UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Integrated groundwater management model for underground coal gasification plants

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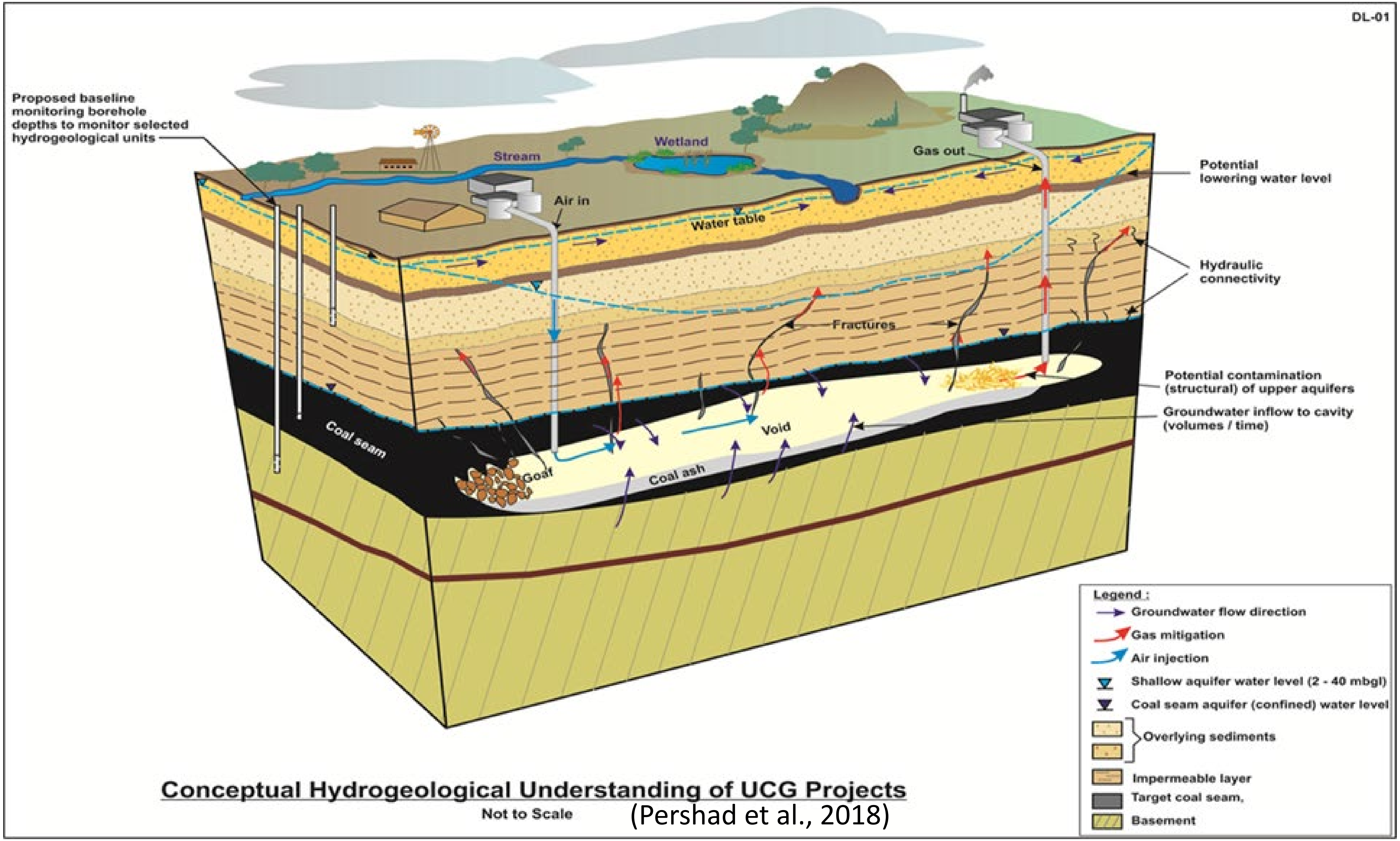
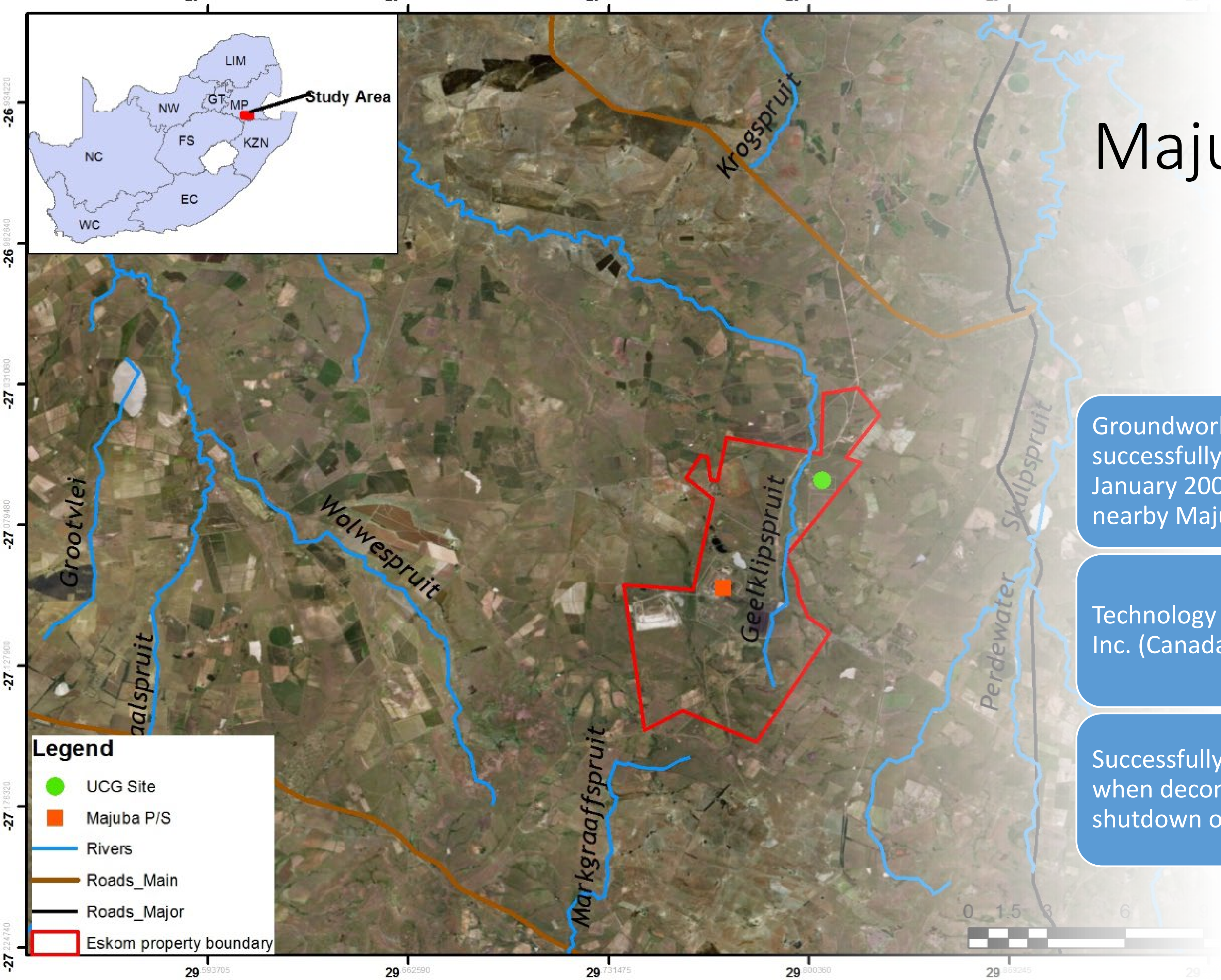
Presentation outline

