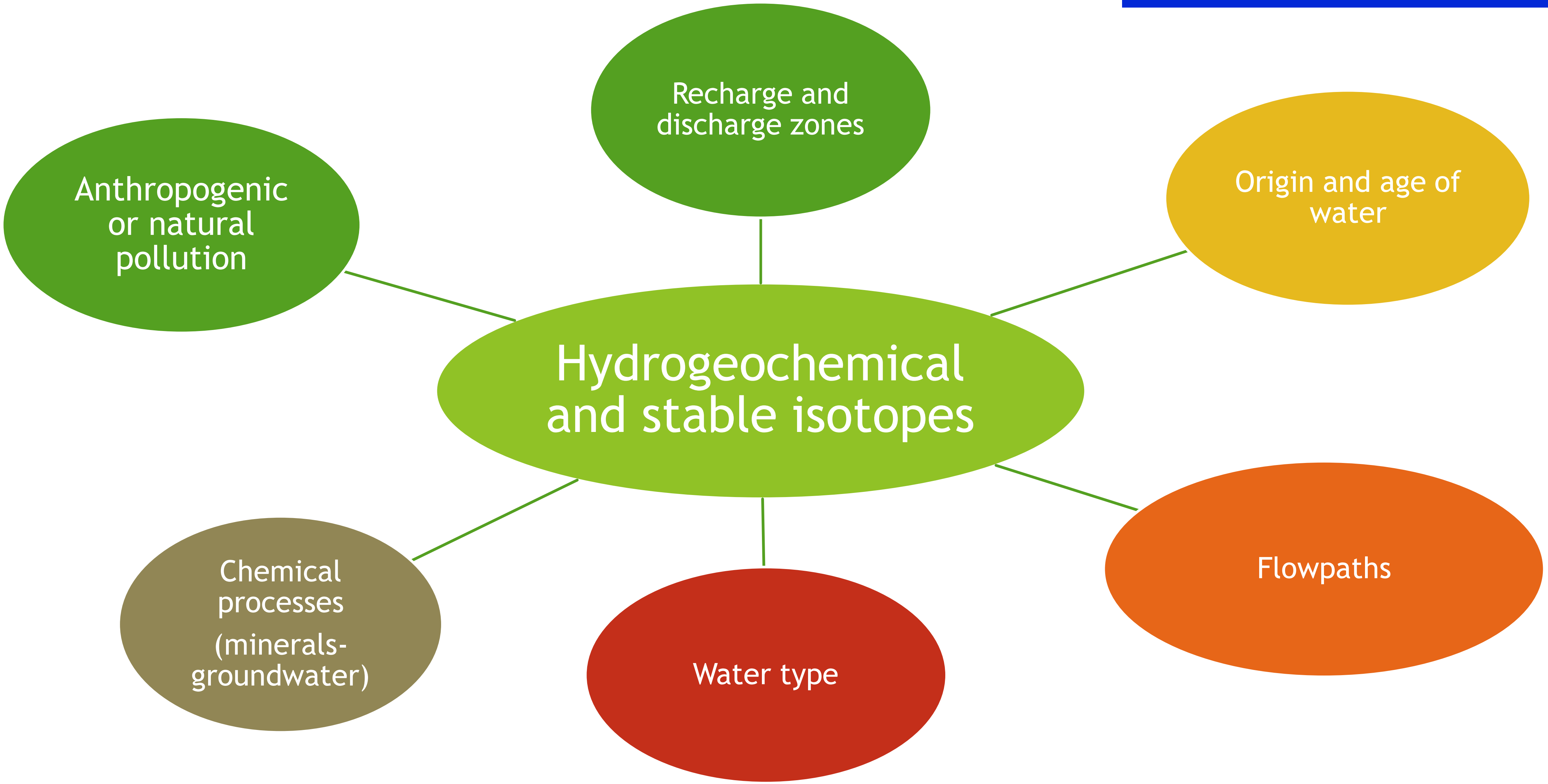
Tutor: Prof. Leonardo DONADO

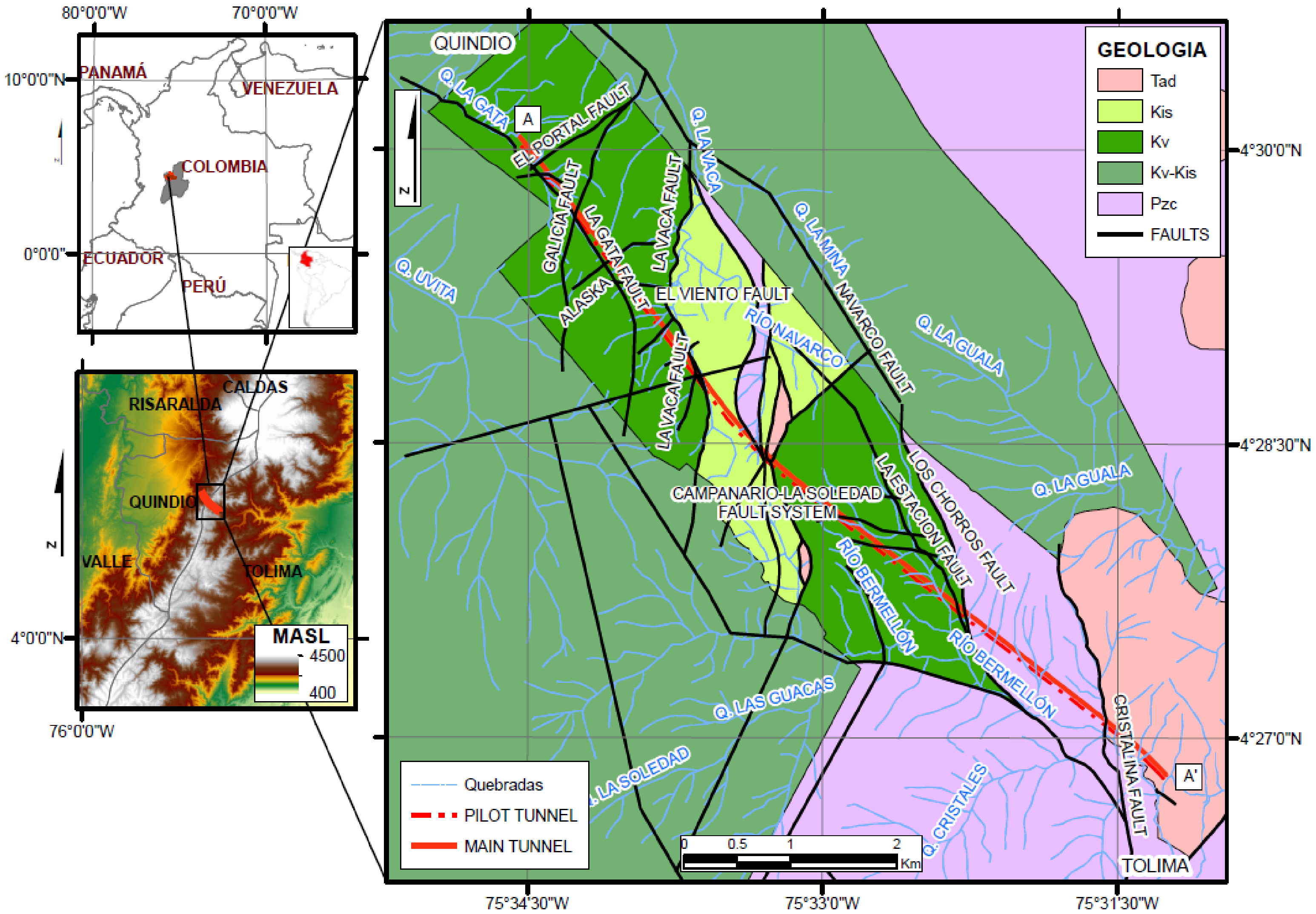
SEDIC
2016

CONTENT

- INTRODUCTION
- METHODOLOGY
- DATA ANALYSIS
- RESULTS
- CONCLUSIONS

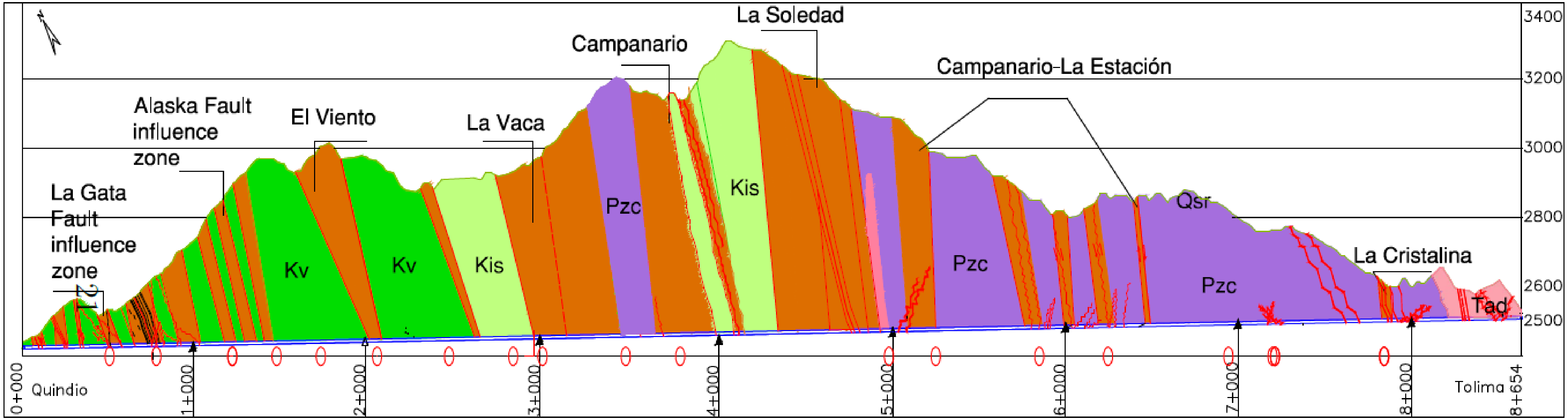

Recharge and discharge zones
Anthropogenic or natural pollution
Origin and age of water
Hydrogeochemical and stable isotopes
Chemical processes
(minerals-groundwater)
Water type
Flowpaths

"STUDY CASE: THE LA LÍNEA TUNNEL"



Geographical situation, project location and local geology description

GEOLOGIC PROFILE



LEGEND

