HYDROGEOCHEMICAL AND ISOTOPIC STUDY OF GROUNDWATER APPLIED IN ENVIRONMENTAL REMEDIATION – URANIUM MINE OSAMU UTSUMI/INB

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CNEN/LAPOC - Comissão Nacional de Energia Nuclear - Poços de Caldas/MG – Brazil.

CNEN/CDTN - Comissão Nacional de Energia Nuclear - Belo Horizonte/MG – Brazil.

INB - Industrias Nucleares do Brasil - UTM/Caldas

Objectives

1. Site Characterization
2. Chemical characterization of groundwater
3. Determination most important geochemical processes between rock / water.
4. Classification and separate types of aquifers
5. Behavior of chemical species
6. Develop a conceptual model Hydrogeochemical

Methods

1 - Geoprocessing and mapping
- Model Digital Elevation
- Geological Map
- Radiometric Map

2 – Groundwater sampling

Low flow pumping

3 – Hydrodinamic
- Potentiometric Map
- Hydraulic Condutivity Map

4 – Hydrochemistry
- piper and stiff
- Multivariate analysis
- Radioactivity and Radon
- Environmental isotopes
  - O/D and Tritium
  - Sulfur isotopes

5 - Hidrogeochemistry Conceptual Model

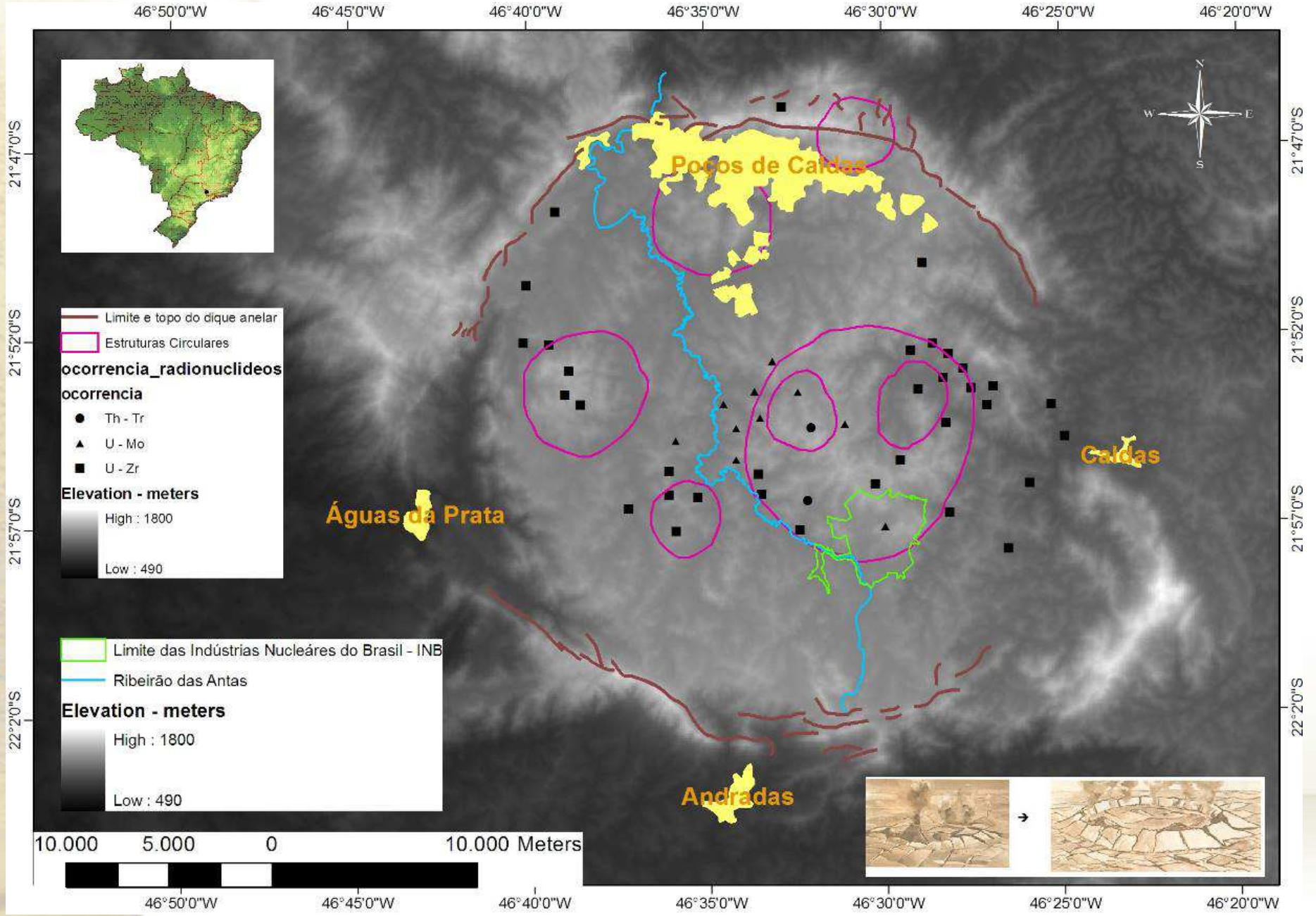
5 - Hidrogeochemistry Conceptual Model

The hydrogeochemical models attempt to understand and represent chemical dynamics applied to geological systems and the rock-water interaction (Nordstrom & Campbell, 2014).

interpretation or predictions

Why build a hydrogeochemistry conceptual model?

- understand the behaviour of the aquifer and systematize information.
- guide remediation projects showing priority areas.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46°20'0"W
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21°52'0"S
21°57'0"S
22°2'0"S
Poços de Caldas
Caldas
Águas da Prata
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Limite e topo do dique anelar
Estruturas Circulares
ocorrencia_radionuclideos
ocorrencia
Th - Tr
U - Mo
U - Zr
Elevation - meters
High : 1800
Low : 490
Limite das Indústrias Nucleáres do Brasil - INB
Ribeirão das Antas
Elevation - meters
High : 1800
Low : 490
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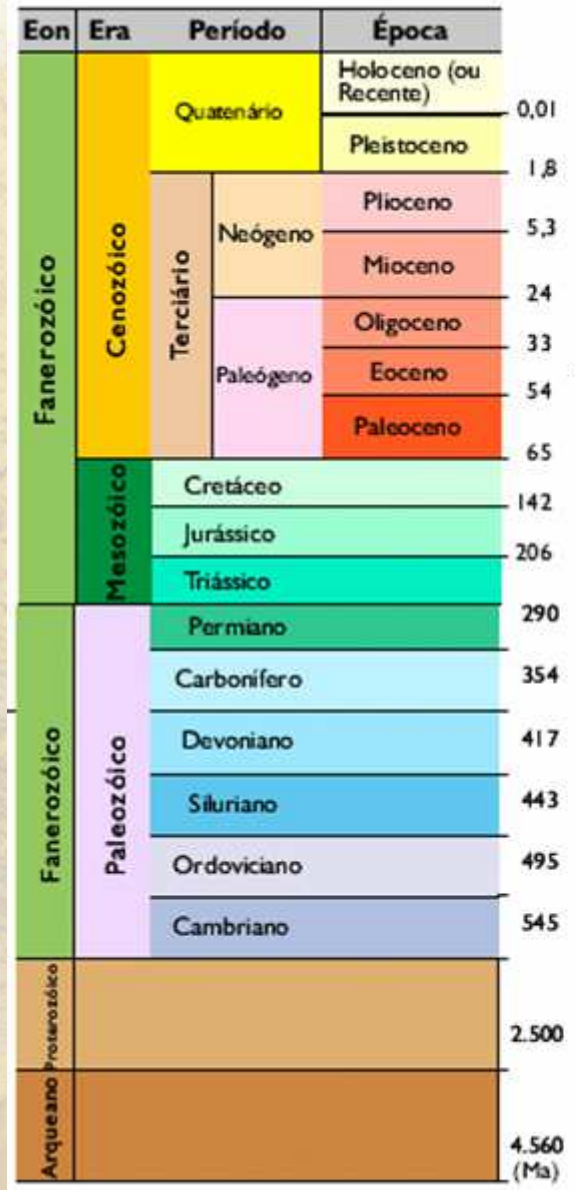