- Brief outline of UCG
- Majuba UCG plant
- Mineralogical assessment of the spent gasifier
- Leaching dynamics of post gasification products
- Pathways of groundwater contamination
- Conclusions



(Pershad et al., 2018)



Majuba UCG Pilot Plant

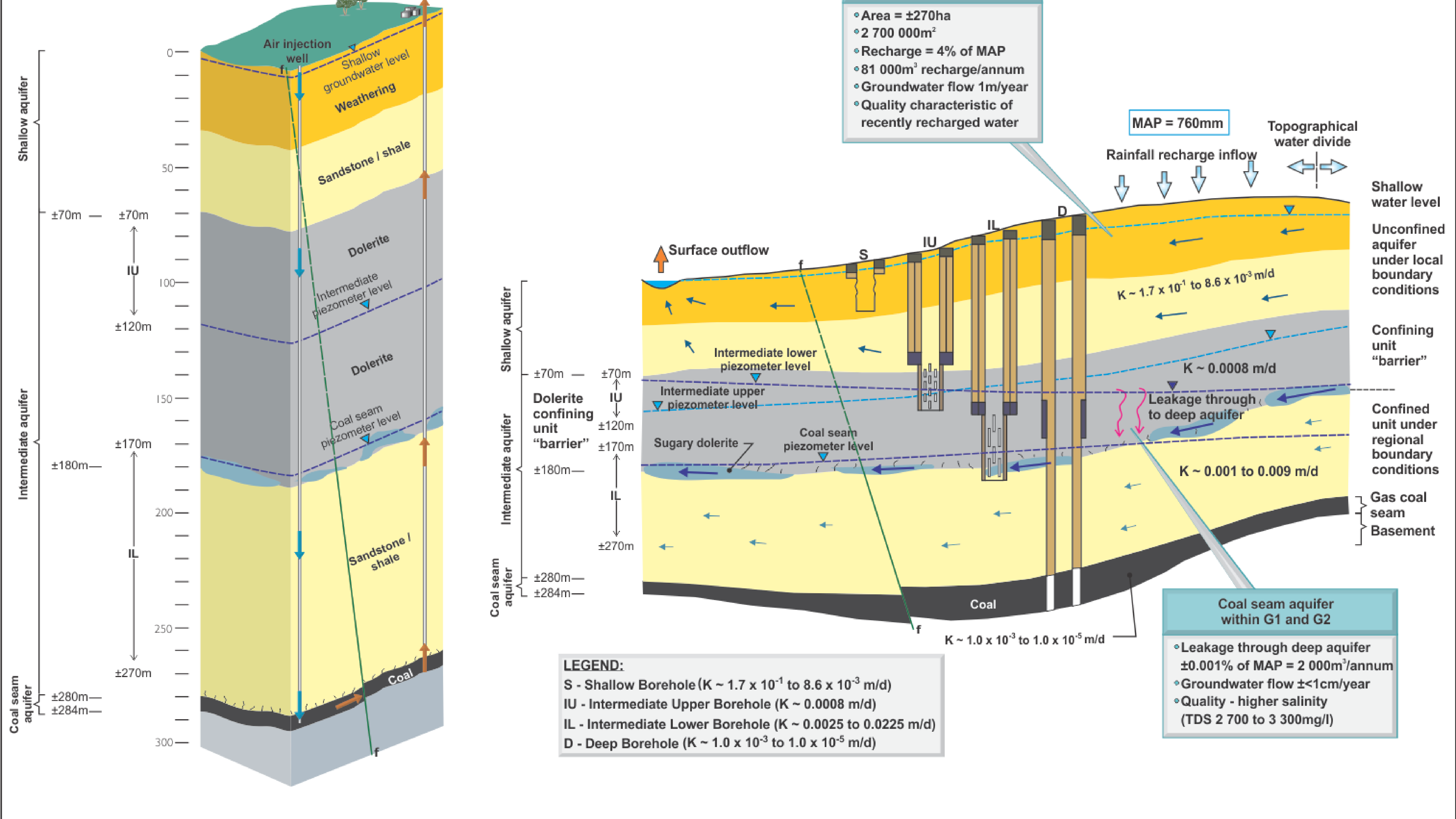
Groundwork began around 2001 and a pilot plant was successfully commissioned at Majuba coalfield in January 2007 with product gas being co-fired into the nearby Majuba Power station by October 2010.

Technology provider was Ergo Exergy Technologies Inc. (Canada)