Qsr: Volcanic ashes, residual soils and saprolites.

Tad: Igneous hipoabiasales rocks

Fracture zone

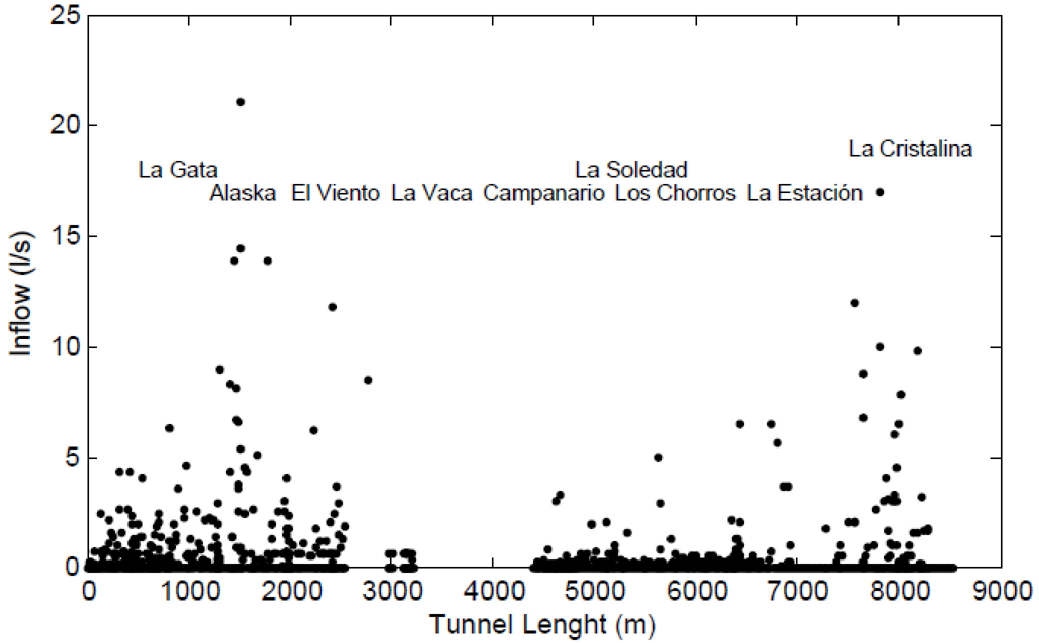
Fault

Kis Sedimentary member of Quebradagrande group

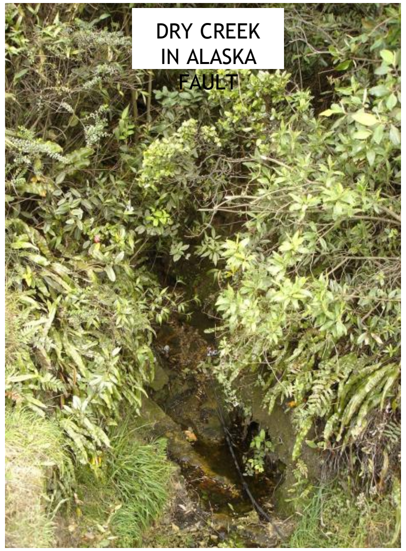
Kv Volcanic member of Quebradagrande group

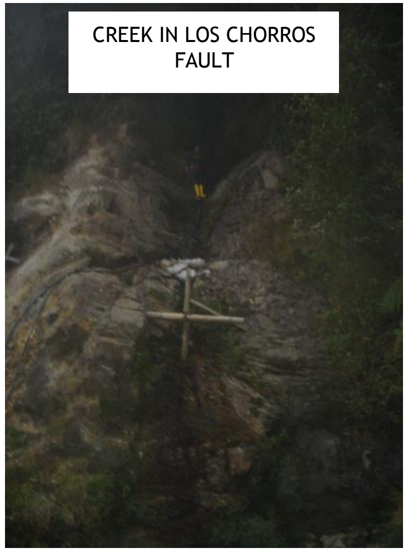
Pzc Cajamarca Group

Sampling borehole

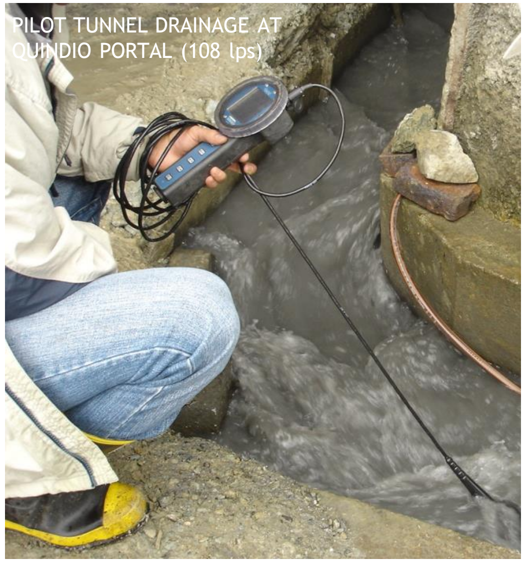

Inflow (l/s)
25
20
15
10
5
0
La Gata
Alaska
El Viento
La Vaca
Campanario
La Soledad
Los Chorros
La Estación
La Cristalina
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Tunnel Lenght (m)