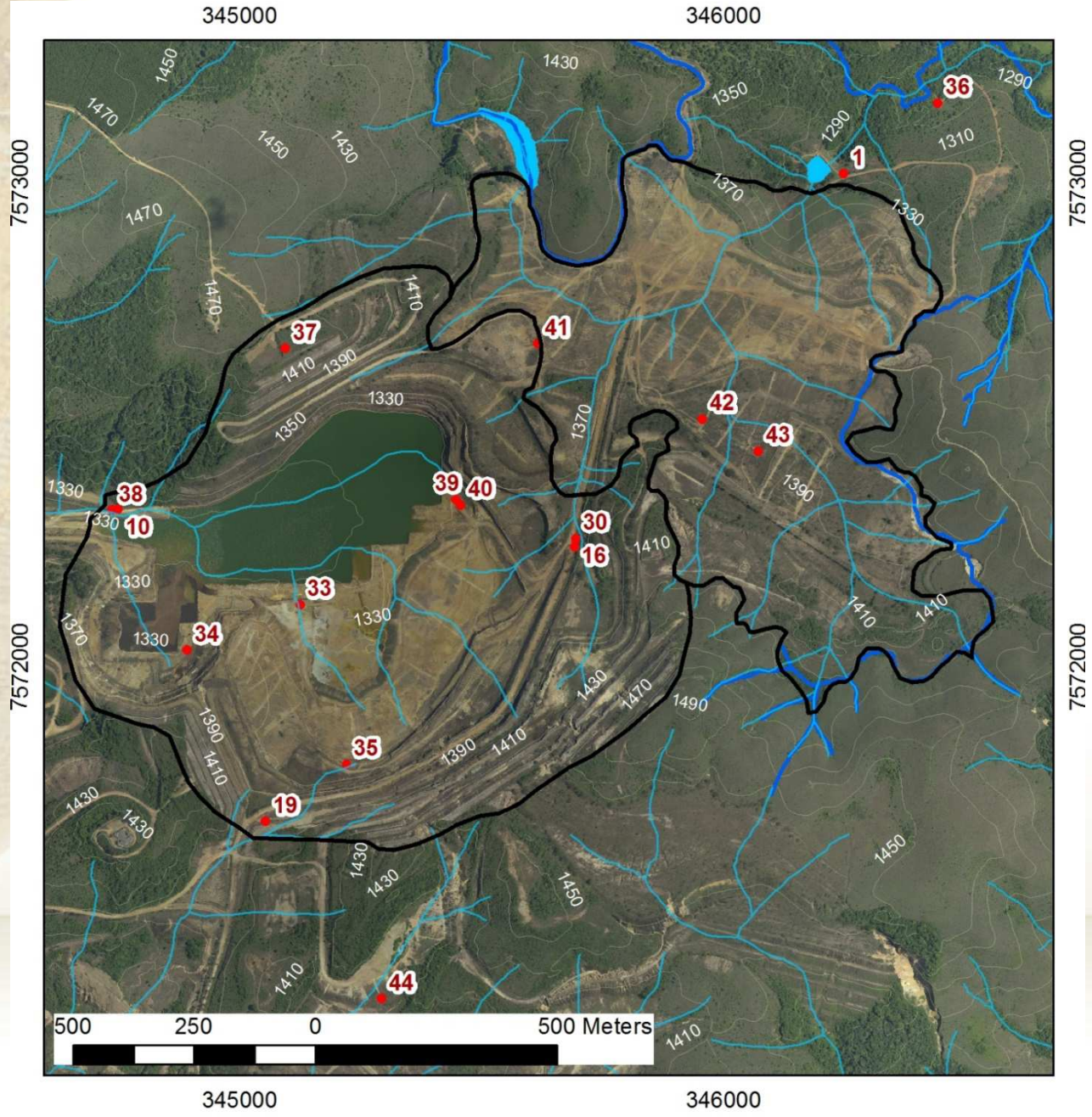
weathering / intemperism

dinosaurs extinction
separation of continents
much igneous activity

Poços de Caldas Plateau
80 - 60 Myear

hydrothermal solutions
contaminating alkaline rocks

1 - Geoprocessing and mapping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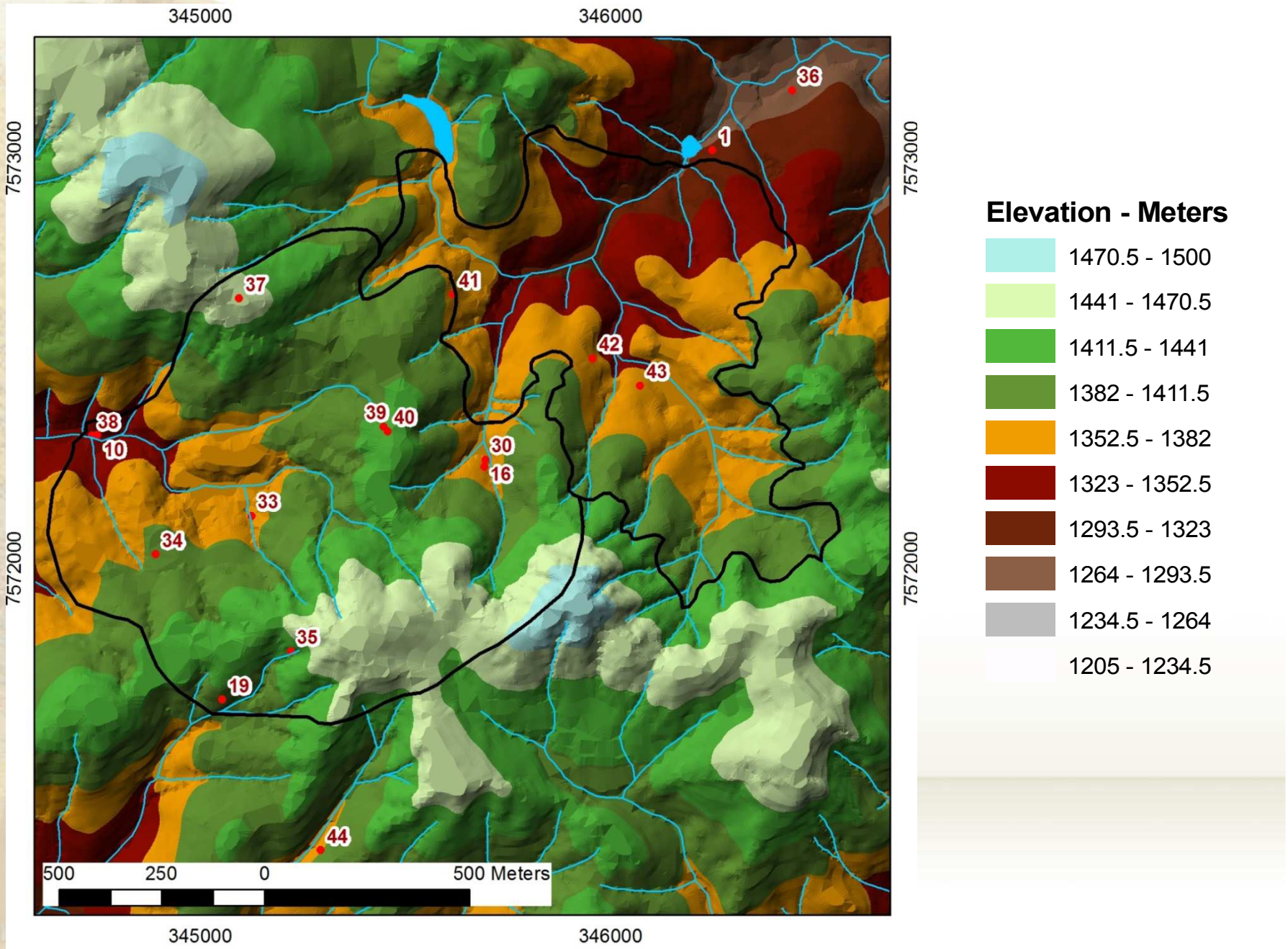
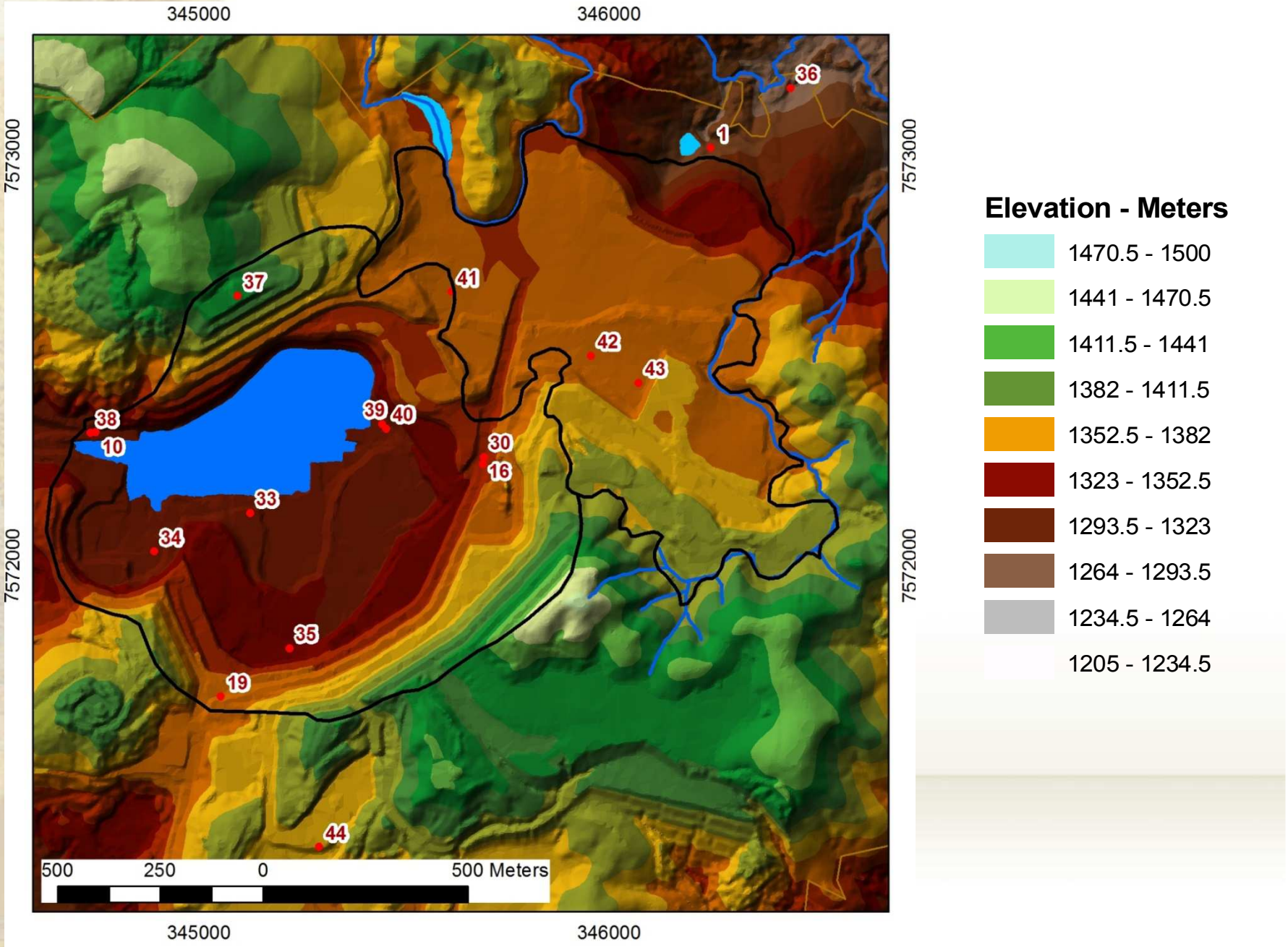
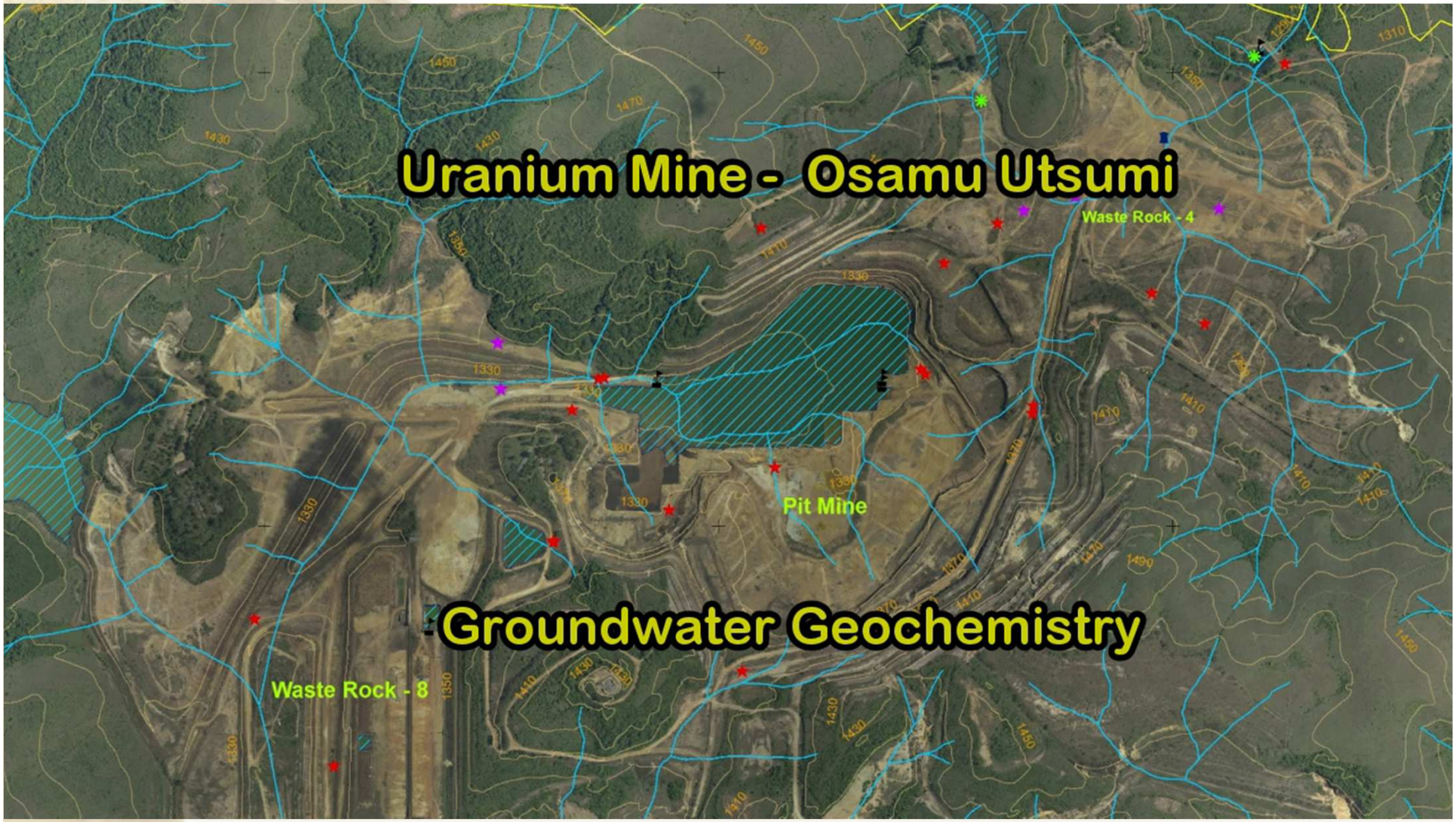
Model Digital Elevation – Before mining

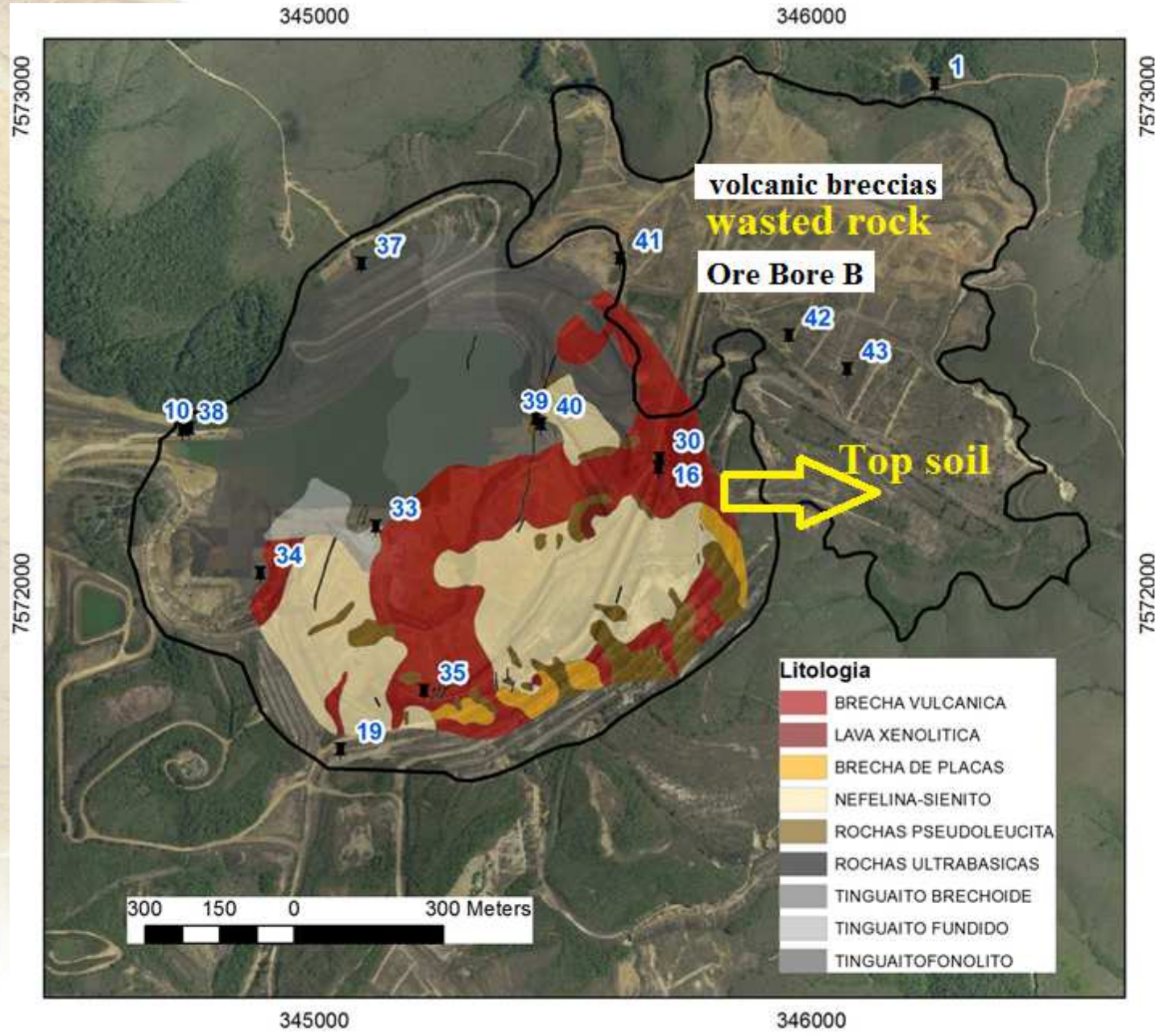


Model Digital Elevation – After mining



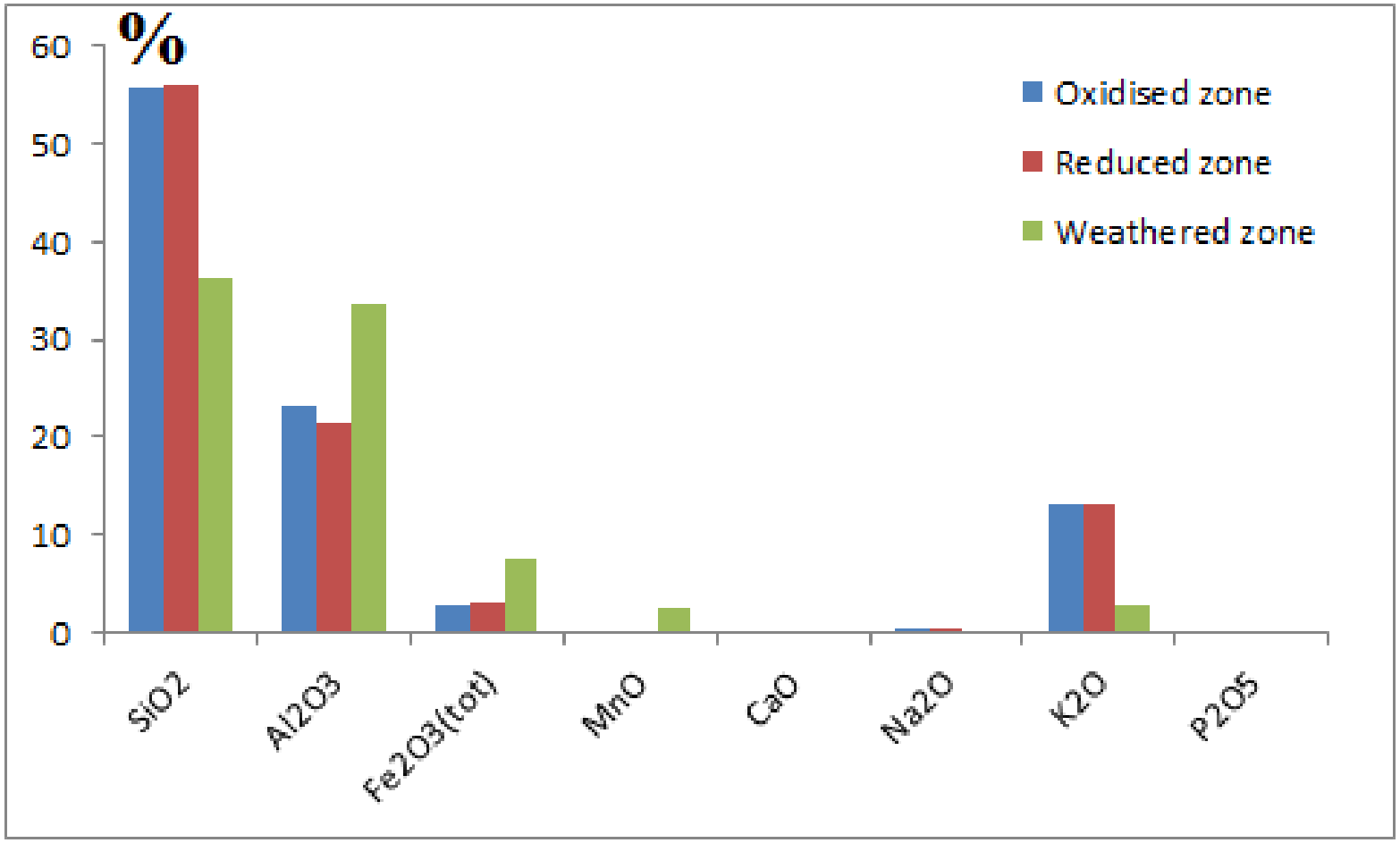

Uranium Mine - Osamu Utsumi
Waste Rock - 4
Pit Mine
Groundwater Geochemistry
Waste Rock - 8

Geological Map

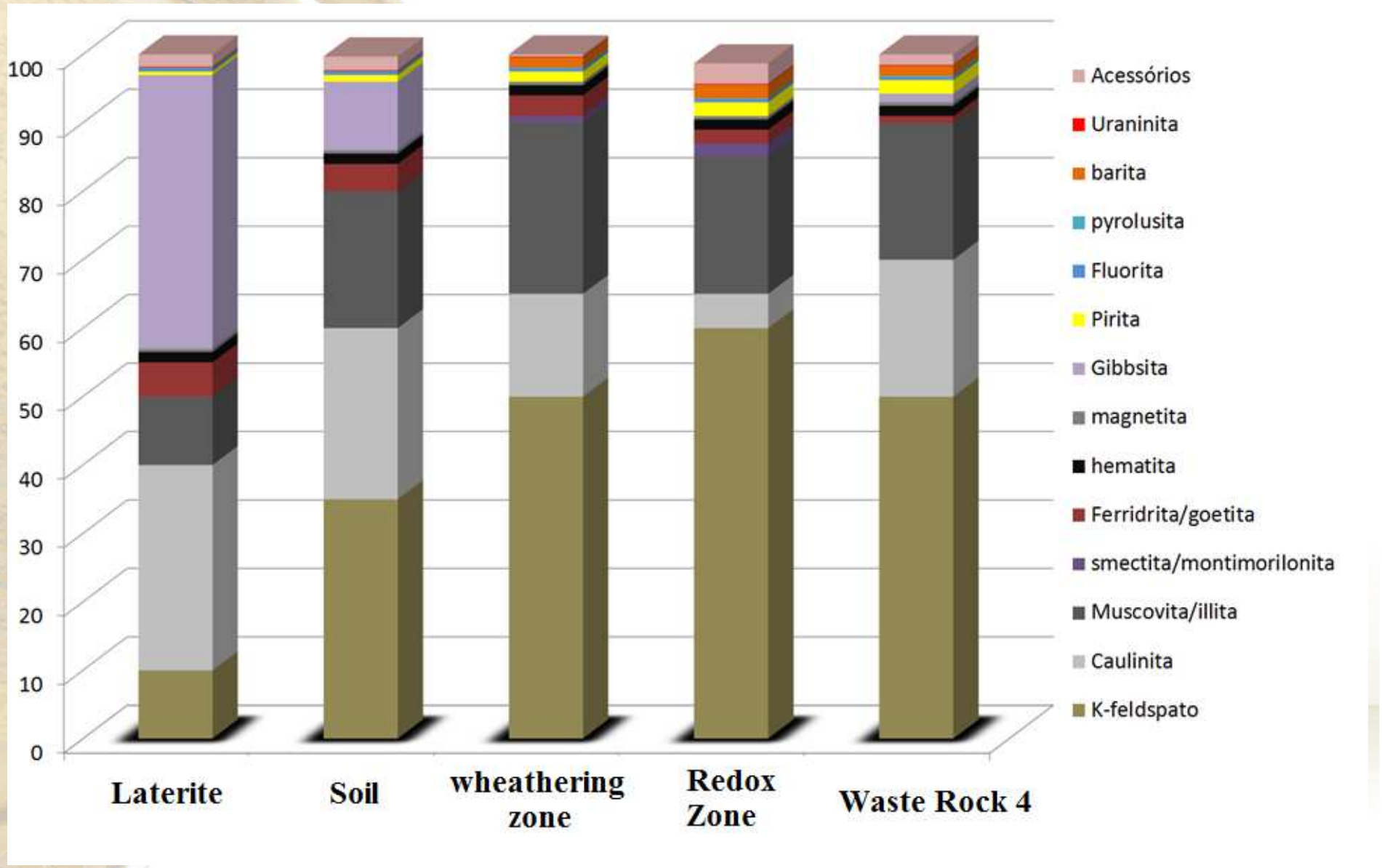


1 – Reduced Rock	Minerals
Fonolitos	k-feldspato, ilitas, Sericita, caulinita, Aegirine-augite, óxidos de Fe
Fonolitos alterados	k-feldspato, ilitas, Sericita, caulinita, Aegirine-augite, óxidos de Fe, Pirita, fluorita, pyrolusita, barita
Nefelina-sienitos	k-feldspato, ilitas, Sericita, caulinita, clinopiroxênios, Pirita, fluorita, esmectitas, montimorilonitas, cloritas, pyrolusita, barita
Brechas	k-feldspato, ilitas, Sericita, caulinita, clinopiroxênios, Pirita, fluorita, esmectitas, montimorilonitas, cloritas, Carbonatos (siderita), Ilsemannite, uraninita, calcopirita e esfarelita, pyrolusita, barita
Biotita Lamprófilos	Biotita, piroxênios, olivina, apatita, leucita, carbonatos.
2 – Wheathered zone	k-feldspato, ilitas, caulinita, ferridrita, Goethita, pyrolusita, crandalita, alunite, jarosite
3 – Laterite Soil	Caulinita, Gibbsita, ferridrita, Goethita, crandalita, alunite, jarosite.