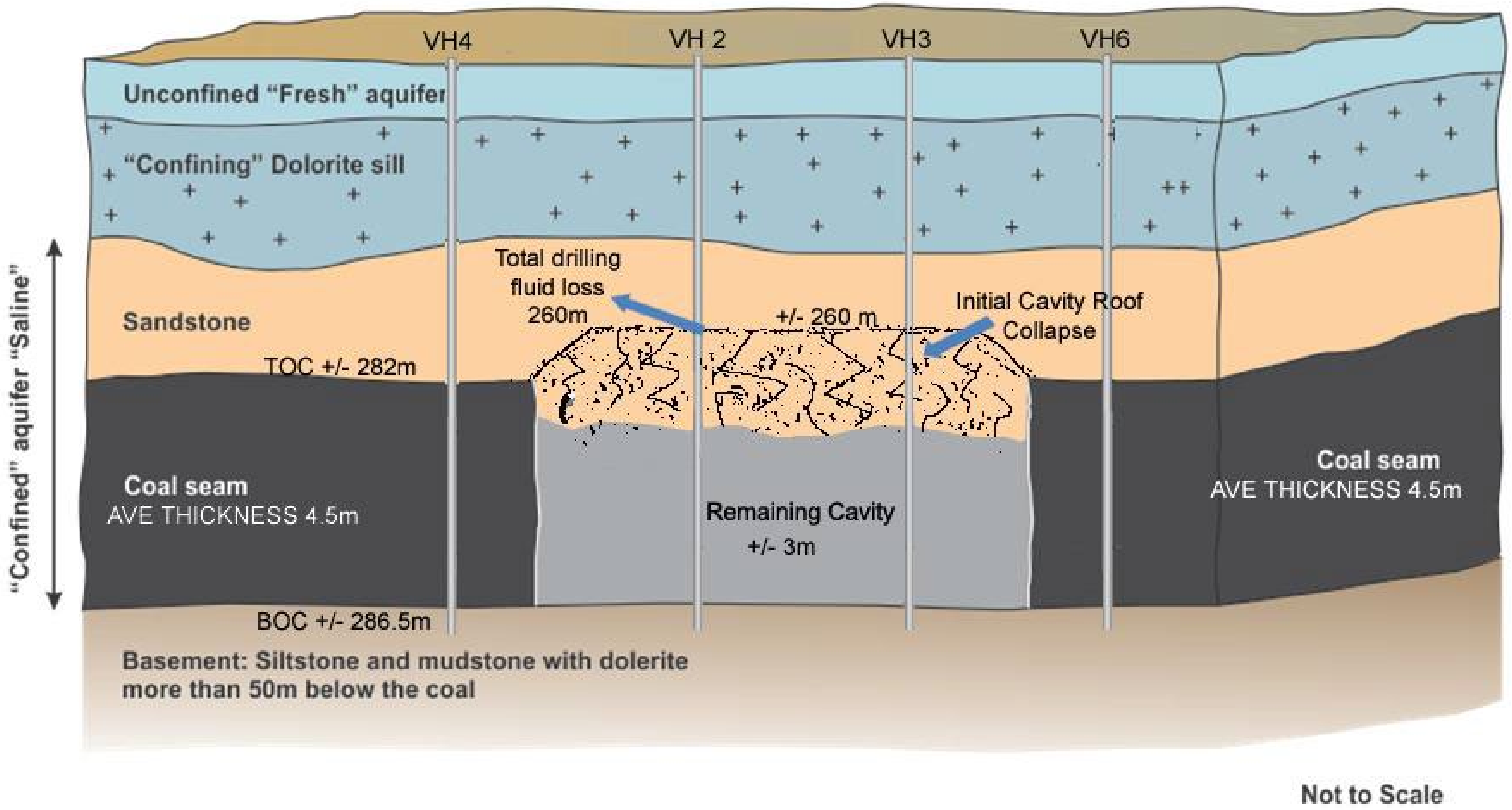
Successfully operated through to September 2011 when decommissioning commenced with the shutdown of the gasifier (G1)

Eskom Majuba UCG

- The gasifier was formally declared shutdown in June 2015
- The successful shutdown of G1 presented an opportunity to investigate some of the key environmental questions regarding groundwater contamination

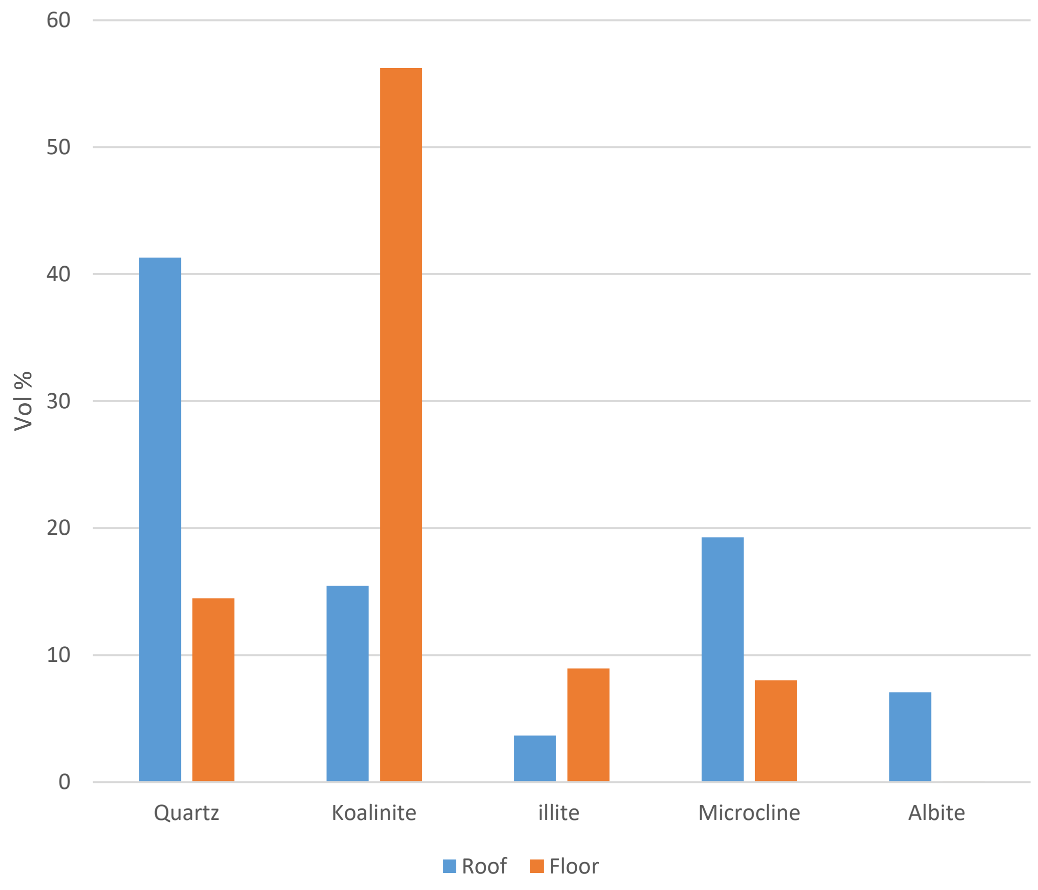


Shallow aquifer
Intermediate aquifer
Coal seam aquifer
±70m
±70m
IU
±120m
±170m
±180m
IL
±270m
±280m
±284m
0
50
100
150
200
250
300
Air injection well
Shallow groundwater level
Weathering
Sandstone / shale
Dolerite
Intermediate piezometer level
Dolerite
Coal seam piezometer level
Sandstone / shale
Coal
f
f
Area = ±270ha
2 700 000m²
Recharge = 4% of MAP
81 000m³ recharge/annum
Groundwater flow 1m/year
Quality characteristic of recently recharged water
MAP = 760mm
Topographical water divide
Rainfall recharge inflow
Shallow water level
Unconfined aquifer under local boundary conditions
Confining unit "barrier"
Confined unit under regional boundary conditions
Gas coal seam
Basement
Surface outflow
S
IU
IL
D
K ~ 1.7 x 10⁻¹ to 8.6 x 10⁻³ m/d
K ~ 0.0008 m/d
Leakage through to deep aquifer
K ~ 0.001 to 0.009 m/d
Intermediate lower piezometer level
Intermediate upper piezometer level
Sugary dolerite
Coal seam piezometer level
Dolerite confining unit "barrier"
±70m
±70m
IU
±120m
±170m
±180m
IL
±270m
±280m
±284m
Shallow aquifer
Intermediate aquifer
Coal seam aquifer
Coal
K ~ 1.0 x 10⁻³ to 1.0 x 10⁻⁵ m/d
f
f
Coal seam aquifer within G1 and G2
Leakage through deep aquifer ±0.001% of MAP = 2 000m³/annum
Groundwater flow ±<1cm/year
Quality - higher salinity (TDS 2 700 to 3 300mg/l)
LEGEND:
S - Shallow Borehole (K ~ 1.7 x 10⁻¹ to 8.6 x 10⁻³ m/d)
IU - Intermediate Upper Borehole (K ~ 0.0008 m/d)
IL - Intermediate Lower Borehole (K ~ 0.0025 to 0.0225 m/d)
D - Deep Borehole (K ~ 1.0 x 10⁻³ to 1.0 x 10⁻⁵ m/d)