LA GATA
CREEK


DRY CREEK
IN ALASKA
FAULT


CREEK IN LOS CHORROS
FAULT


INFLOWS INSIDE THE TUNNEL


PILOT TUNNEL DRAINAGE AT
QUINDIO PORTAL (108 lps)


OUTCROP IN LA GATA CREEK

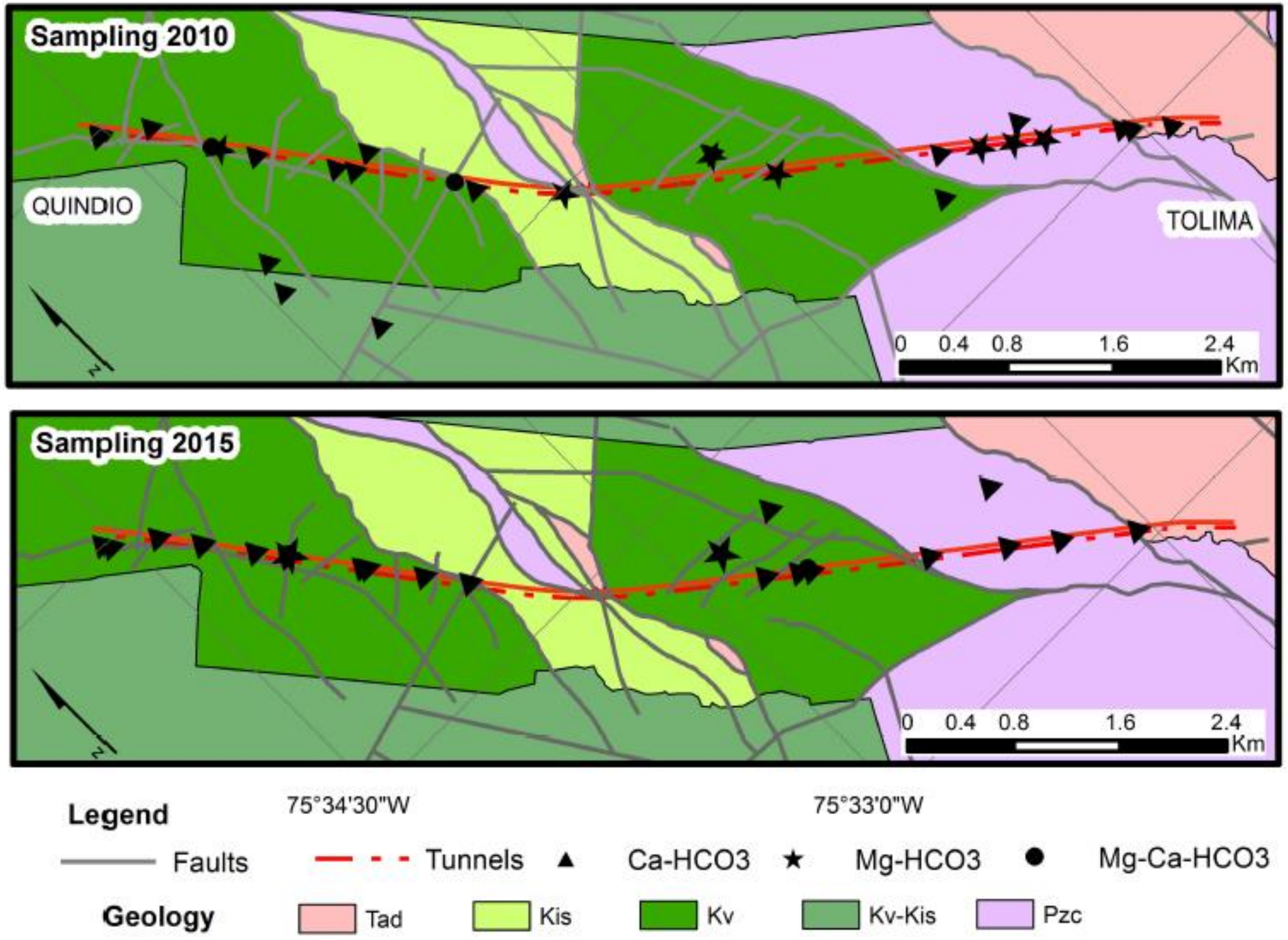

EL DIAMANTE CREEK -
LA VACA FAULT


LA VACA CREEK


LA CRISTALINA
CREEK

2010

Sample locations



- **FIELD WORK**
  - Sampling campaigns in 2010 and 2015 (60 samples).
  - Collection of water samples in surface and inside the tunnel following the Colombian regulation (IDEAM).
  - Primary physico-chemical parameters were measured in field (pH, electrical conductivity, temperature and dissolved oxygen) using portable multi-parameter probes.
  - Samples were collected in 1000 ml plastic bottles for physico-chemical analysis and 250 ml ambar plastic bottles for the stable isotopes.
  - Laboratories for the physico-chemical and Stable isotopes analyses:
    - Accredited laboratory of Environmental Engineering of Universidad Nacional de Colombia in Bogotá.
    - University of Waterloo in Canada.
  - Measured parameters: Ca^2+, Mg^2+, K^+, Na^+, Cl^-, F^-, NO_3^-, NO_2^- SO_4^2- Fe, Mn, Si HCO_3^- TDS

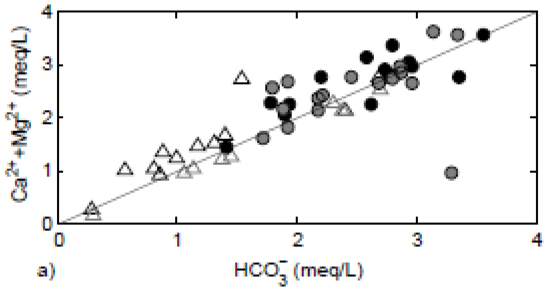
- **DATA ANALYSIS**
  - Statistical analysis were performed in samples with charge balance error below 10%.
  - **Multivariate statistical analysis** (Güller et al. 2002, Montcoudiol et al. 2014 and Ghesquiere et al. 2015).
  - Graphical analysis
  - Stable isotopes analysis

- **RESULTS**

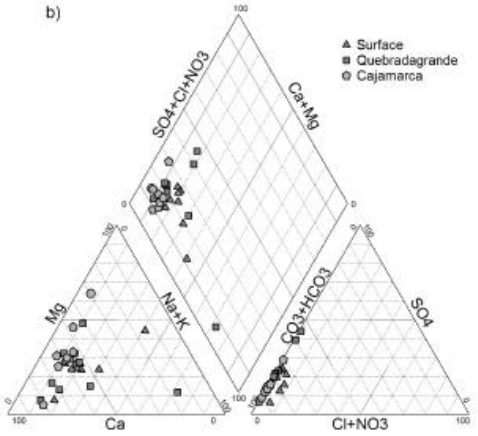
Multivariate statistical analysis

Raw data → Data normally distribuited → Standarized values → Factor Analysis to find correlations → Hierachical cluster analysis