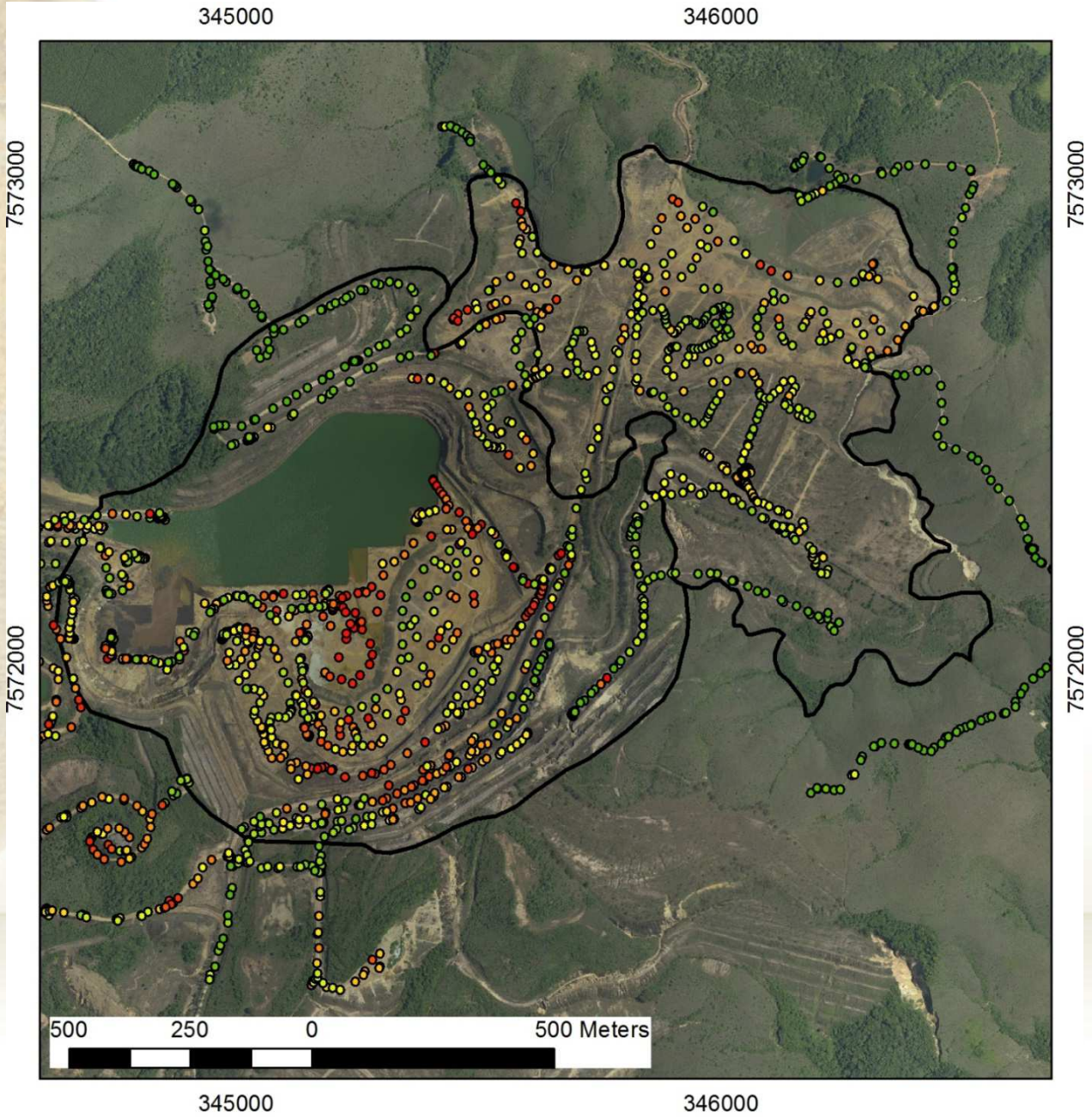
Geochemistry of Rocks



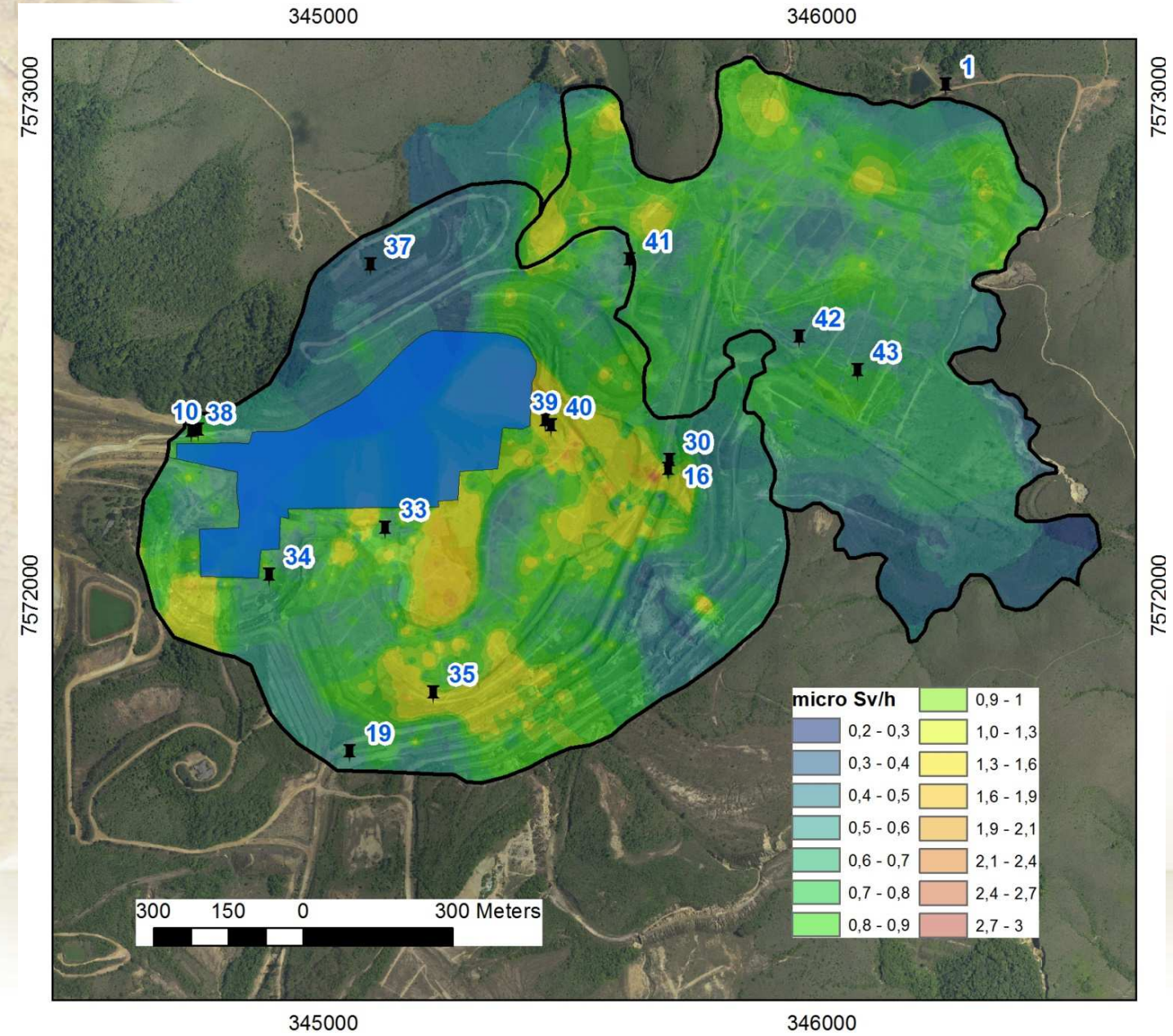
Mineral Balance



Using a mobile radioactivity system (scintillation detector and GPS)

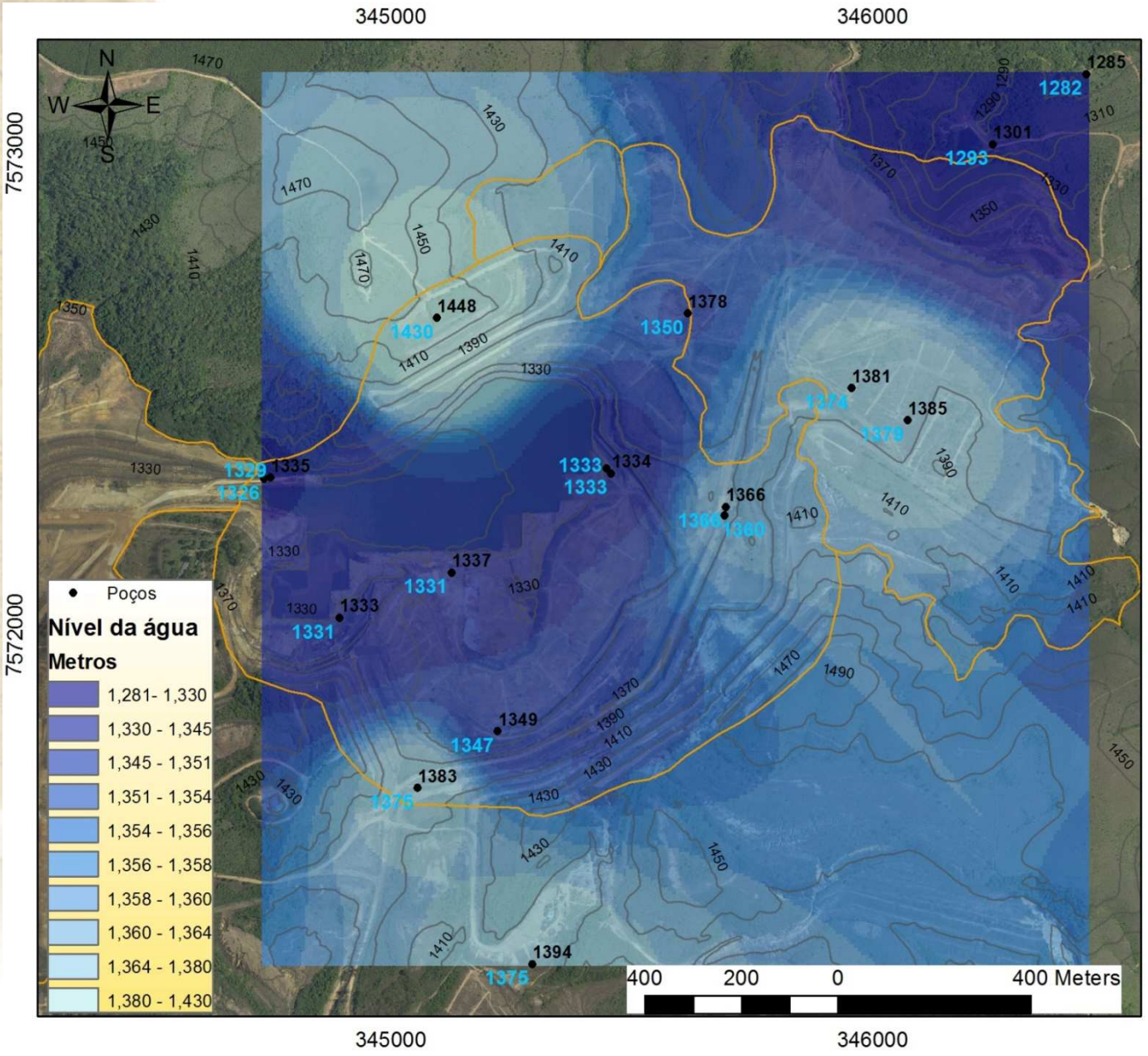


Radiometric Map



3 – Hydrodinamic

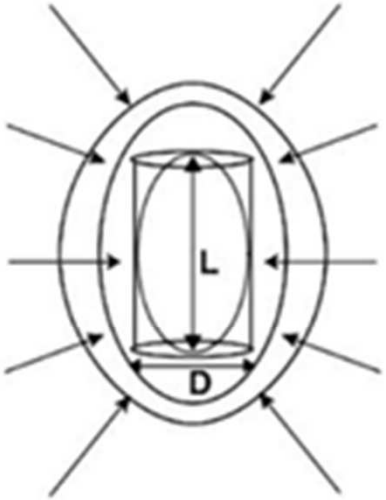
Potentiometric Map – Water level



Hydraulic Condutivity Method

FULL ELLIPSOID

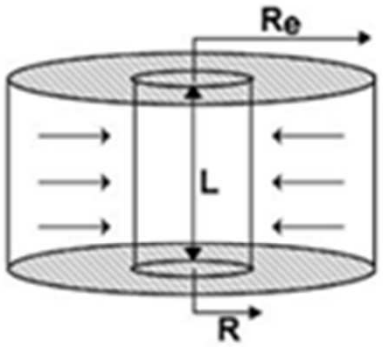
Hvorslev (1951)



$$Q = \frac{2\pi LKH}{2.303\log\left[\frac{L}{D} + \sqrt{1+\left(\frac{L}{D}\right)^2}\right]}$$