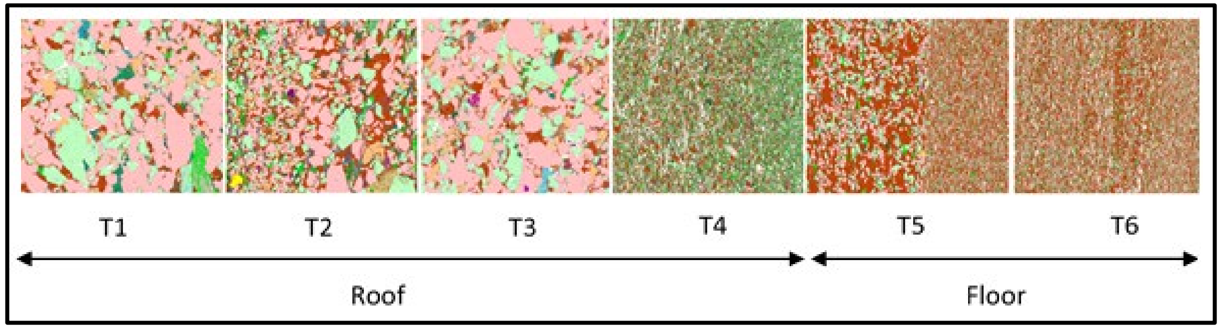


Verification drilling

Primary mineralization

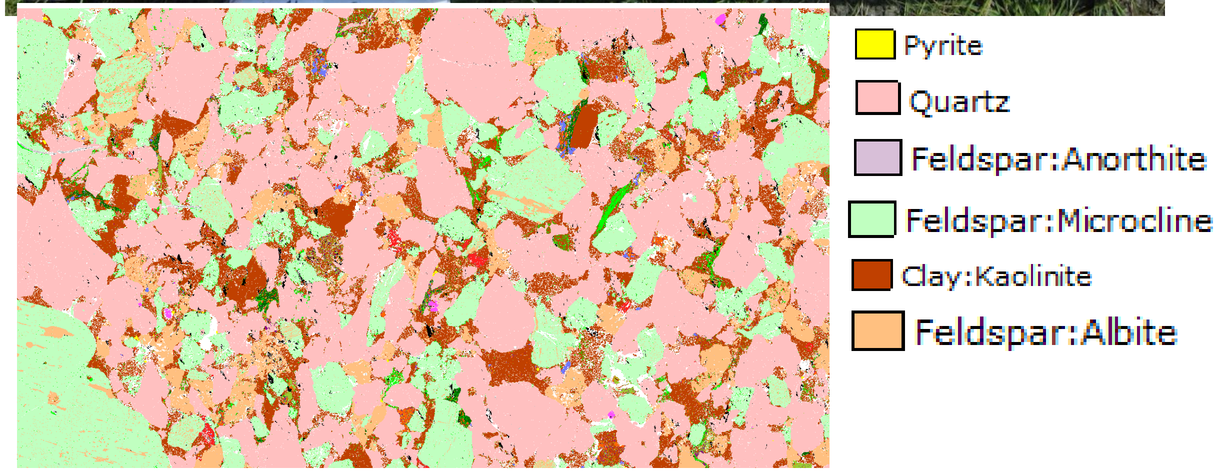


- The arkosic sandstone roof is characterized by (quartz>microcline>kaolinite>albite>illite)
- Argillaceous floor is characterized by (kaolinite> quartz> illite> microcline> albite)