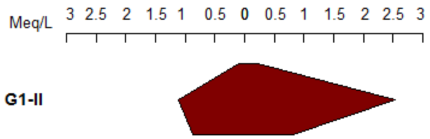
Graphical analysis



Correlations for main elements



Pipper Diagrams



Stiff Diagrams

Stable isotopes analysis

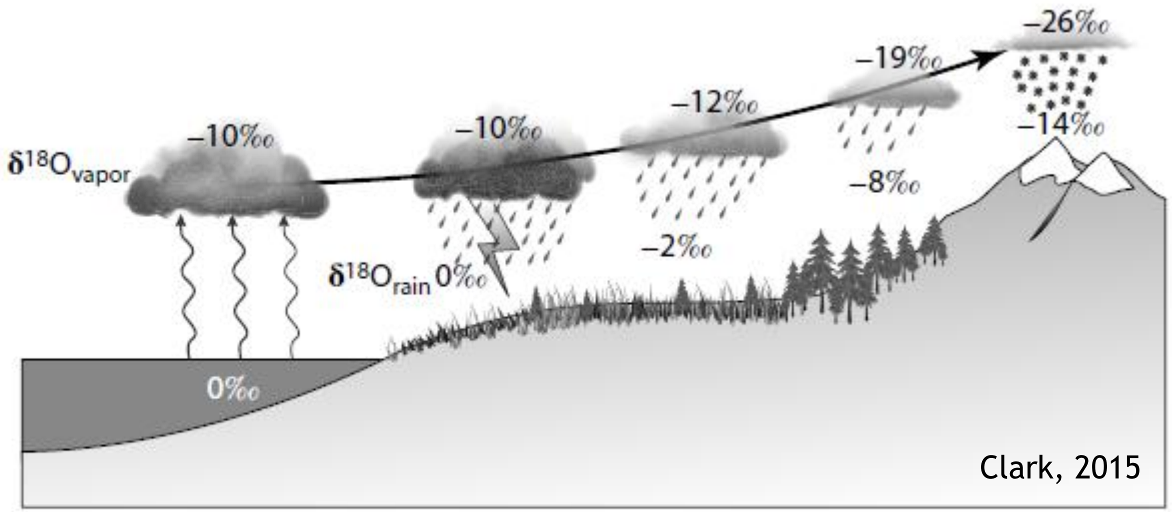


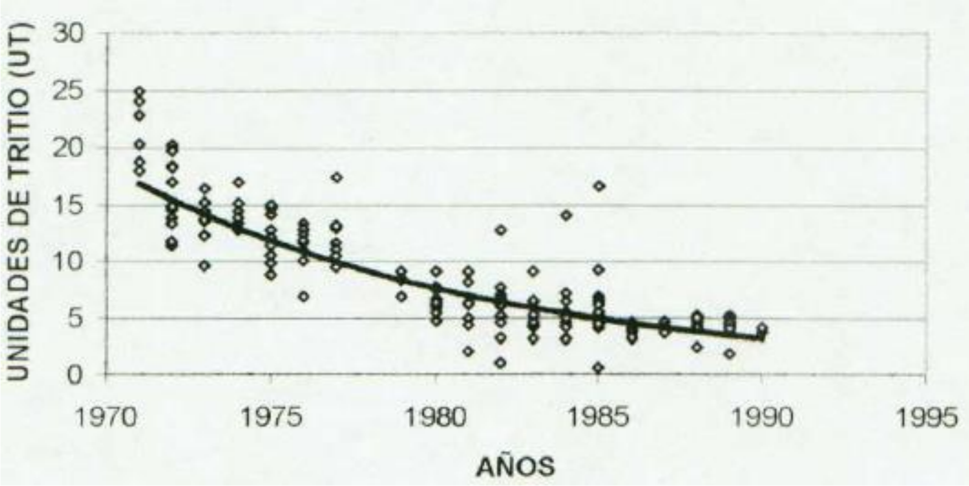
FIGURE 5.4 The evolution in the ^{18}O content of precipitation according to an ideal Rayleigh distillation during rainout. Deuterium follows a similar depletion trend.

$$\delta^2 H = \delta^{18} O + 10‰ \ \mathrm{SMOW}$$

Global Meteoric Line, Craig, 1961

$$^3H$$

- Its introduction to the hydrologic cycle was first in 1952, as a result of large-scale atmospheric testing of thermonuclear bombs.



Tritium evolution (Ingeominas, 2001)

Parameter	S-I AVG±SD	S-II AVG±SD	T-I AVG±SD	T-II AVG±SD
pH	7.71±0.87	8.20±0.26	9.03±0.83	8.23±0.10
EC	152.8±89.17	247.3±131.1	301.5±72.05	253.6±43.41
Na^{+}	2.08±0.63	7.38+4.45	4.79+2.25	11.6+11.8
Ca^{2+}	19.60±10.00	20.0±10.5	27.3±6.69	34.60±8.75
Mg^{2+}	6.43±3.23	5.69±2.73	16.0±6.58	9.21±5.74
K^{+}	0.94±0.48	1.52±0.59	0.79±0.54	0.70±0.57
Mn^{2+}	0.05±7.24	0.05±0.00	0.06±0.14	0.03±0.03
Fe^{+3}	0.21±0.56	0.36±0.19	0.04±0.00	0.40±0.98
HCO_3^-	75.74±42.95	103.8±50.46	156.2±36.53	151.5±33.40
Cl^-	0.53±0.68	2.62±2.45	1.23±1.'Si	0.51±0.23
SO_4^{2-}	14.50±12.4	19.30±13.3	29.2±15.20	29.60±17.10
NO_3^-	0.16±0.13	0.13±0.07	0.11±0.04	0.11±0.05
SiO_2	30.73±6.04	22.02±4.92	4.82±6.95	20.52±4.44
TDS	154.17±179.13	147.78±71.79	187.53±40.00	409.35±346.20
$\delta^{18}O$ (‰)	NA	-11.20±0.53	NA	-11.30±0.60
$\delta^{2}H$ (‰)	NA	-78.97±3.97	NA	-81.30±4.02
^{3}H (TU)	NA	NA	NA	¡ 6

S : Surface samples / T : Tunnel samples
I : 2010 / II : 2015

Higher concentrations in tunnel samples

Parameter	S-I AVG±SD	S-II AVG±SD	T-I AVG±SD	T-II AVG±SD
pH	7.71±0.87	8.20±0.26	9.03±0.83	8.23±0.10
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HCO_3^-	75.74±42.95	103.8±50.46	156.2±36.53	151.5±33.40
Cl^-	0.53±0.68	2.62±2.45	1.23±1.76	0.51±0.23
SO_4^{2-}	14.50±12.4	19.30±13.3	29.2±15.20	29.60±17.10
NO_3	0.16±0.13	0.13±0.07	0.11±0.04	0.11±0.05
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δ^2H (‰)	NA	-78.97±3.97	NA	-81.30±4.02
^3H (TU)	NA	NA	NA	¡ 6

- Higher in 2010 than in 2015
- Storage water in the massif

- Carbonate reacctions
- Weathering of **silicate** or **carbonate** rocks

- Leaching of igneous or sedimentary rocks

S : Surface samples / T : Tunnel samples
I : 2010 / II : 2015

Parameter	S-I	S-II	T-I	T-II
	AVG±SD	AVG±SD	AVG±SD	AVG±SD
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$\delta^{18}O$ (‰)	NA	-11.20±0.53	NA	-11.30±0.60
$\delta^{2}H$ (‰)	NA	-78.97±3.97	NA	-81.30±4.02
^{3}H (TU)	NA	NA	NA	¡ 6

S : Surface samples / T : Tunnel samples
I : 2010 / II : 2015

- **54** samples were kept in order to guarantee the quality of the analysis (charge balance error below 10%).