RADIAL FLOW

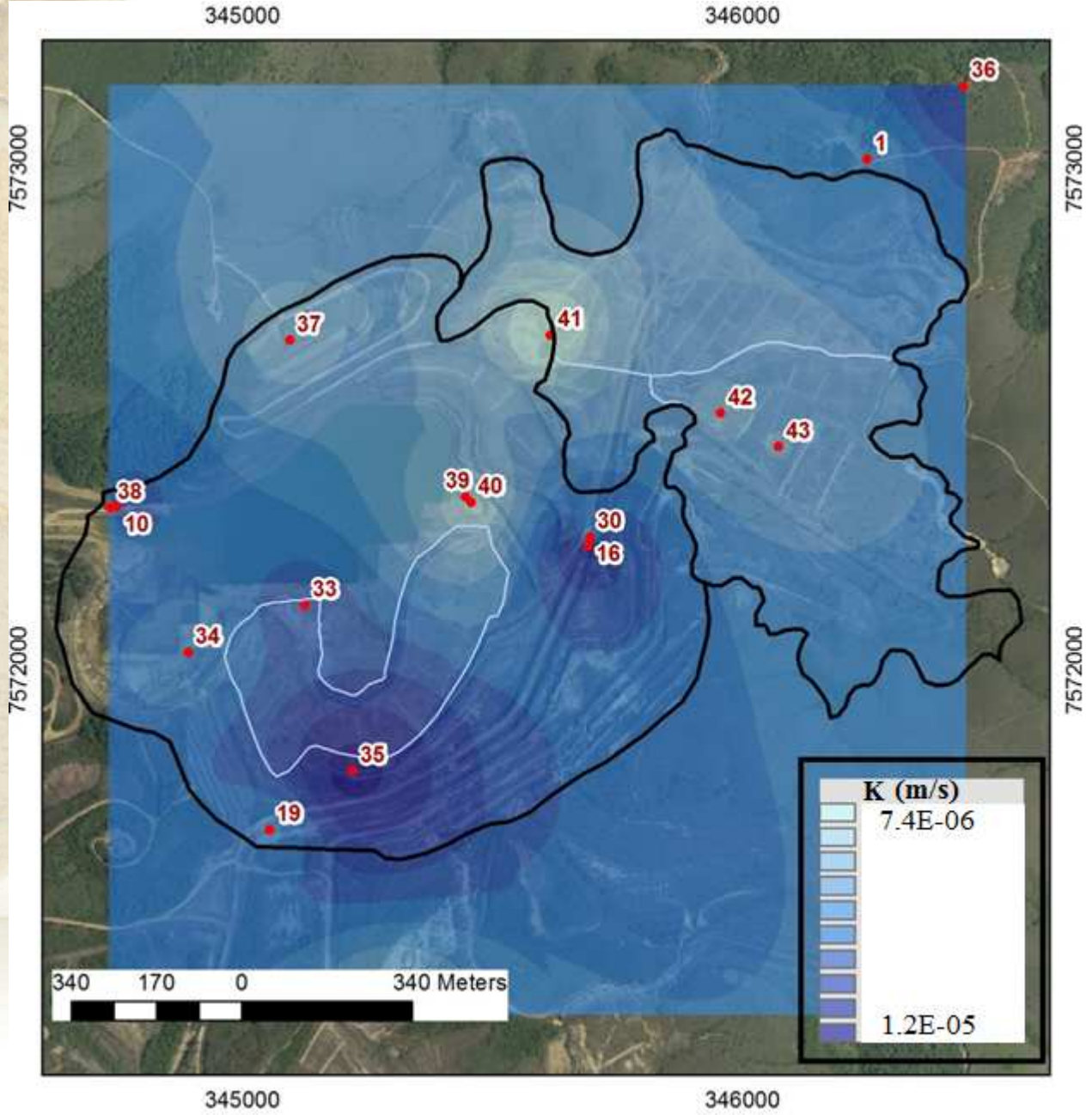
Muskat (1937)



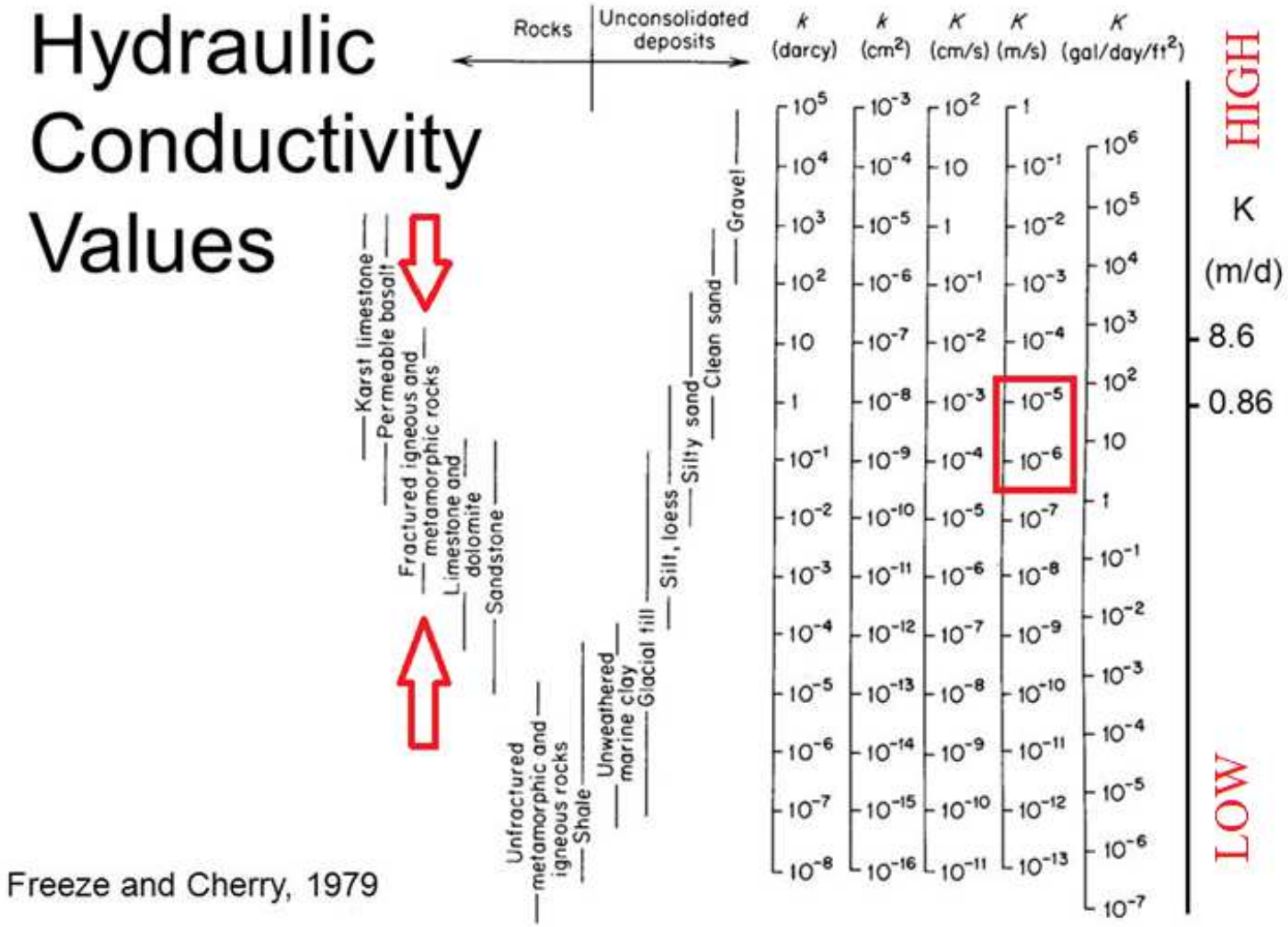
$$Q = \frac{2\pi LKH}{2.303\log[R_e/R]}$$

Onde,
Q = vazão purga;
L = comprimento da sessão filtrante;
H = nível estático do aquifero
(NA estático – NA dinânmico),
R = raio do poço (2 polegadas),
D = diametro do poço (2*R),
Re = raio de influência.