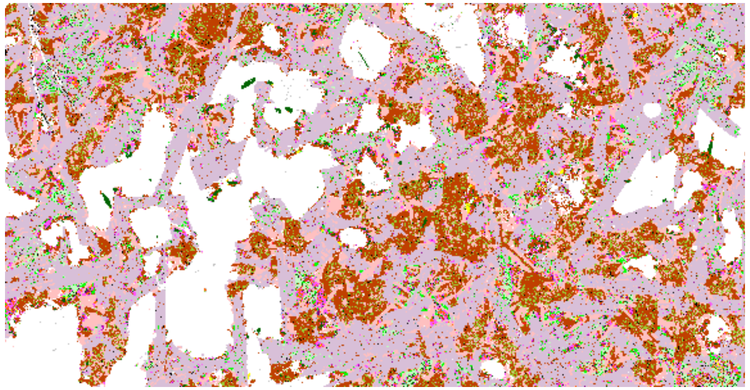


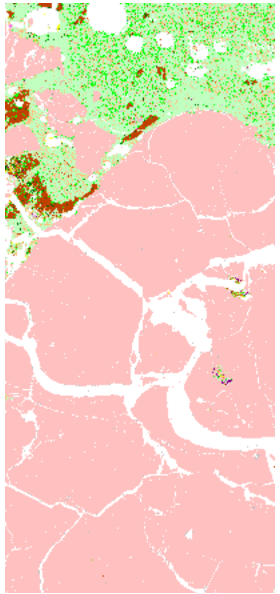
Change in Mineralogy

Original sandstone

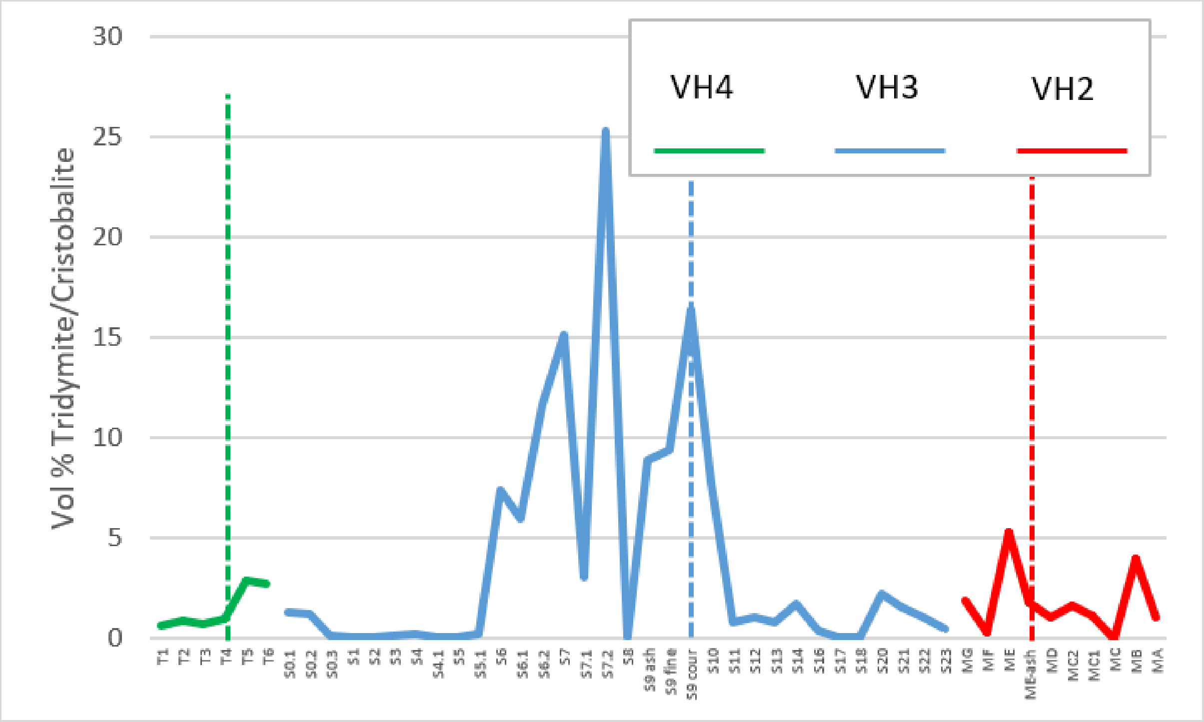


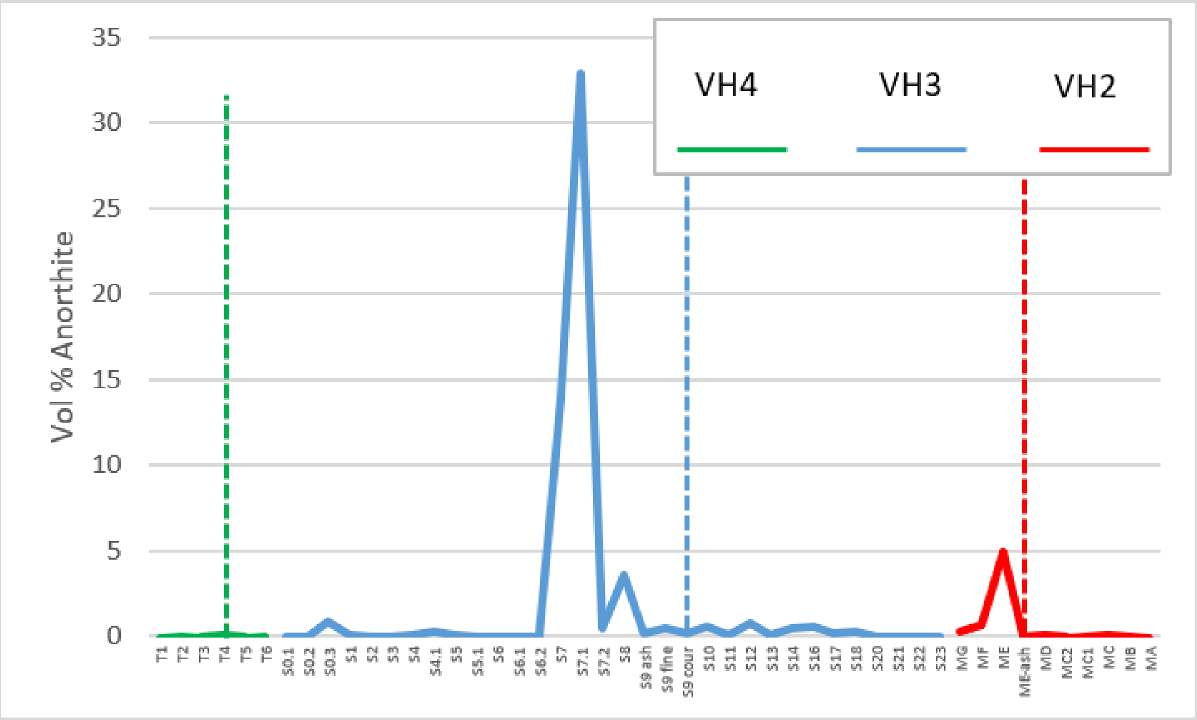
Heat affected sandstone



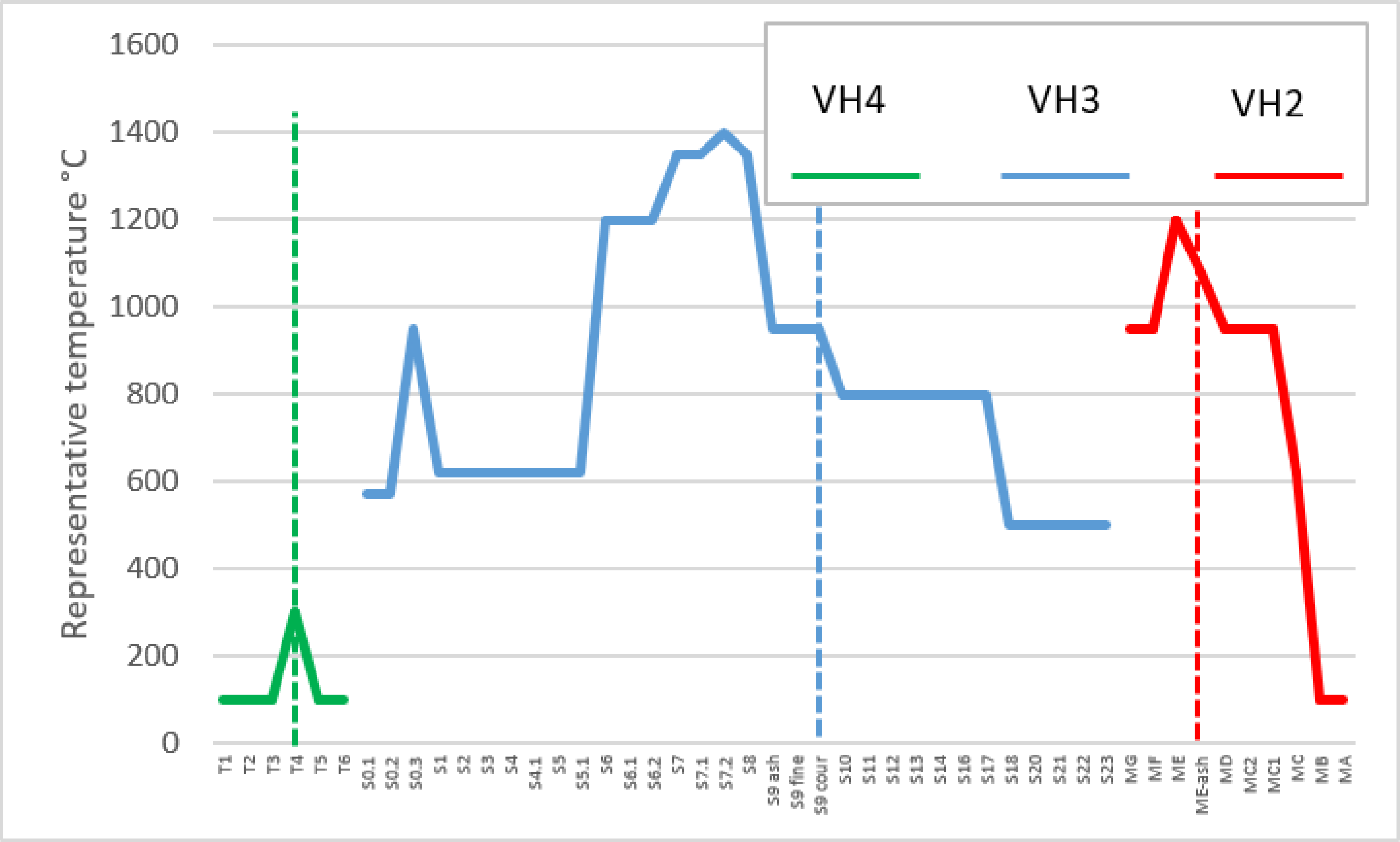