11 parameters were considered:

Positively skewed

$pH\ Na^+ Mn^2+\ Fe\ Mg^2+\ Cl^-\ K^+$

$Ca^2+\ HCO_3^-\ SO_4^2-\ Si$

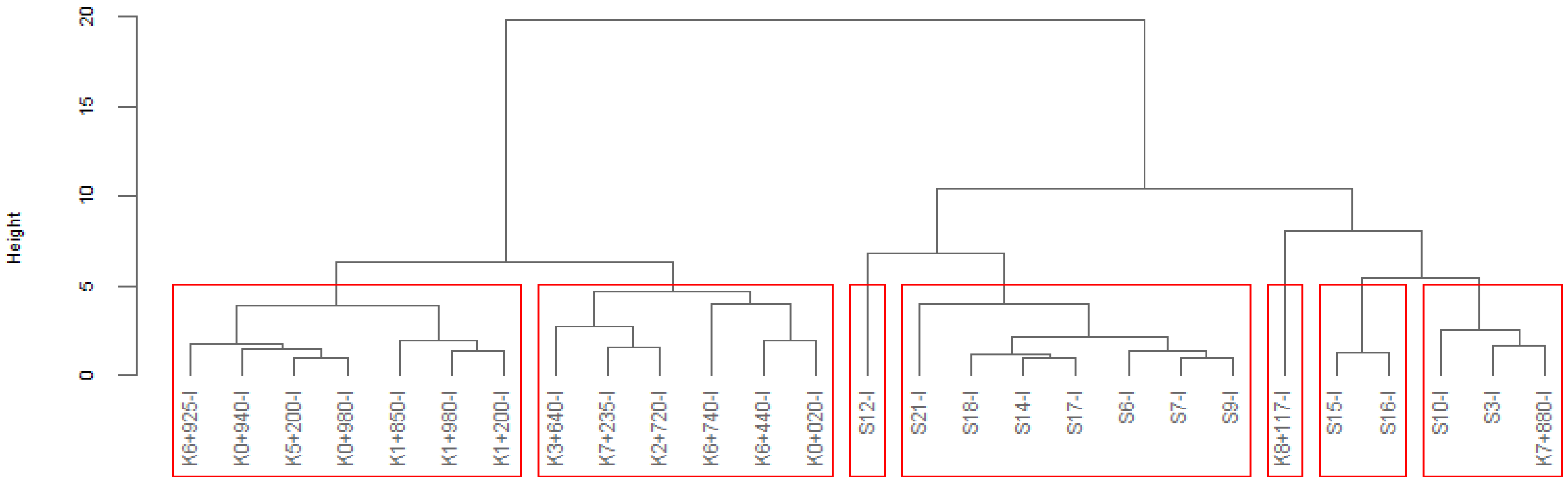
Normally distributed

Factor Analysis

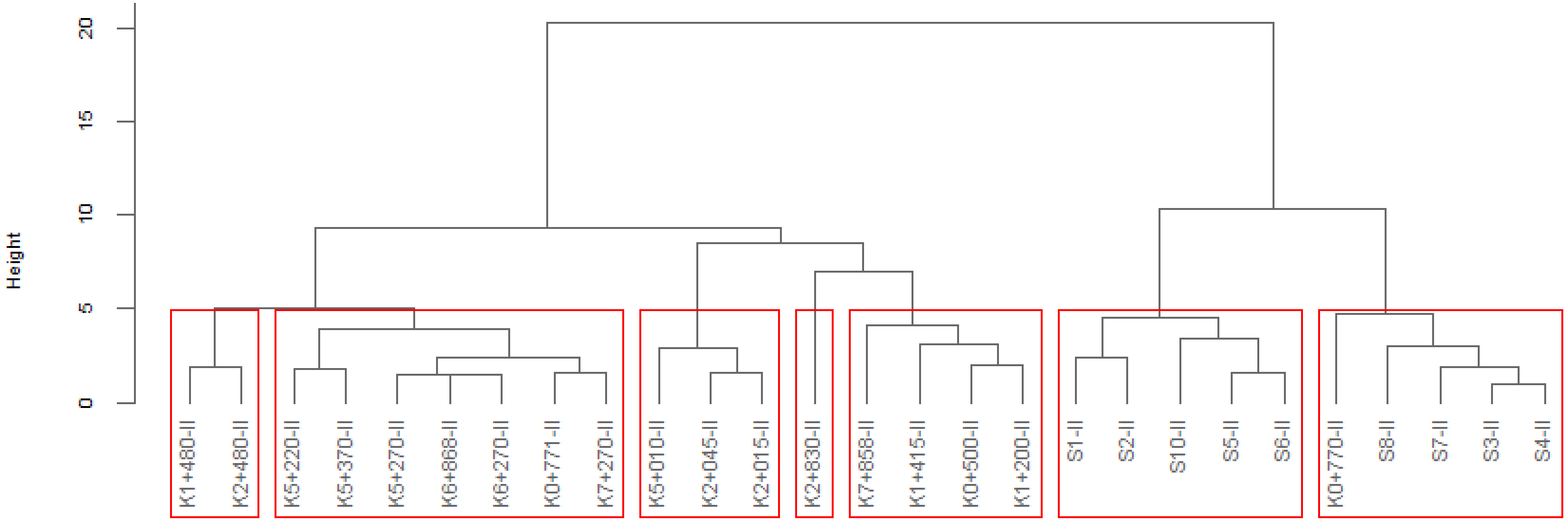
Parameter	FA-I Factor 1	FA-I Factor 2	FA-I Factor 3	FA-II Factor 1	FA-II Factor 2	FA-II Factor 3
pH	0.650	-0.457	-0.270	0.261	0.379	0.285
Na^{+}	0.653	-0.363		0.22	0.521	0.355
Ca^{2+}	*0.700*	0.278	0.271	*0.782*	0.1	
Mg^{2+}	*0.913*	-0.238		0.588	0.474	
K^{+}		0.172	0.564	*-0.775*	0.398	0.486
Mn^{2+}	-0.149	*0.938*	0.305	-0.516	-0.114	0.245
Fe	-0.314			-0.362		0.248
HCO_3^{-}	*0.886*	-0.276	0.365	0.598	*0.792*	-0.101
Cl^{-}	0.346			-0.314		0.635
SO_4^{2-}	*0.771*	0.518	-0.364	0.81	-0.212	0.543
Si	0.256	0.107	0.273		0.02	
Explained variance	3.866	1.745	0.915	3.182	1.537	1.289
Explained variance (%)	0.351	0.159	0.083	0.289	0.14	0.117
Cumulative % of variance	35.1	51.0	59.3	28.9	42.9	54.6