Hydraulic Condutivity Map

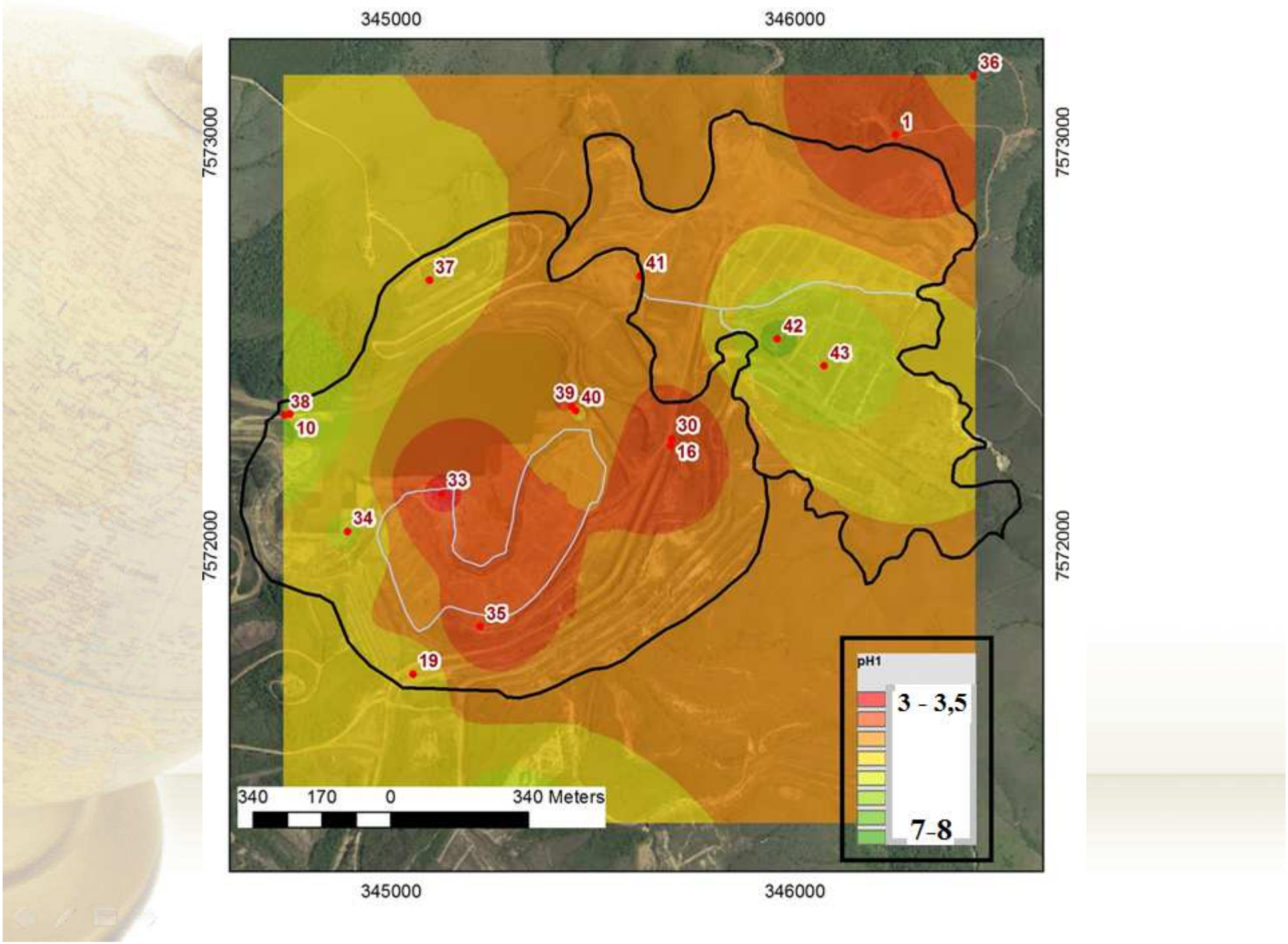


Hydraulic Conductivity Values



Freeze and Cherry, 1979

4 – Hydrochemistry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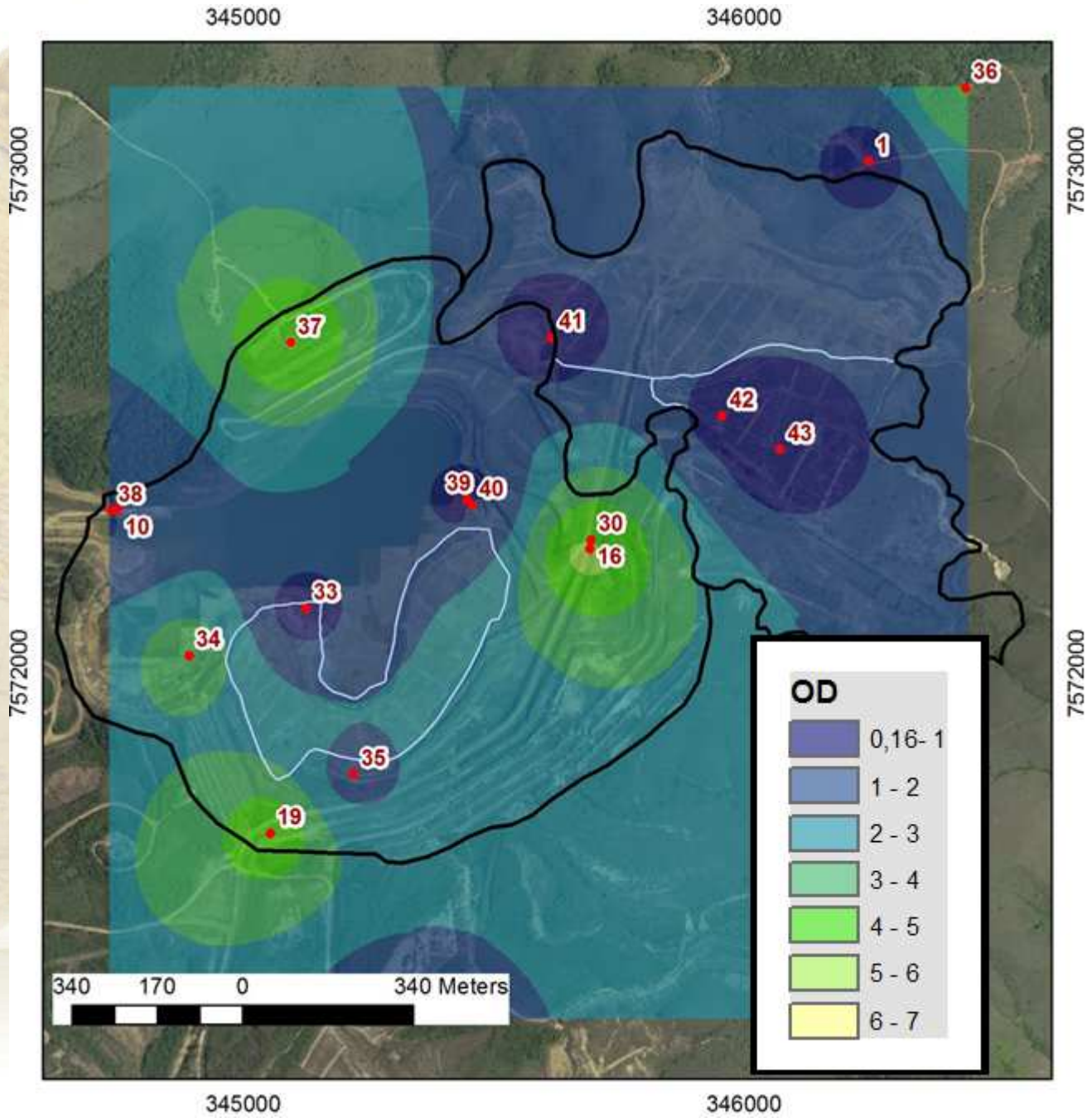
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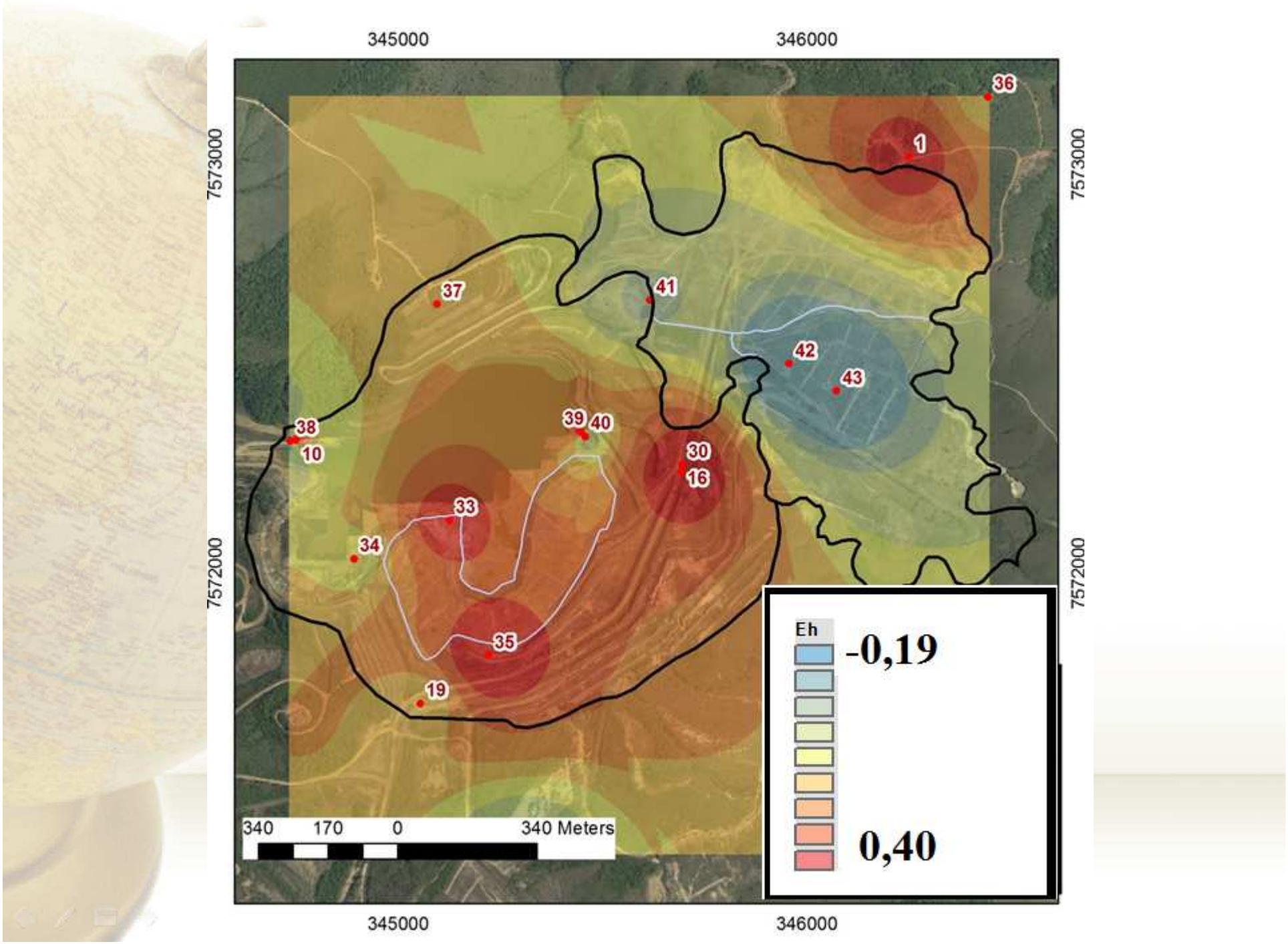
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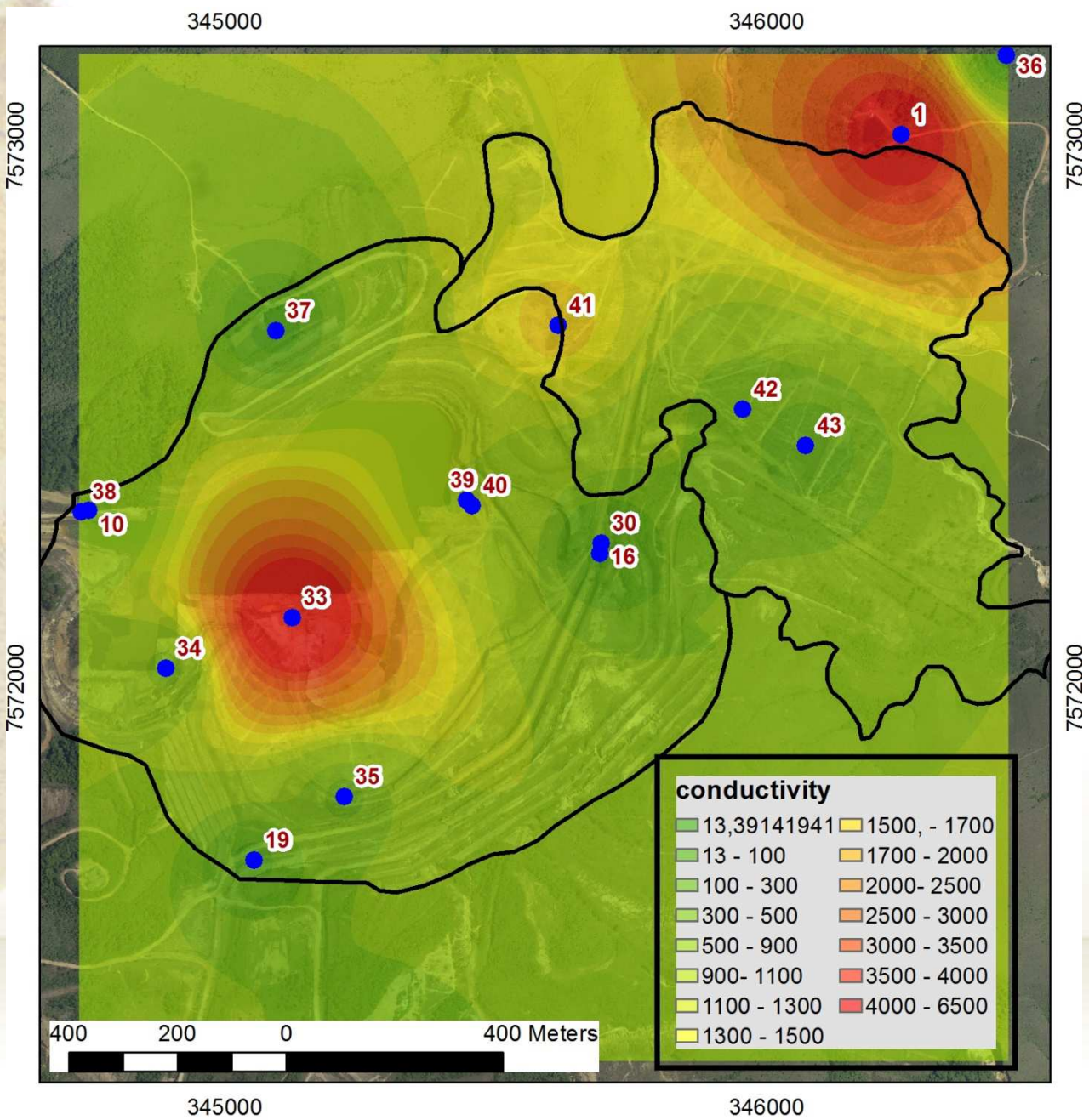
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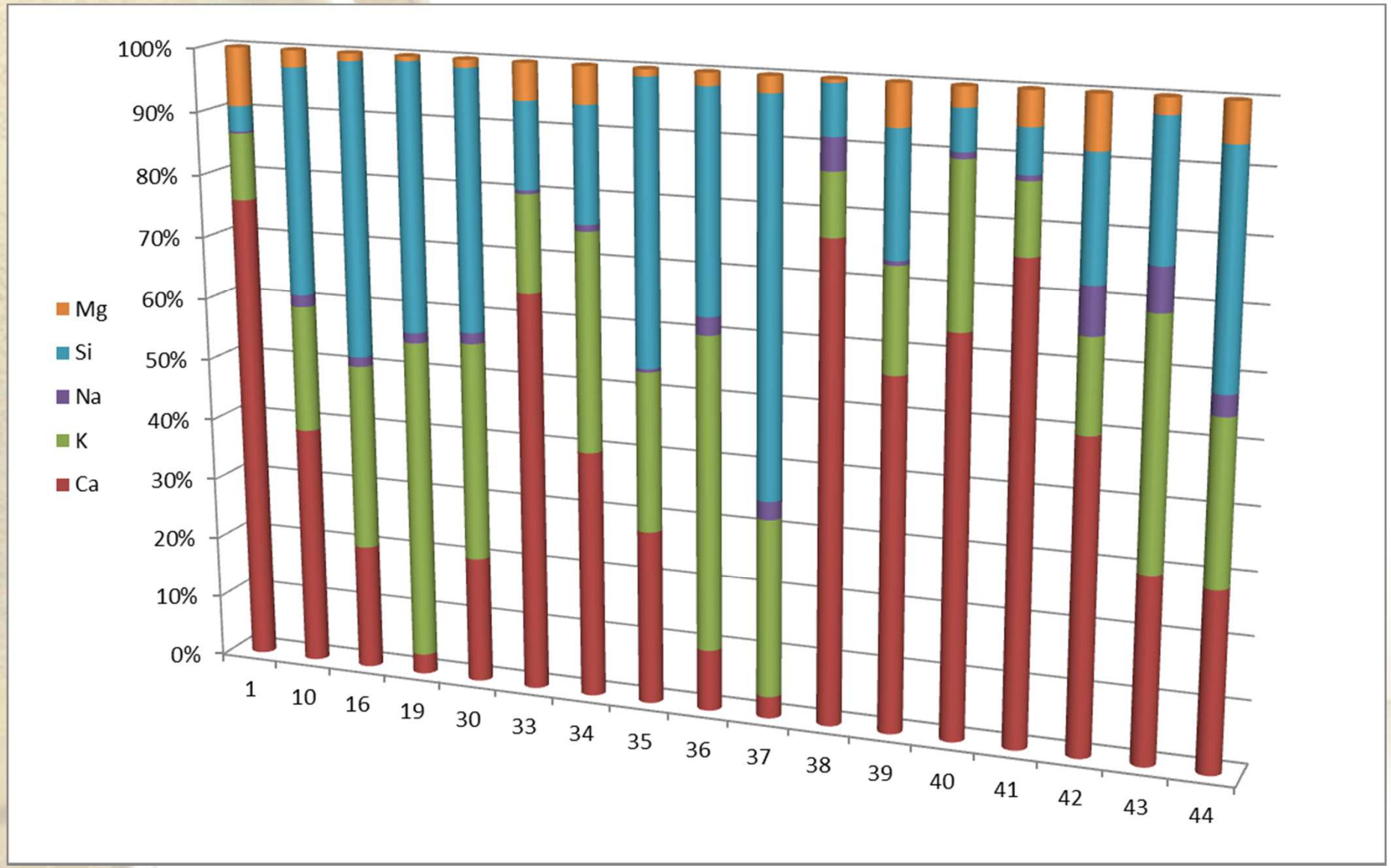
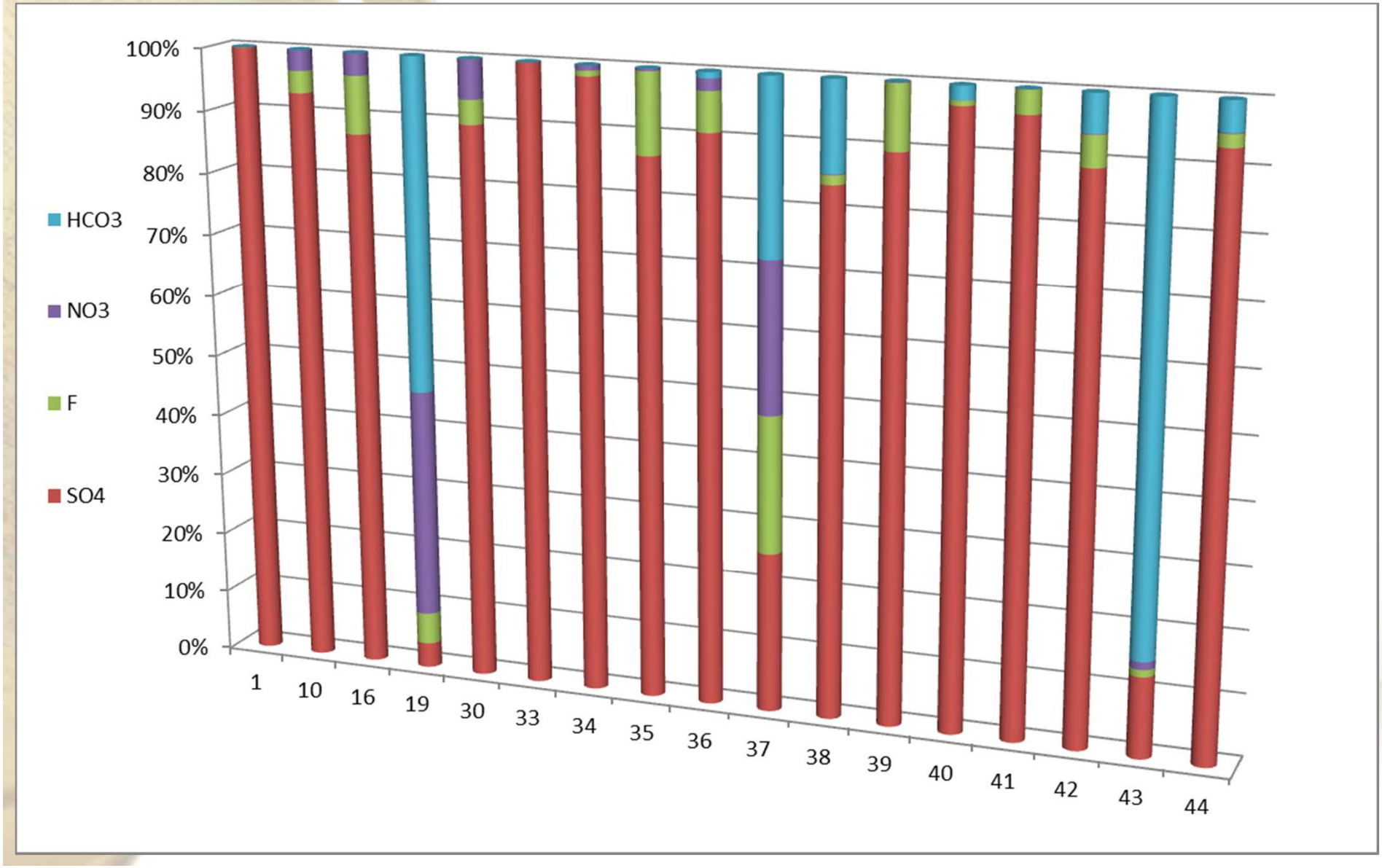
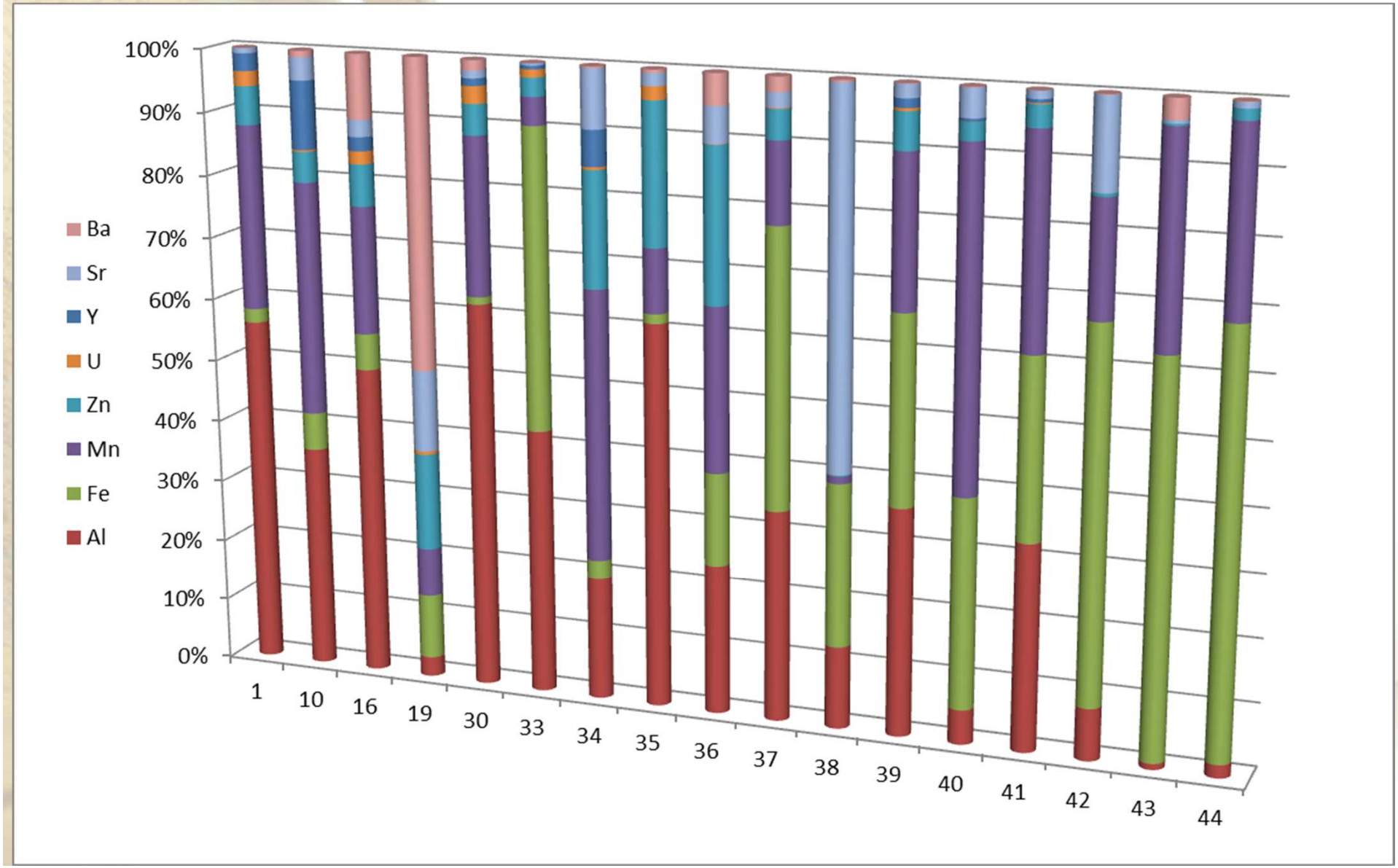
major cations