Pyrometamorphism



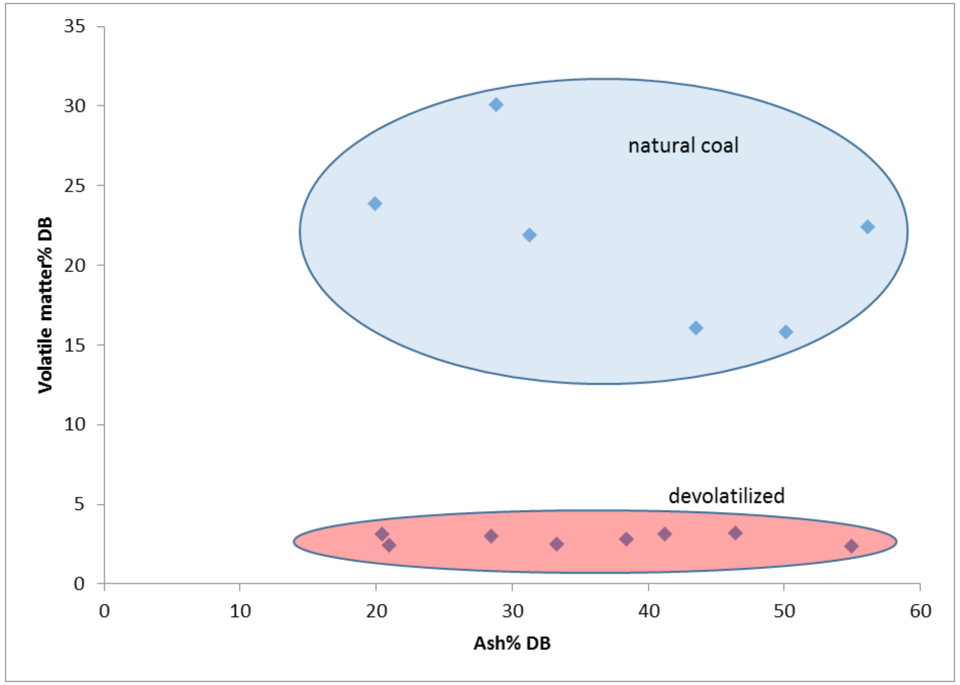


Temperature reconstruction

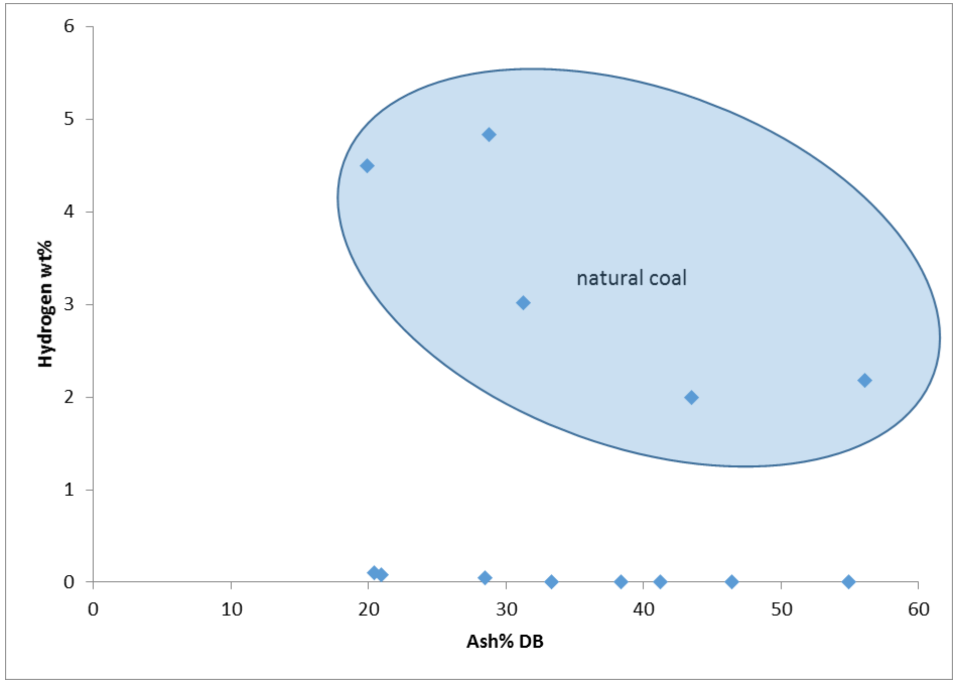


Proximate and Ultimate Analysis

Volatile matter

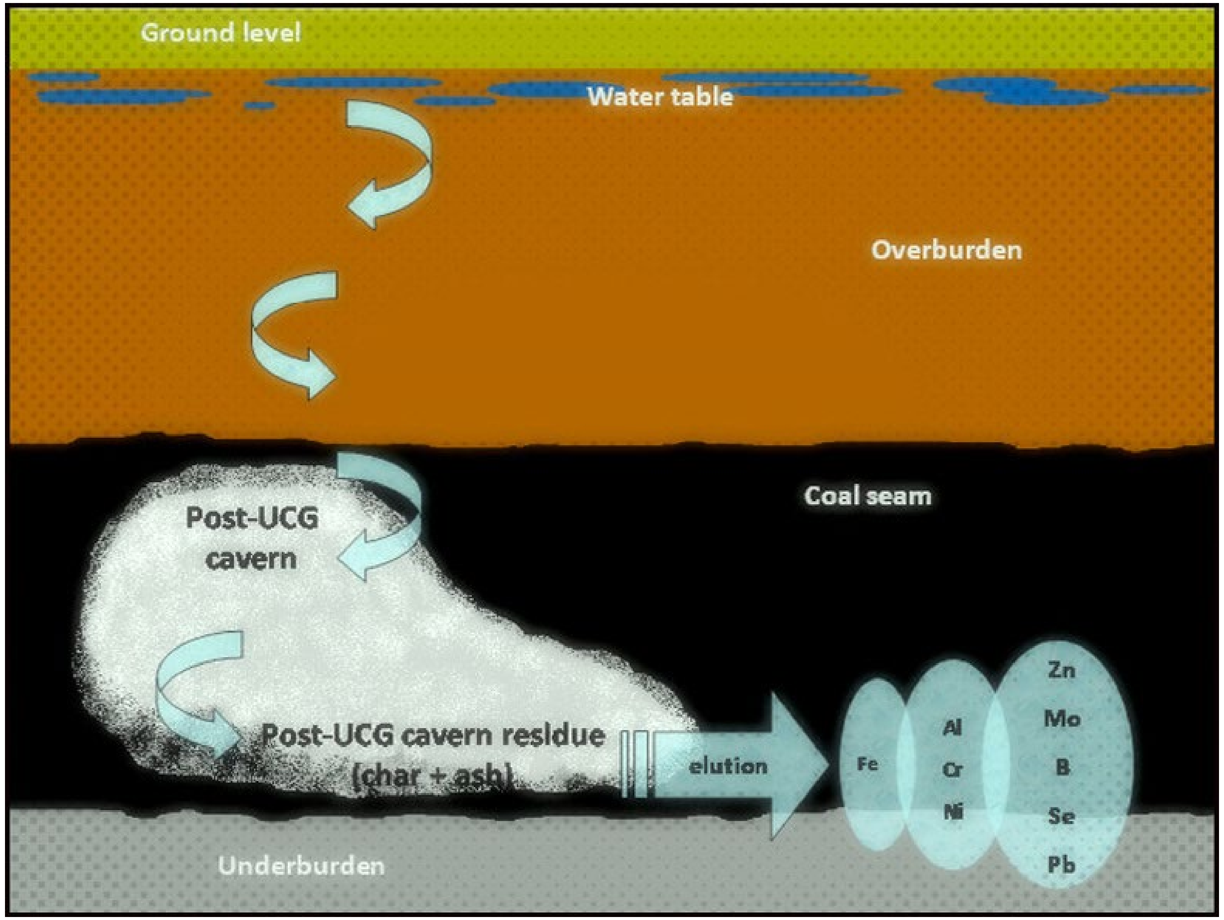


Hydrogen