Hierachical cluster analysis

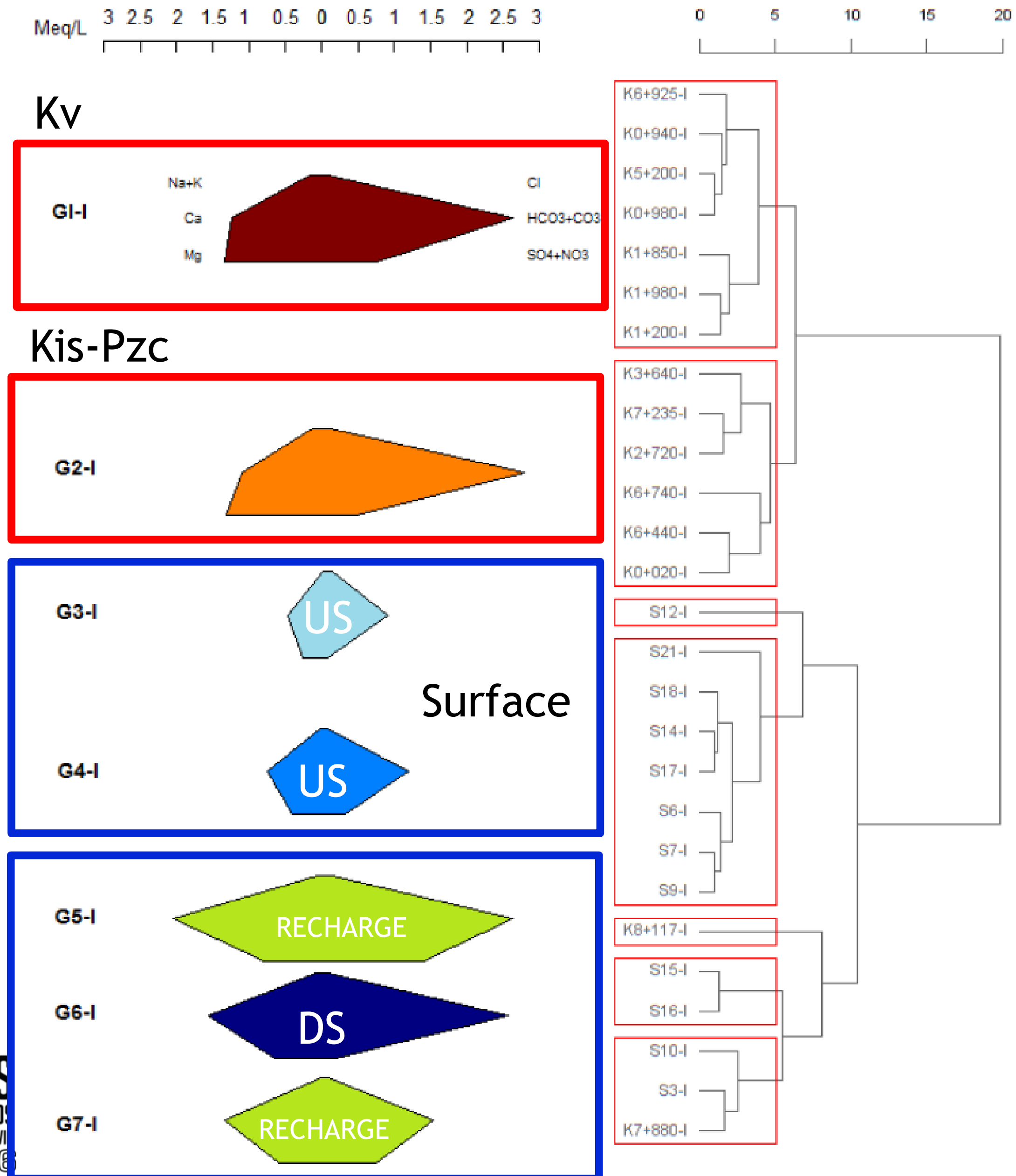
Sampling I

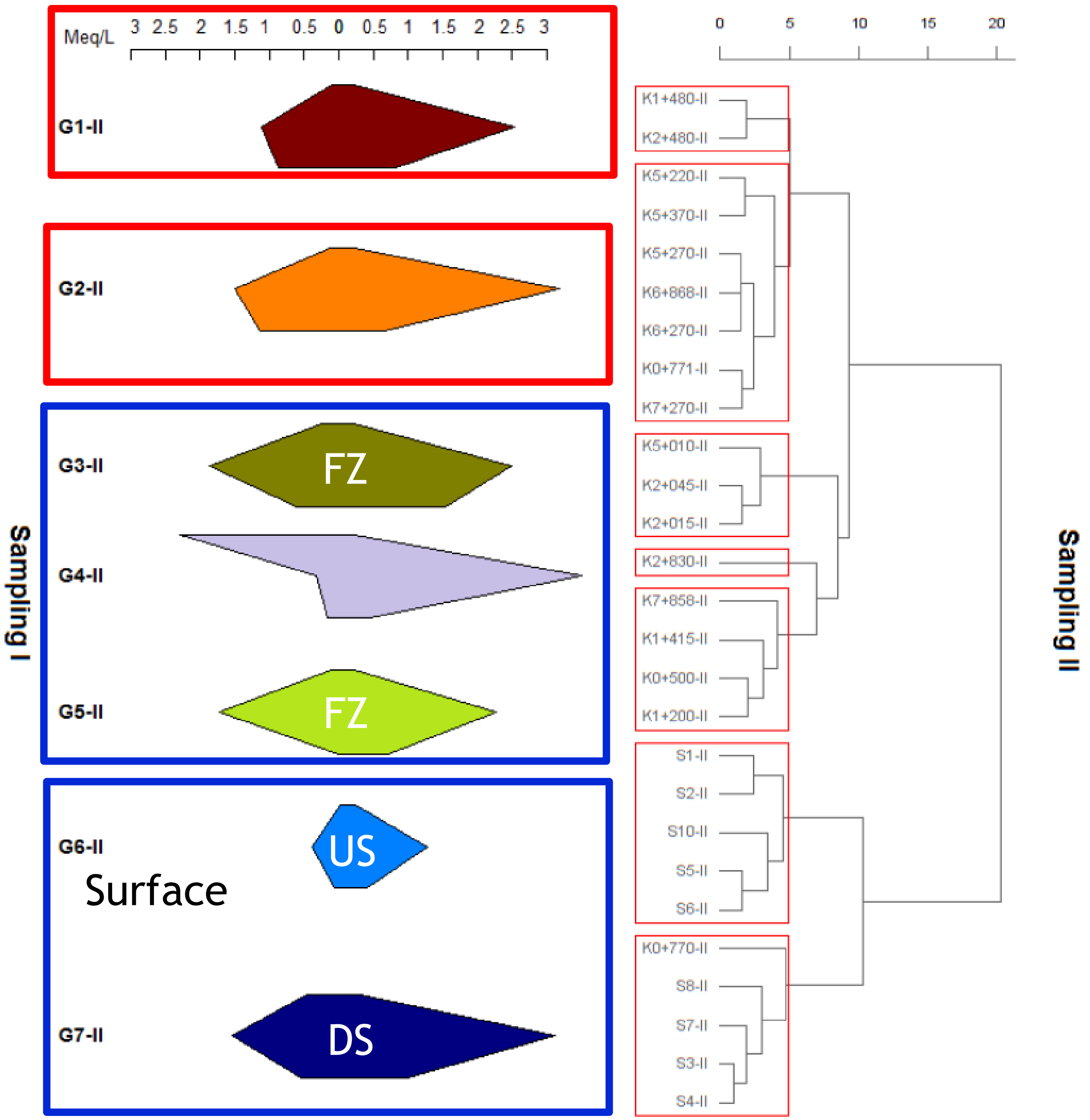


Sampling II

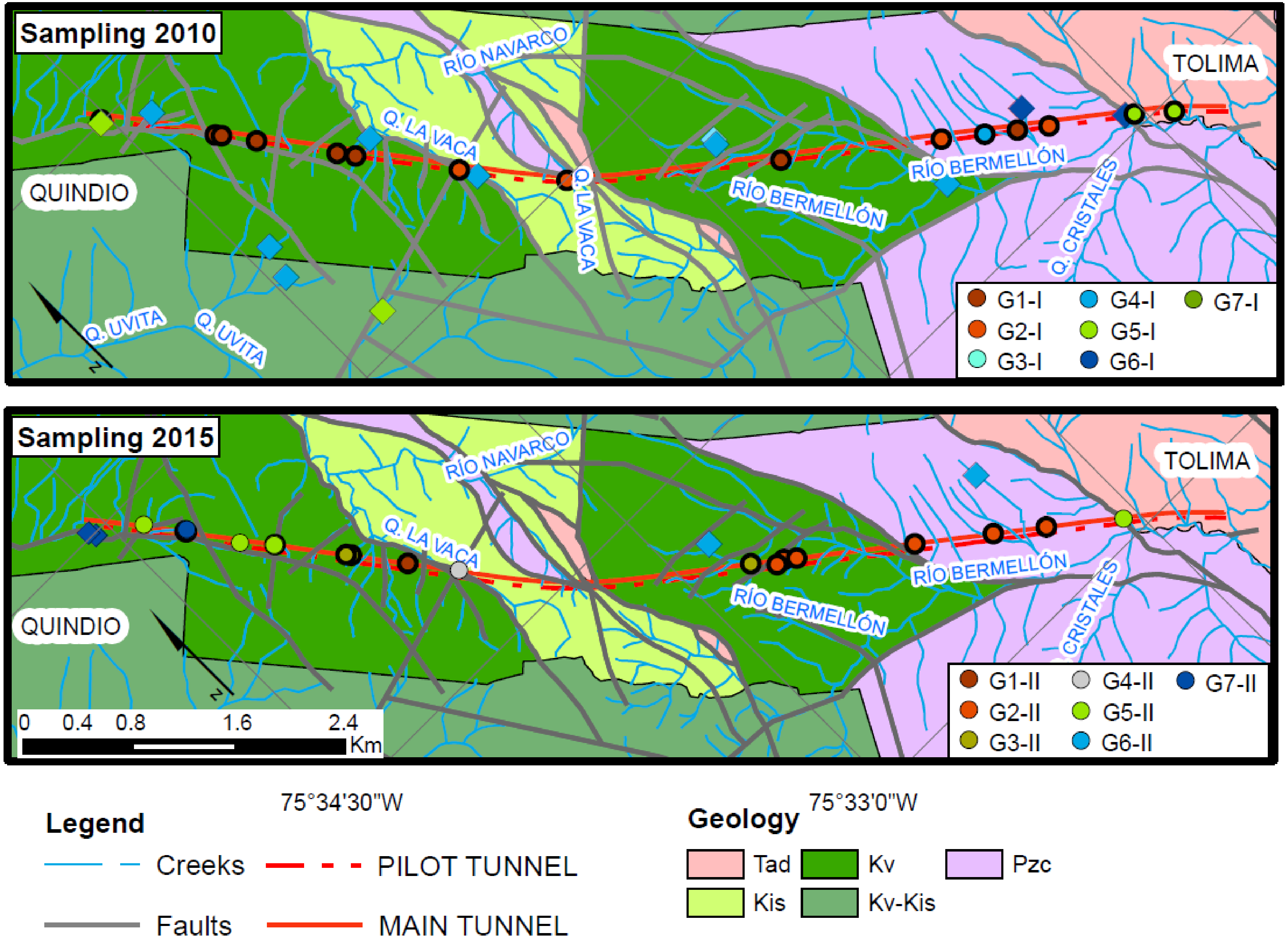


Stiff Diagrams





50 AÑOS POSGRADOS INGENIERÍA CIVIL 1966 – 2016



50 AÑOS POSGRADOS INGENIERÍA CIVIL 1966 – 2016

Piper Diagrams

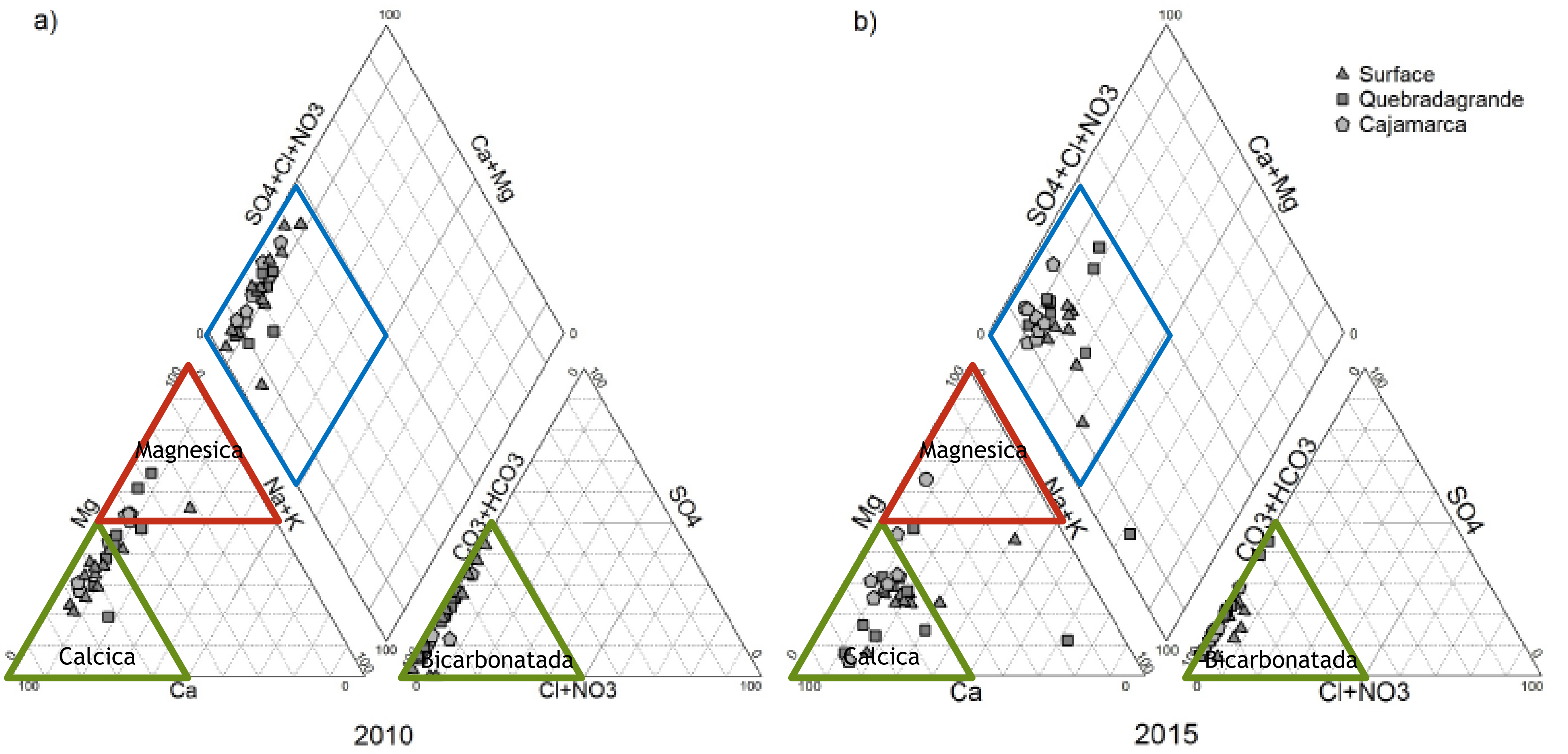


Figure 6: Pipper Diagram, a) 2010 and b) 2015 sampling

Stable Isotopes

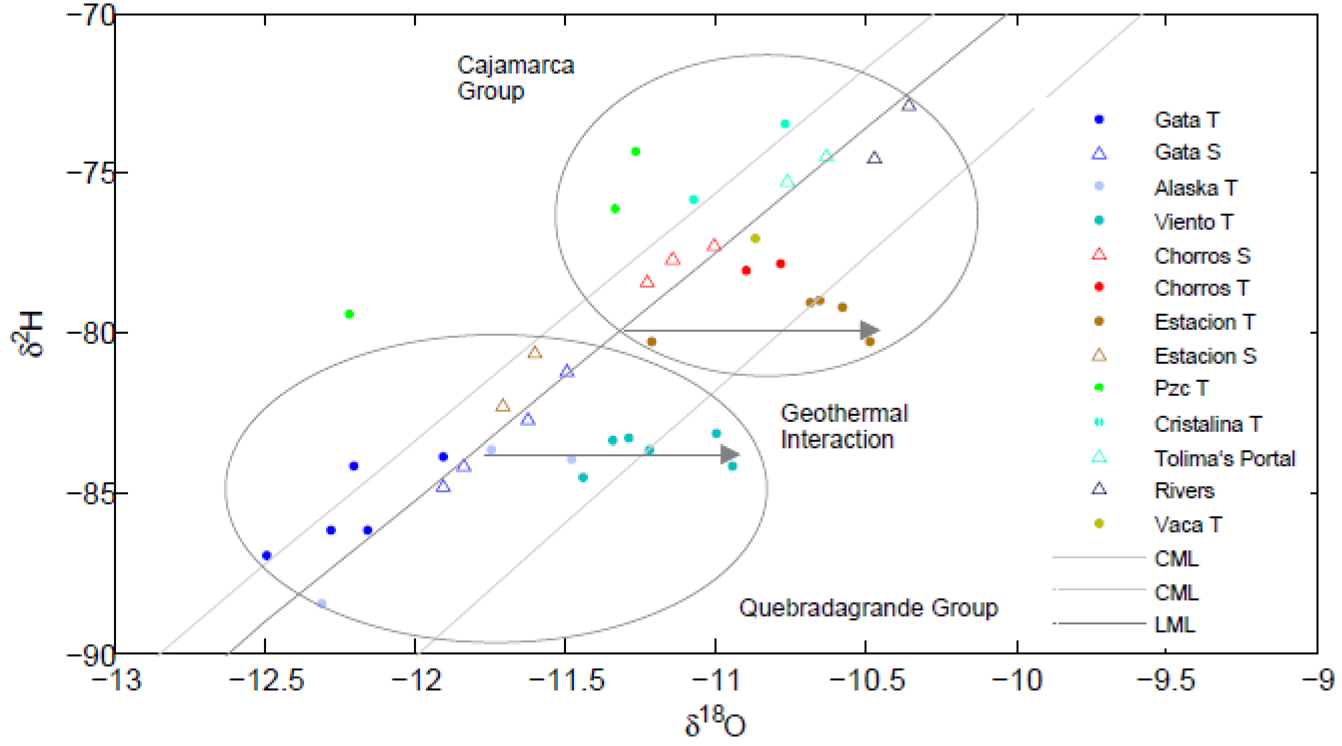


Figure 10: $\delta^2 H$ vs $\delta^{18}O$. The Colombian Meteoric Line (CML) and Local Meteoric Line (LML). Triangles for surface samples and circles for inflows inside the tunnel

CML

$$\delta^2 H = (8.03 \pm 0.28)\delta^{18}O + 9.6$$

Rodríguez, 2004

LML

$$\delta^2 H = 7.7\delta^{18}O + 7.2$$

Stable Isotopes

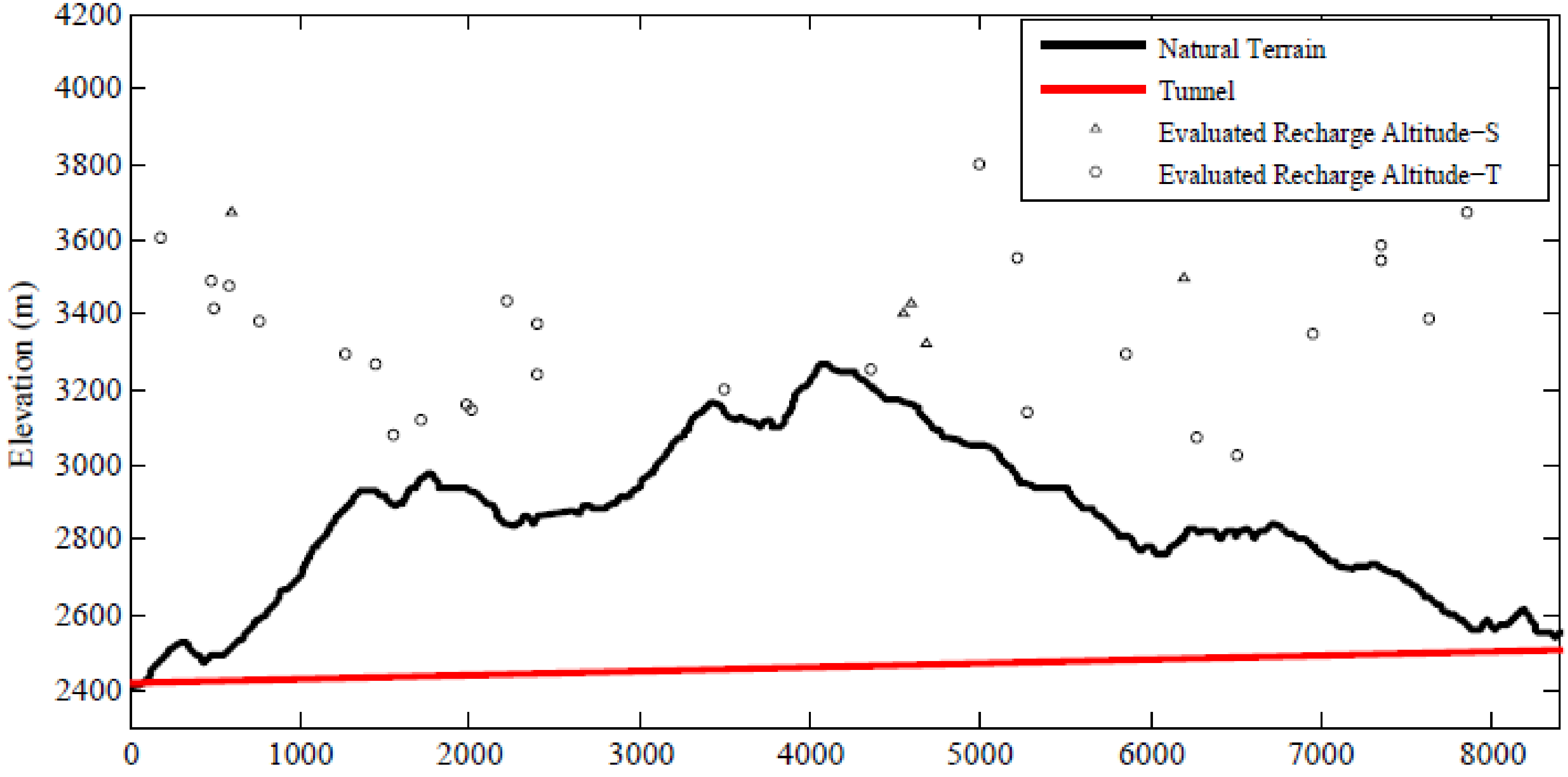