major anions

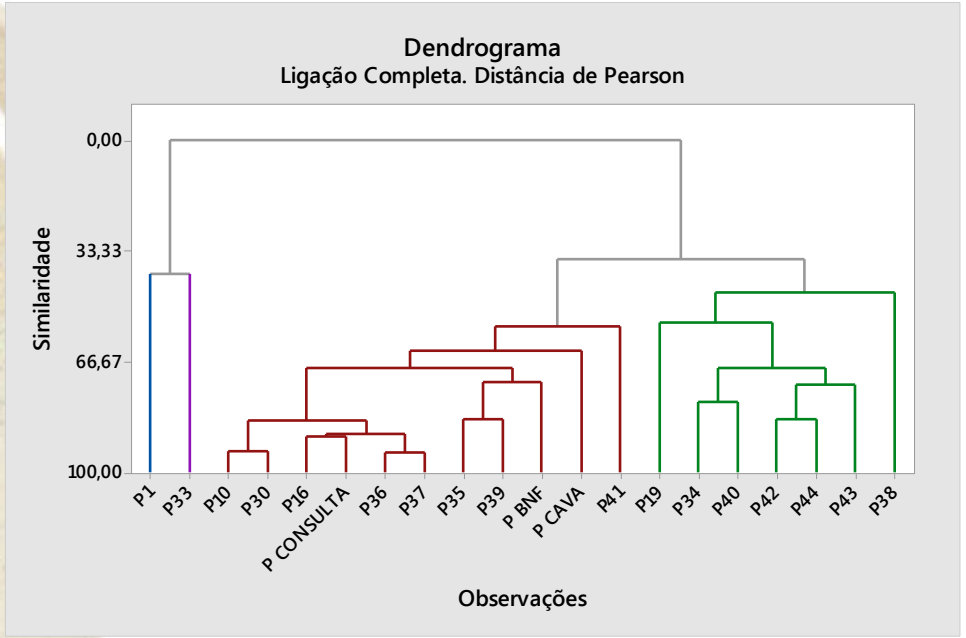


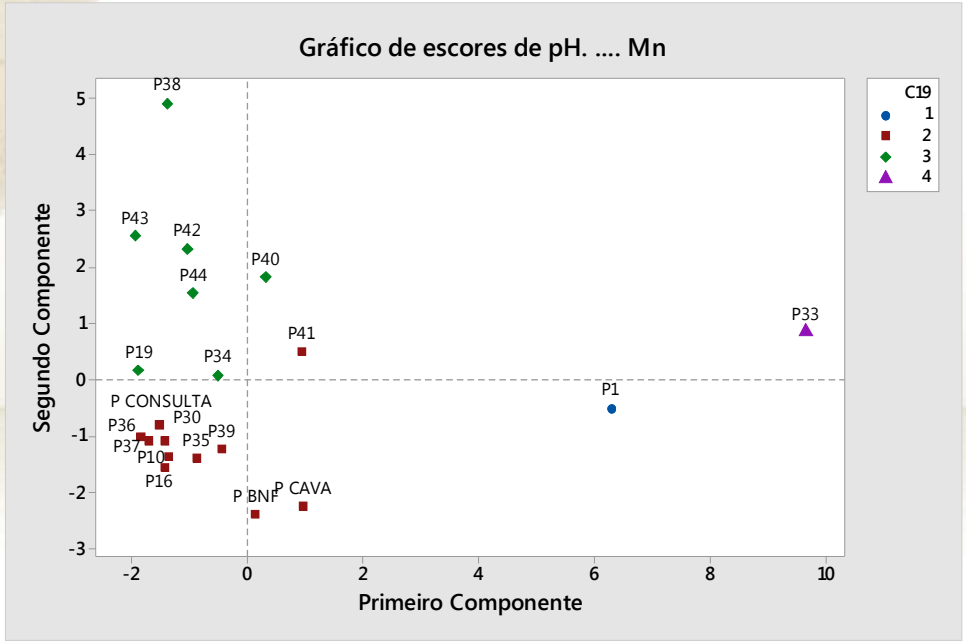
major metals



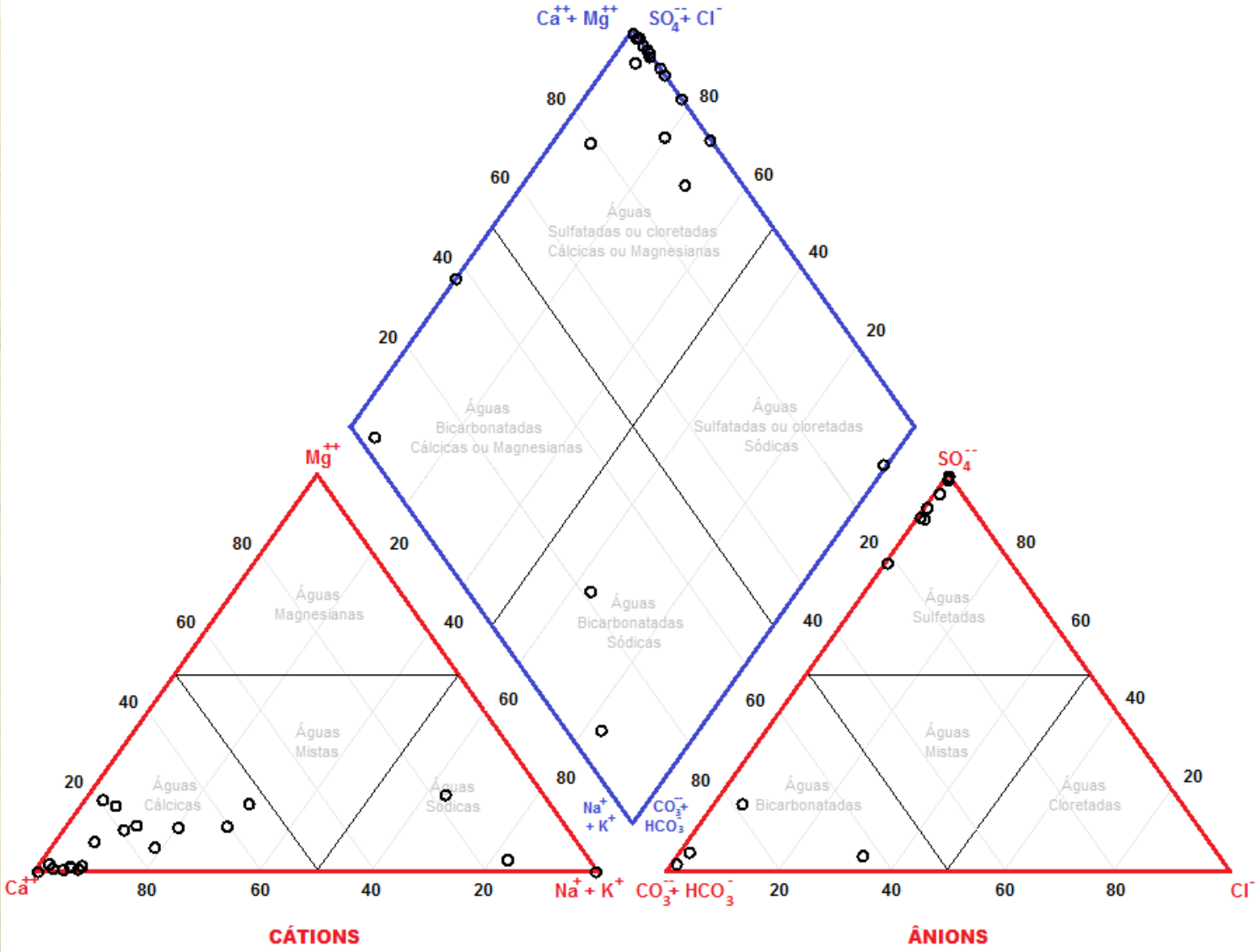
Grouping and classification of groundwater

Cluster analysis - grouping





Piper diagrams



Water classification

Amostra	Campanha 1	Campanha 2	Campanha 3
P1	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P10	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P16	Cálcica Sulfatada	Cálcica Sulfatada	Mista Sulfatada
P19	Sódica Bicarbonatada	Sódica Bicarbonatada	Sódica Bicarbonatada
P30	Mista Sulfatada	Cálcica Sulfatada	Mista Sulfatada
P33	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P34	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P35	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P36	Sódica Sulfatada	Sódica Sulfatada	Sódica Sulfatada
P37	Sódica Mista	Sódica Bicarbonatada	Sódica Bicarbonatada
P38	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P39	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P40	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P41	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P42	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
P43	Mista Bicarbonatada	Cálcica Bicarbonatada	Sódica Bicarbonatada
P44	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
Cava	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
BNF	Cálcica Sulfatada	Cálcica Sulfatada	Cálcica Sulfatada
Consulta	Sódica Bicarbonatada	Cálcica Bicarbonatada	Sódica Bicarbonatada

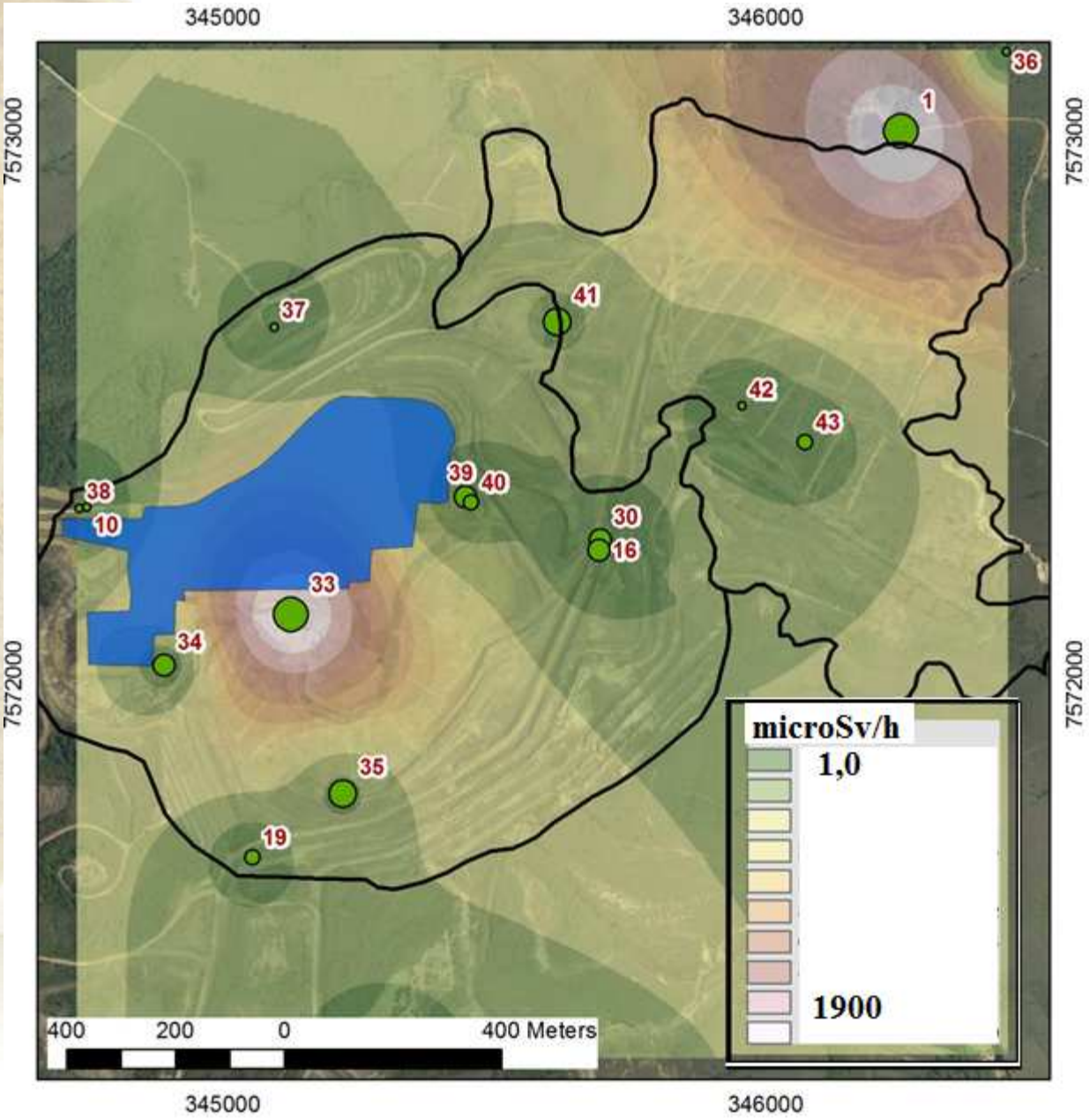
Environmental isotopes applied in hydrogeology

Radioactivity and Radon - ^{222}Rn

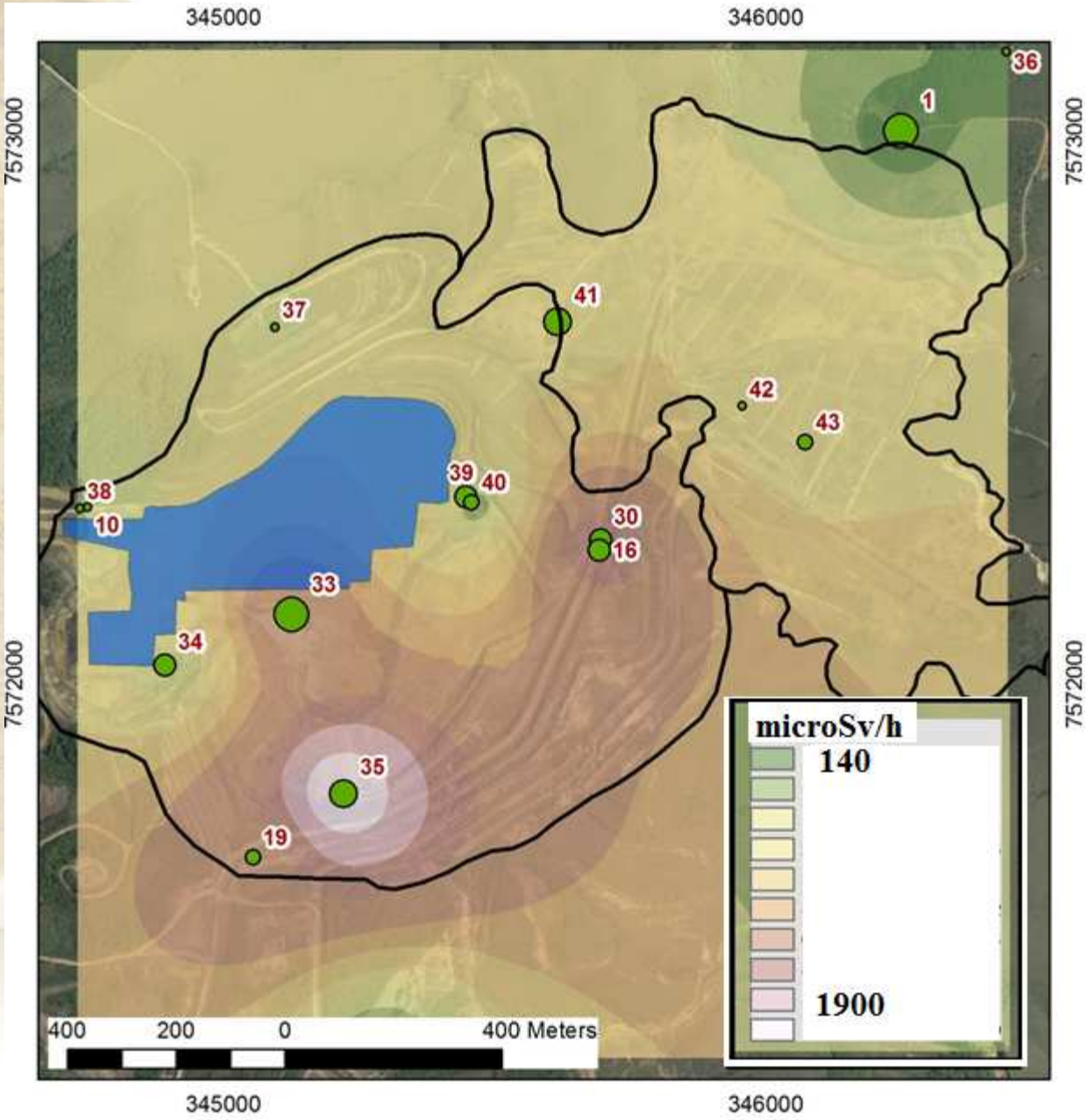
The concentrations of radon dependent basically the concentrations of Uranium and Radio in the rock

Some studies using radon as a environmental tracer for estimation groundwater flow velocities in single-well test. HAMADA (2000) and Schubert *et.al* (2010).