Sample Name	S10	S11	S12	S13	S14	S16	S17	S18	VH4 Gus A	VH4 Gus B	VH4 Gus C	VH4 Gus D	VH6 Gus
Total Sulphur (%)	0.75	0.87	0.31	0.49	1.18	0.77	0.48	0.12	1.45	1.55	1	1.77	3.28

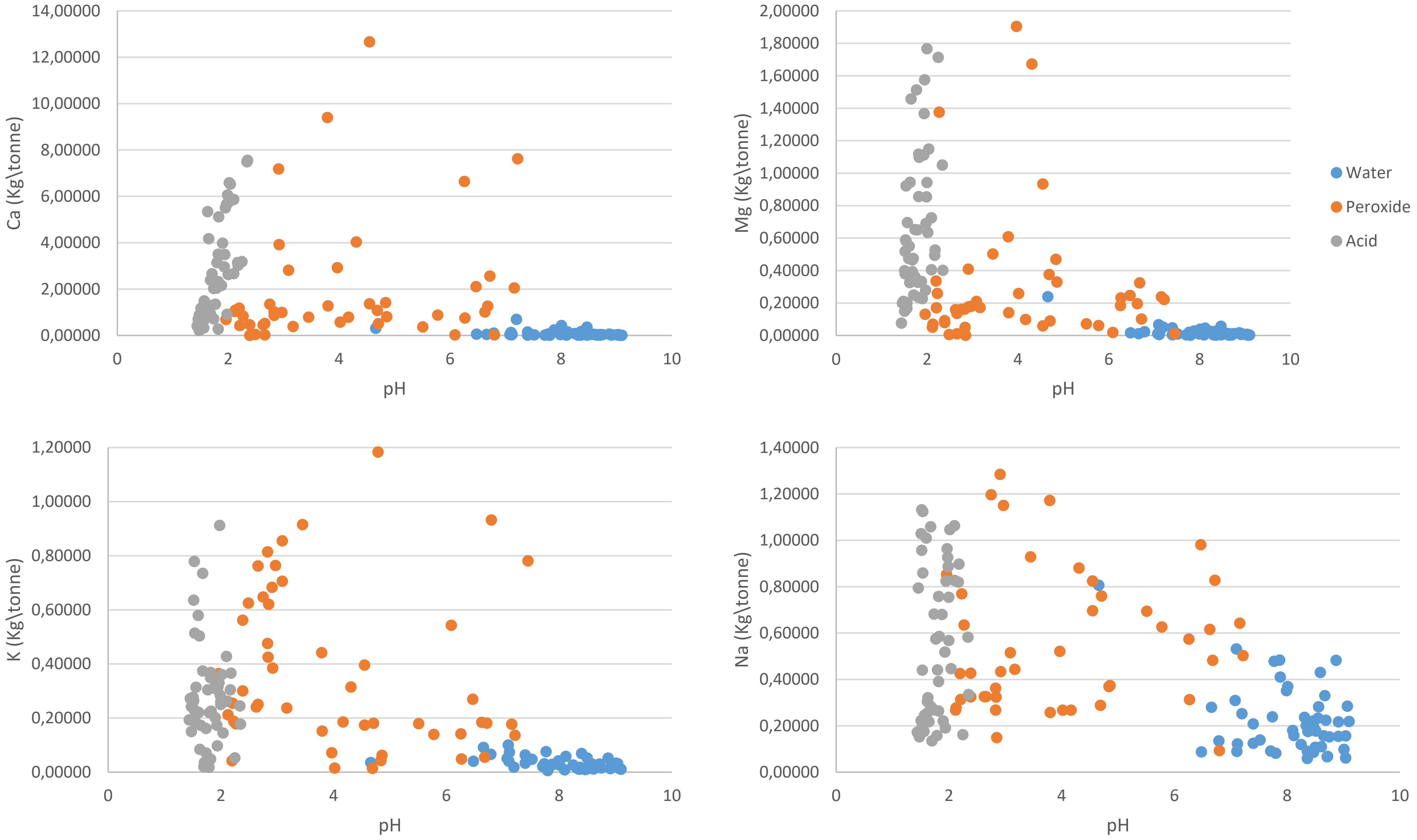
Leaching dynamics



(Strugała-Wilczek and Stańczyk, 2015)