Figure 11: Evaluated Recharge Altitude using δ^{18}O

$$\delta^2 H = 7.7\delta^{18} O + 7.2$$

Rodríguez, 2004

CONCLUSIONS

- Hydrogeochemical and isotopes analysis are useful tools for a better understanding of the hidrogeological behaviour of a highly fractured massif like La Línea mountain.
- Fractures defined preferential flow paths, connecting surface sources like creeks with underground infrastructure works like tunnels.
- Most samples are classied by cations as Ca^{2+} in a major proportion followed by Mg^{2+} dominance. According to the anions, all samples are HCO_3^- type.
- Factor Analysis (FA) and Hierachical Cluster Analysis (HCA) combined with graphical analysis let us to identify seven clusters for each year and to relate with the geology of the zone.
- It is observed an evolution of the water type related with the interaction with the host rock.

Stable Isotopes

- Ideam, Guia para el monitoreo de Aguas Superciales y Subterraneas,Technical Report, 2003.
- C. Güller, G. D. Thyne, J. E. McCray, K. a. Turner, Evaluation of graphical and multivariate statistical methods for classication of water chemistry data, Hydrogeology Journal 10 (2002) 455-474.
- N. Montcoudiol, J. Molson, J.-M. Lemieux, Groundwater geochemistry of the Outaouais Region (Quebec, Canada): a regional-scale study, Hydrogeology Journal (2014) 377-396.
- O. Ghesquiere, J. Walter, R. Chesnaux, A. Rouleau, Scenarios of groundwater chemical evolution in a region of the Canadian Shield based on multivariate statistical analysis, Journal of Hydrology: Regional Studies 4 (2015) 246-266.
- I. D. Clark, Groundwater Geochemistry and Isotopes, CRC Press, 2015.
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