Total water radioactivity (U, Th, ^{228}Ra, ^{226}Ra, ^{210}Pb)

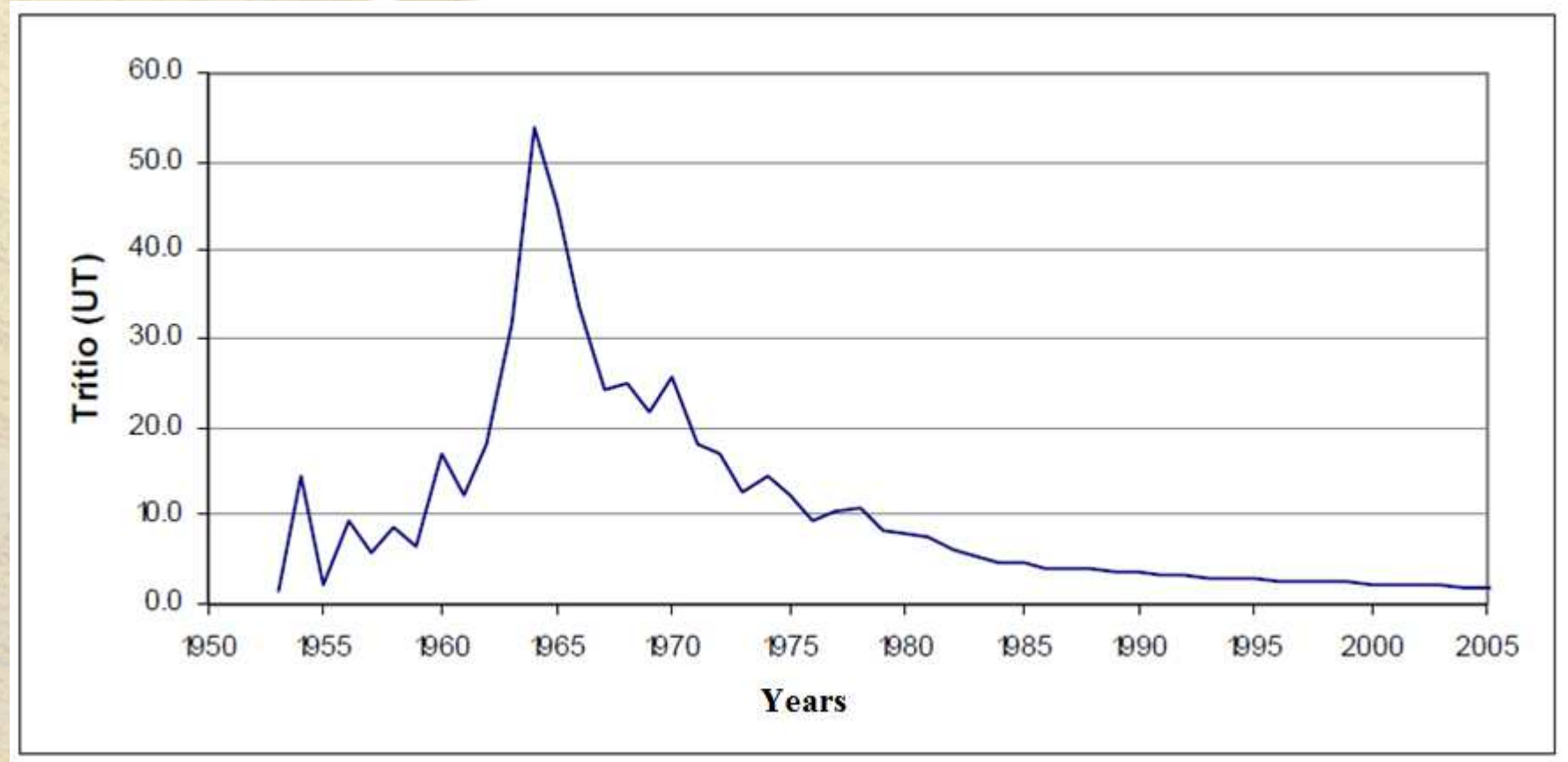


Radon - ^{222}Rn (Radiation Monitoring – ALPHAGUARD)



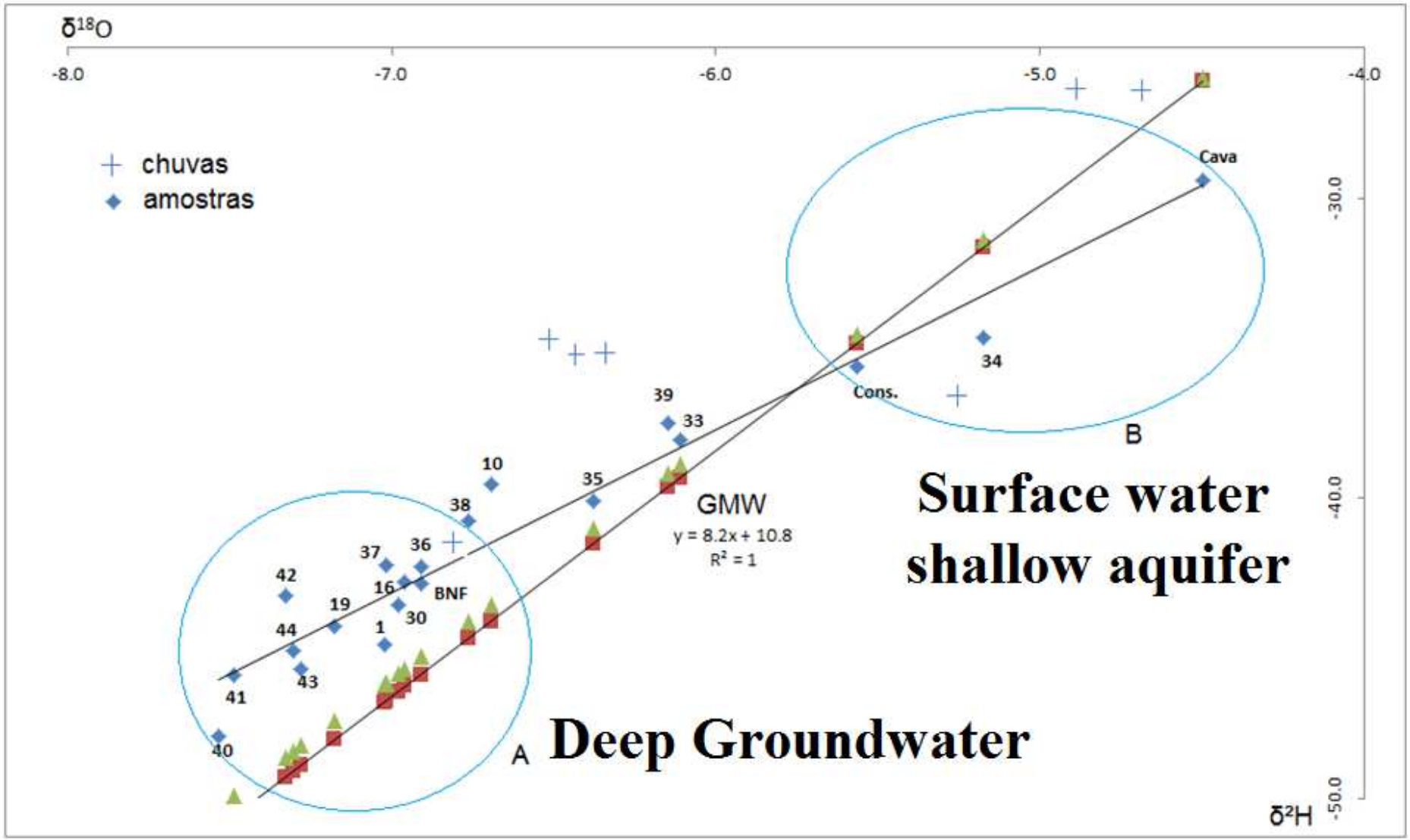
Dating groundwater / Tritium – H^3

Wells	1	10	16	19	30	33	34	35	36	37	38	39	40	41	42	43	44	Cava	BNF	Consulta
UT	1.41	2.09	1.69	1.65	1.44	1.91	1.67	1.86	2.00	1.92	1.70	1.92	0.37	1.45	1.93	1.61	1.40	1.85	1.81	2.16



Concentrations of tritium estimated for rainfall in Brazil

isotopes of oxygen and hydrogen - $^{18}O/^{2}H$



The isotopic signature
SULFUR

Atmospheric oxygen	$\delta^{18}O = 23,5‰$
Dissolved oxygen water	$\delta^{18}O = -12‰$ e $-4‰$
Oxygen in the sulfate - Groundwater	$\delta^{18}O - SO_{4=}$ -4.4 a -1,0 ‰
Sulphur - Rocks	$\delta^{34}S - SO_4 = -3,63$ a $+1,24‰$
Sulphur - Sediment	$\delta^{34}S - SO_4 = -23$ ‰
Sulphur - Groundwater	$\delta^{34}S - SO_4 = -3.06$ a $-0,31$ ‰

Sulfur isotopes

Poços	SO_4 (mg/L)	$\delta^{34}S_{SO4}$	$\delta^{18}O_{SO4}$	$\delta^{18}O_{H2O}$	x	1-x
1	4339.0	-2.79	-1.0	-7.0	0.50	0.50
10	34.3	-1.56	-2.1	-6.7	0.59	0.49
16	19.1	-1.40	-4.0	-7.0	0.92	0.08
19	<0,5			-7.2		
30	33.1	-1.28	-3.0	-7.0	0.84	0.16
33	7796.6	-1.85	-3.5	-6.1	0.74	0.26
34	163.6	-2.77	-3.9	-5.2	0.86	0.14
35	53.2			-6.4		
36	10.8	-1.79		-6.9		
37	<0,5			-7.0		
38	172.0	-3.28	-2.4	-6.8	0.62	0.38
39	264.8	-1.99	-2.9	-6.1	0.73	0.27
40	398.3	-2.56	-3.3	-7.5	0.63	0.37
41	944.9	-2.90	-1.4	-7.5	0.48	0.52
42	72.1	-3.72	-4.3	-7.3	0.72	0.28
43	0.8	-2.04	-3.4	-7.3	0.65	0.35
44	68.6			-7.3		
Cava	991.5	-0.31	-3.5	-4.5	0.90	0.10
BNF	415.3	-3.06	-4.4	-6.9	0.76	0.24
Consulta	<0,5			-5.6		

(X) The oxidation of the pyrite due to the oxygen present on the water
(1-X) The oxidation of the pyrite by oxygen in the air

Main chemical species and chemical complexs PHREEQC

Elemento	Espécie Química
Ca	Ca+2
	CaSO4
K	K+
	KSO4-
Na	Na+
	NaSO4-
Si	SiO2
	HSiO3-
Mg	Mg+2
	MgSO4
S(6)	SO4-2
	AlSO4+
F	AlF+2
	F-

Elemento	Espécie Química
N(5)	NO3-
	CaNO3+
Al	AlSO4+
	AlF+2
Fe+2	Fe+2
	FeSO4
Fe+3	Fe(OH)3
	Fe+3
Mn	Mn+2
	MnSO4
Zn	Zn+2
	ZnSO4
U4	U(OH)4
	UF3+

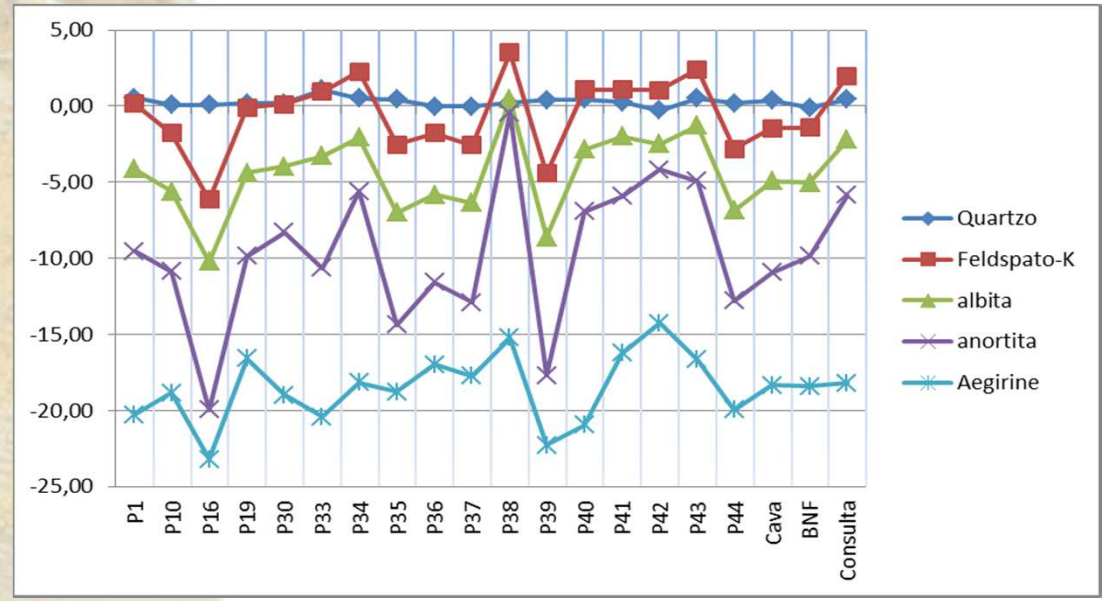
Elemento	Espécie Química
U6	UO2SO4
	UO2+2
Y	Y+3
	YSO4+
Sr	Sr+2
	SrSO4
Ba	Ba+2
	BaNO3+
Cd	Cd+2
	CdSO4
Pb	Pb+2
	PbNO3+

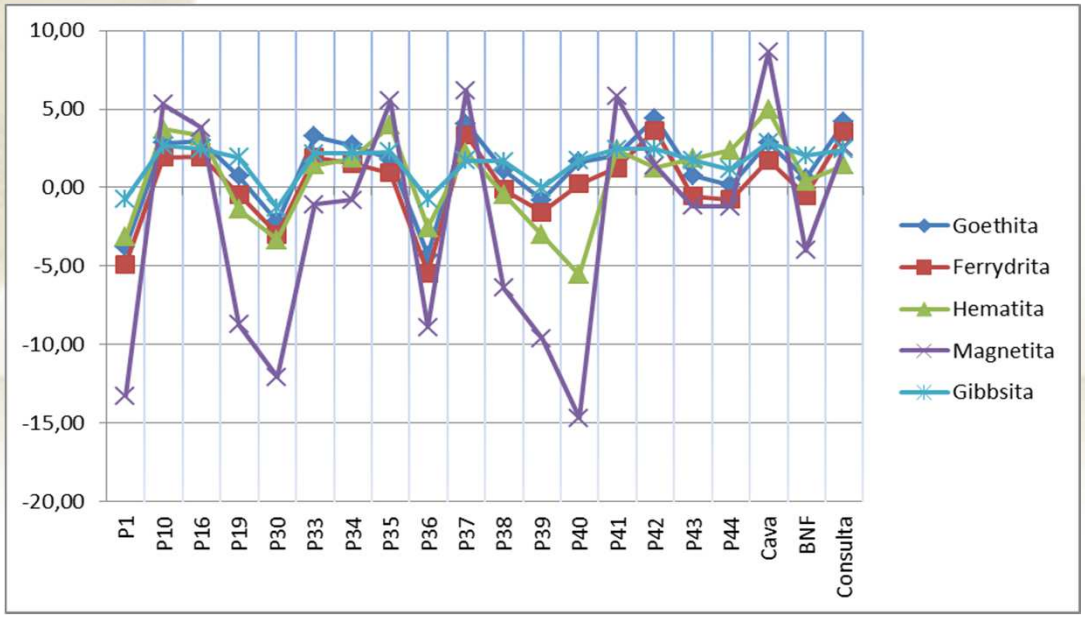
	U(6)/U(4)			Fe(3)/Fe(2)		
	Campanha 1	Campanha 2	Campanha 3	Campanha 1	Campanha 2	Campanha 3
P1	2,33E+05	1,06E+06	4,63E+08	4,21E-07	6,901E-08	4,644E-06
P10	3,34E+06	1,58E+05	3,45E+09	9,38E-05	3,33E-03	1,54E-03
P16	7,14E+02	5,01E+04	5,55E+08	1,73E-07	6,81E-05	9,33E-04
P19	4,65E+02	0,00E+00	2,52E+02	2,31E-04	1,78E-02	0,00E+00
P30	7,55E+04	3,95E+03	2,68E+08	8,29E-05	5,59E-06	3,42E-04
P33	1,61E+04	1,33E+03	2,34E+07	2,70E-08	1,47E-09	4,25E-07
P34	9,24E+00	5,43E+04	1,27E+01	3,01E-06	1,02E-04	6,77E-08
P35	7,61E+09	4,92E+06	8,59E+09	1,61E-03	1,22E-03	4,23E-05
P36	4,76E+04	0,00E+00	0,00E+00	2,69E-04	1,86E-02	1,65E-05
P37	7,70E+03	0,00E+00	0,00E+00	7,20E-05	1,35E-08	2,60E-05
P38	**2,15E-07**	0,00E+00	0,00E+00	1,85E-07	2,21E-04	3,36E-02
P39	1,66E+03	6,84E+05	4,34E+09	4,73E-08	7,83E-06	1,50E-04
P40	**1,09E-04**	**5,29E-05**	**1,29E-04**	6,44E-09	7,56E-10	3,75E-09
P41	**1,23E-05**	**4,00E-09**	**6,83E-03**	2,23E-10	6,13E-13	7,03E-10
P42	**5,43E-05**	**1,10E-03**	0,00E+00	9,67E-08	4,89E-07	5,23E-09
P43	**1,17E-02**	0,00E+00	0,00E+00	8,69E-06	6,76E-06	9,44E-07
P44	**1,08E-04**	0,00E+00	0,00E+00	9,13E-08	5,93E-07	1,26E-06
Cava	1,12E+09	7,92E+08	9,99E+08	3,95E-05	4,68E-04	3,36E-05
BNF	6,94E+11	1,34E+12	7,01E+11	3,48E-03	7,51E-03	1,37E-03
onsulta	0,00E+00	0,00E+00	0,00E+00	4,912E-06	0,0353742	8,093E-06

More the water is oxidizing
the ratio of U^{+6} / U^{+4} is higher
higher mobility of uranium in the solution.

Main chemical species - PHREEQC

precipitation or solubilization





Main chemical species - PHREEQC

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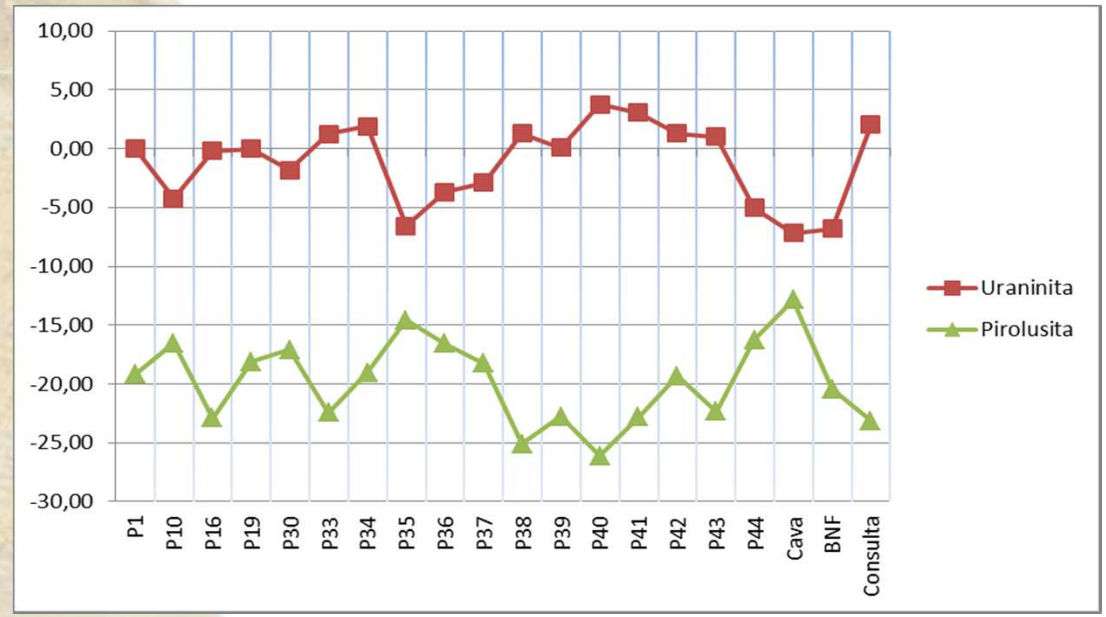
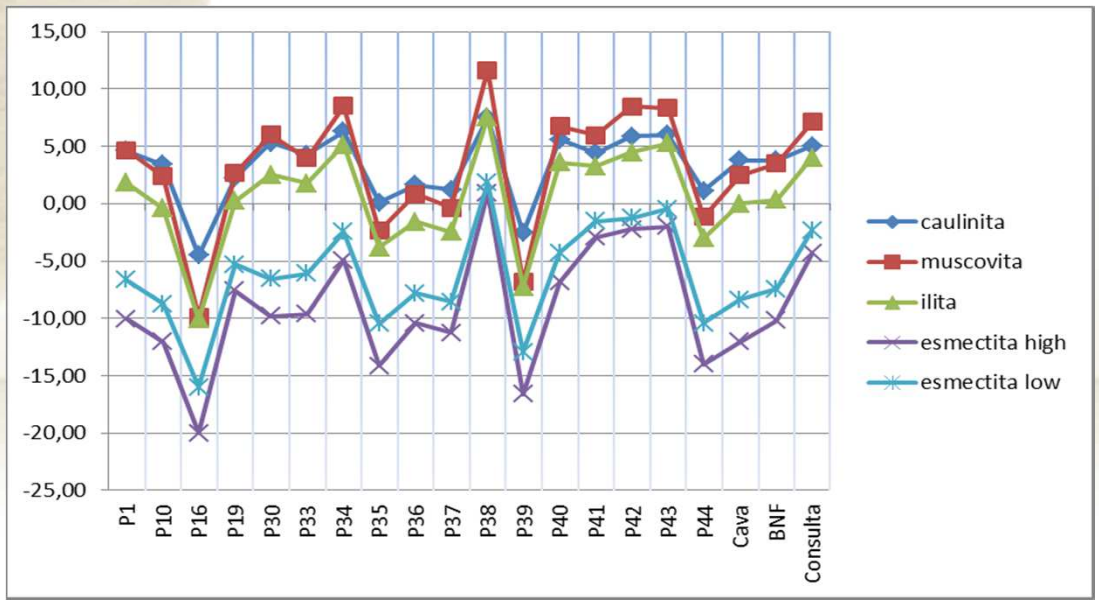
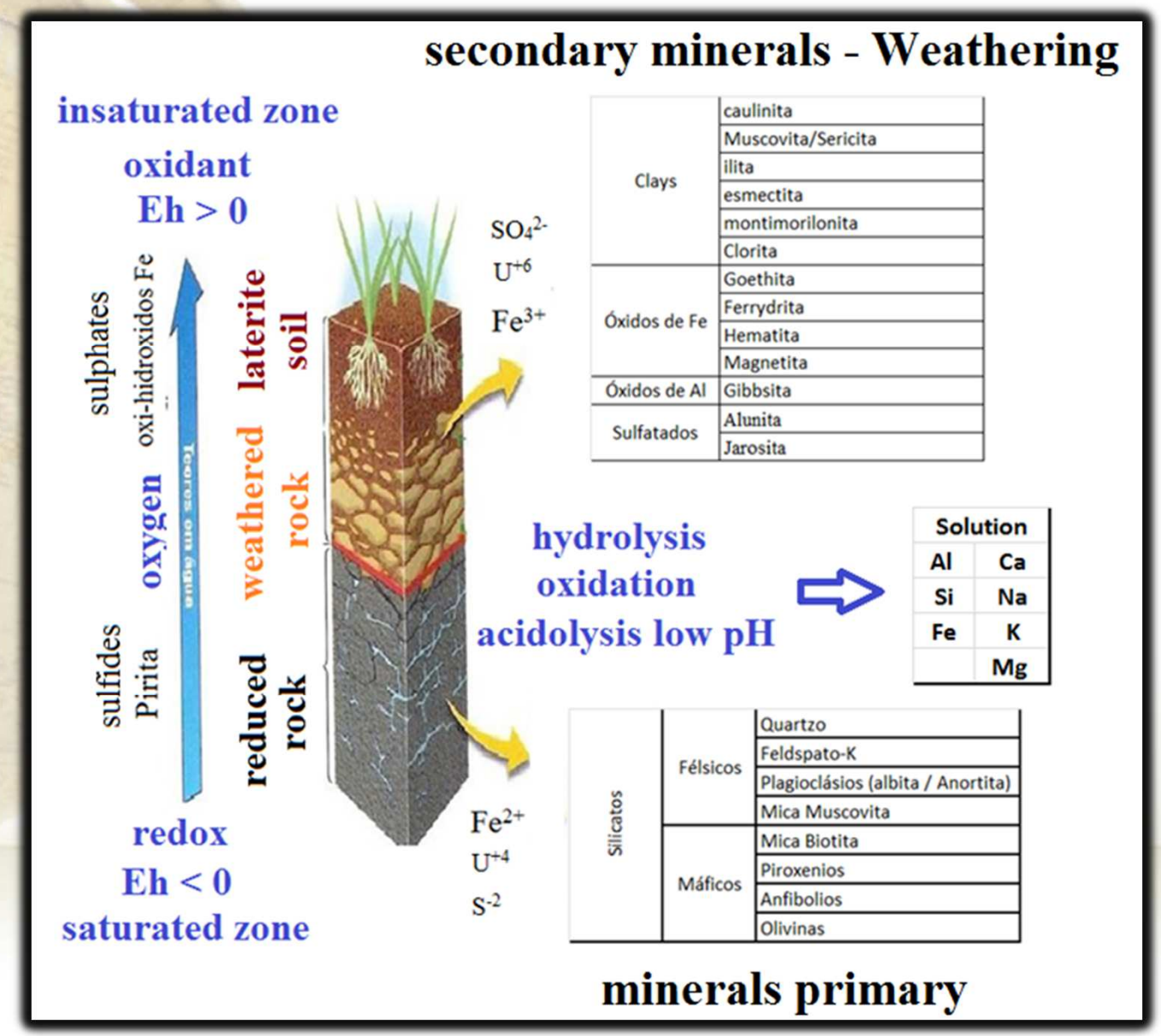


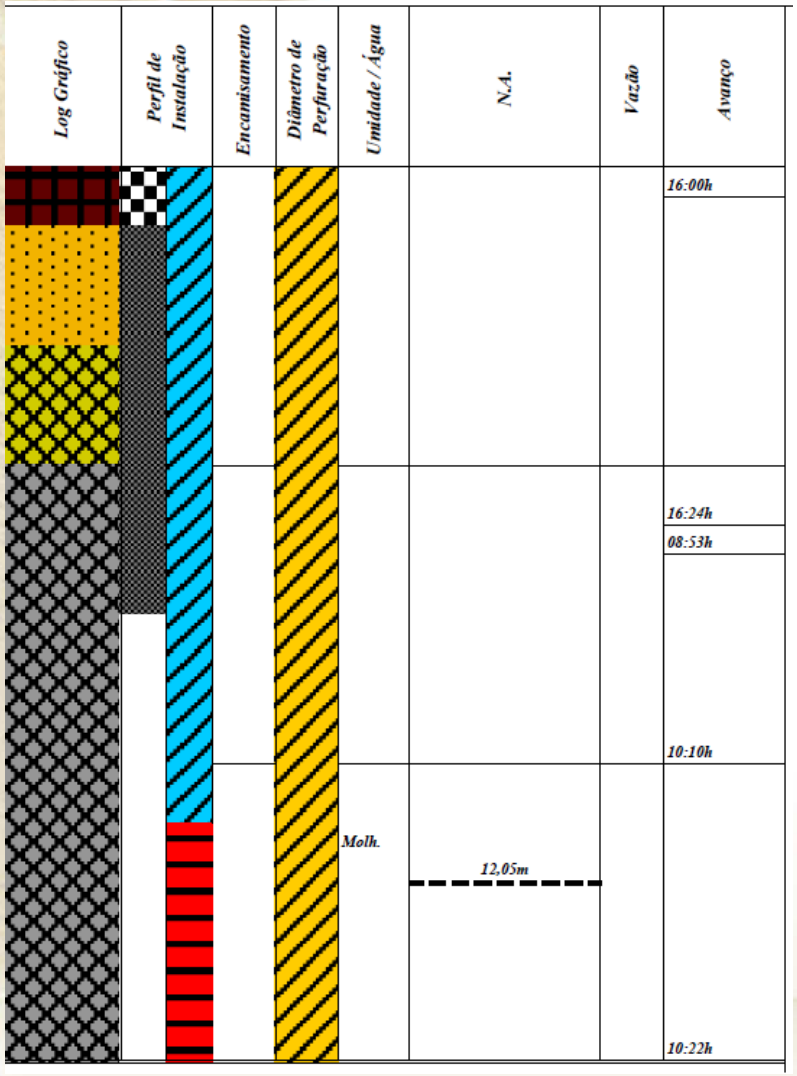


5 - Hidrogeochemistry Conceptual Model



Schematic geological section

Wells profile



Minerals

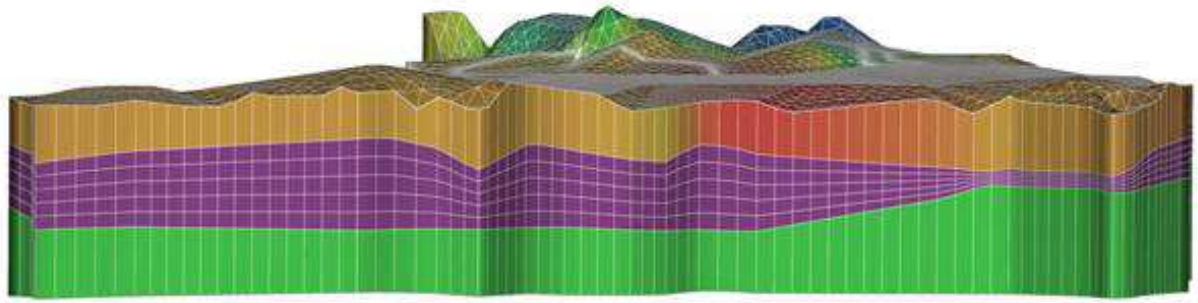
Caulinta	stage III
Gibbsita	
Óxidos e hidroxidos de Fe	
Muscovita, ilita	stage II
Esmectitas	
Calcita, dolominta e apatita	stage I
Olivina, anfibolios e piroxênios	
Biotita, clorita	
Albita plagioclásios	
Quartzo	

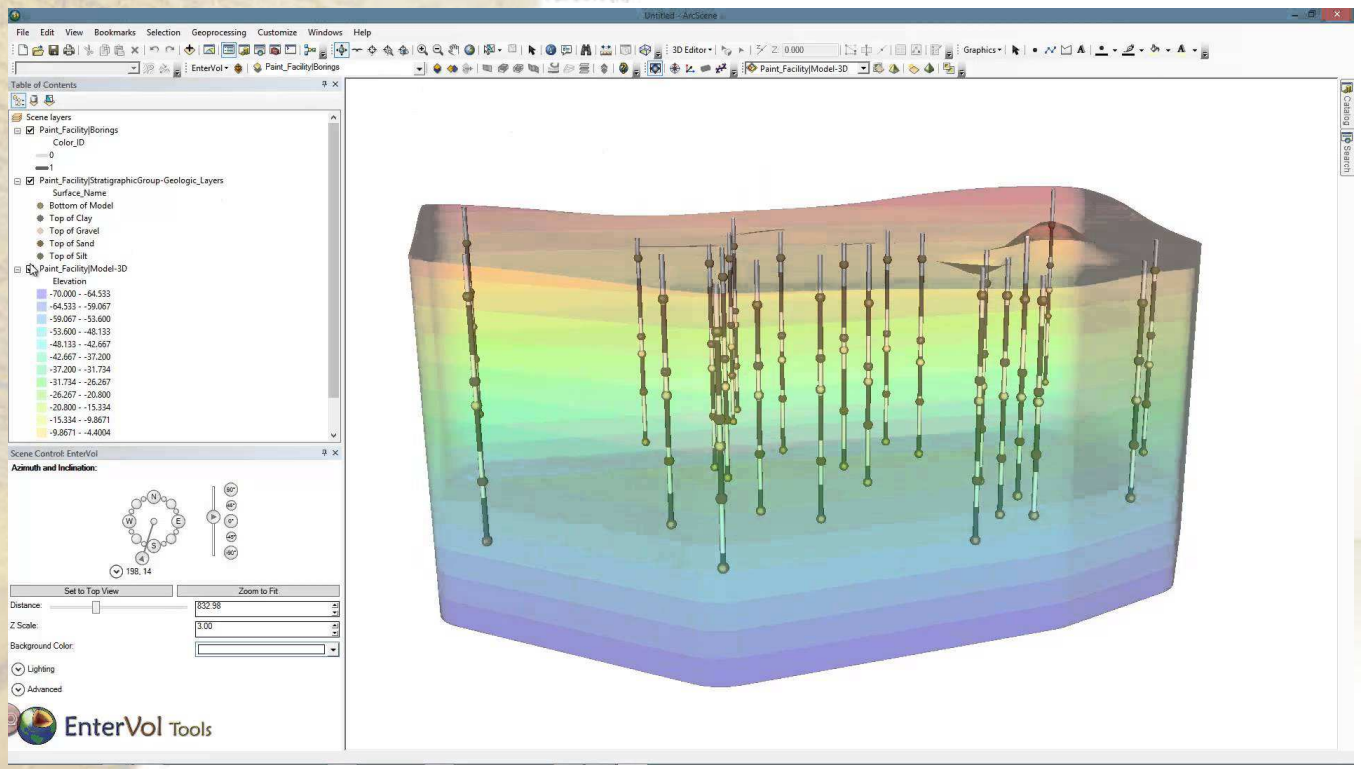
NEXT STEP
Geology Stratigraphic Models

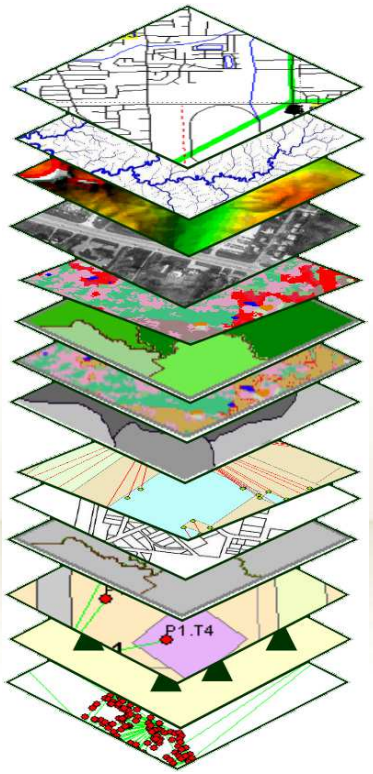
Future Softwares:

FEFLOW

ArcGis groundwater







Thank you!!!