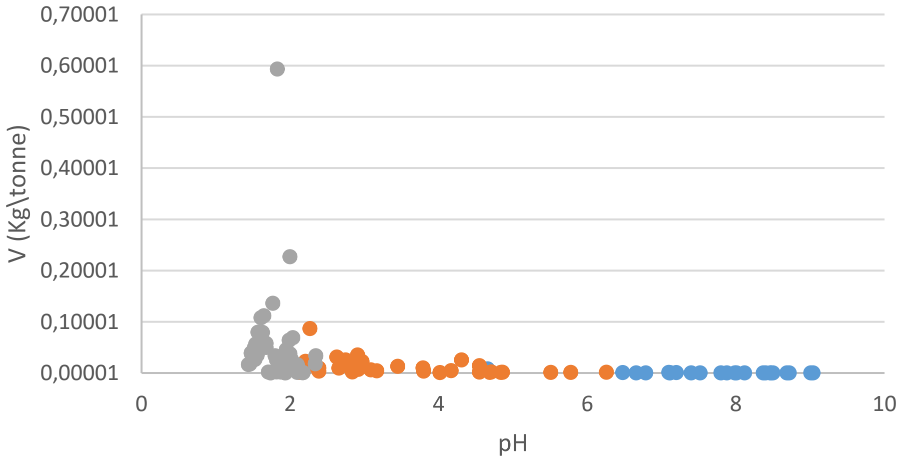
- Deionized water elution test was carried out over 24 hours using a ratio of 50 ml of deionized water to 5 g solid material
- Hydrogen peroxide elution test was conducted over 24 hours at 2 g solid material to 80 ml hydrogen peroxide
- Acid elution test was also carried out over 24 hours using 5 g solid material and 50 ml of 0.1N sulphuric acid
- Post carven residue samples were eluted using mine water on a 1:10 ratio for 24 hours at 25 °C and at 70 °C

Majors

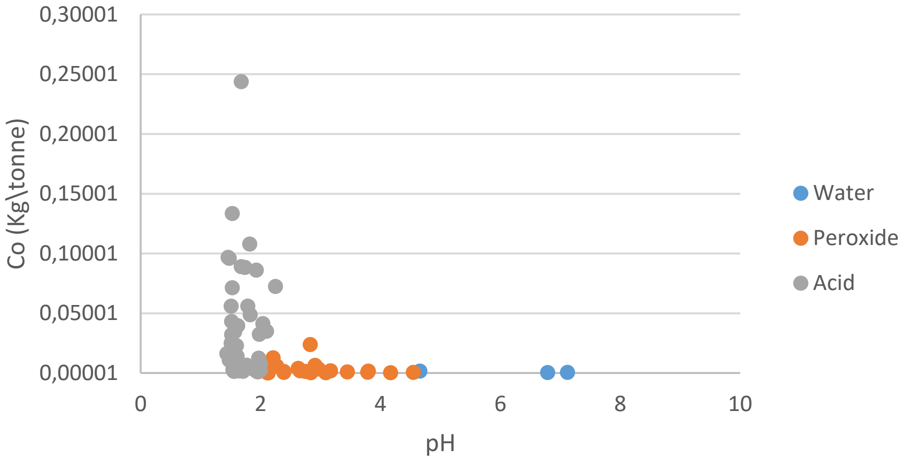


14,00000
12,00000
10,00000
8,00000
6,00000
4,00000
2,00000
0,00000
Ca (Kg\tonne)
0
2
4
6
8
10
pH
2,00000
1,80000
1,60000
1,40000
1,20000
1,00000
0,80000
0,60000
0,40000
0,20000
0,00000
Mg (Kg\tonne)
pH
Water
Peroxide
Acid
1,20000
1,00000
0,80000
0,60000
0,40000
0,20000
0,00000
K (Kg\tonne)
pH
1,40000
1,20000
1,00000
0,80000
0,60000
0,40000
0,20000
0,00000
Na (Kg\tonne)
pH

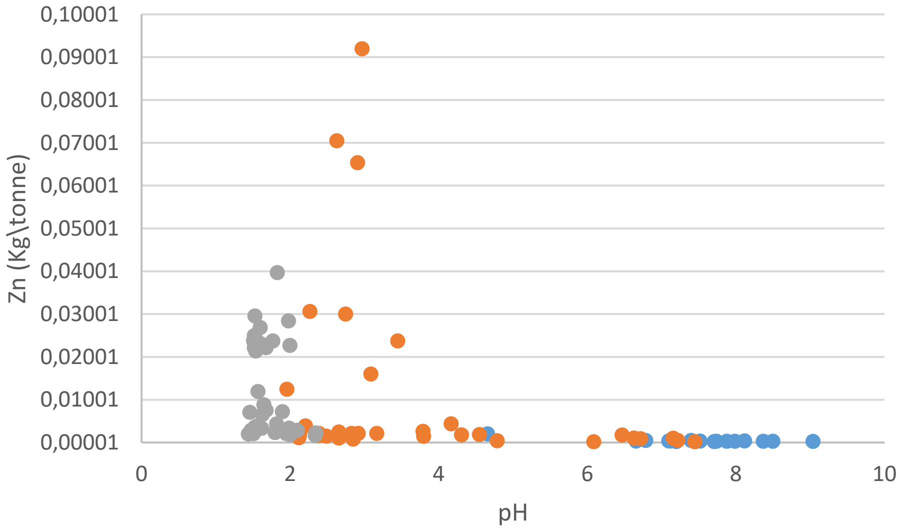
Trace



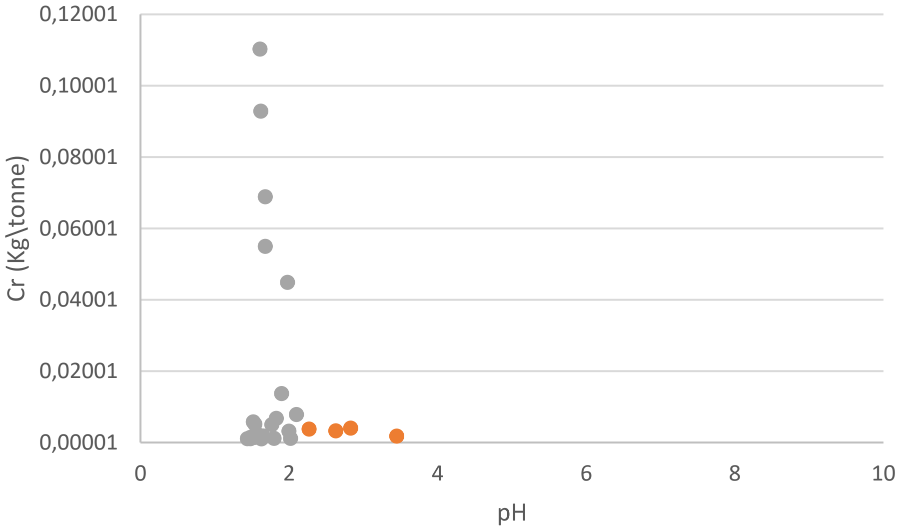
0,70001
0,60001
0,50001
0,40001
0,30001
0,20001
0,10001
0,00001
V (Kg\tonne)
0 2 4 6 8 10
pH



0,30001
0,25001
0,20001
0,15001
0,10001
0,05001
0,00001
Co (Kg\tonne)
0 2 4 6 8 10
pH
Water
Peroxide
Acid



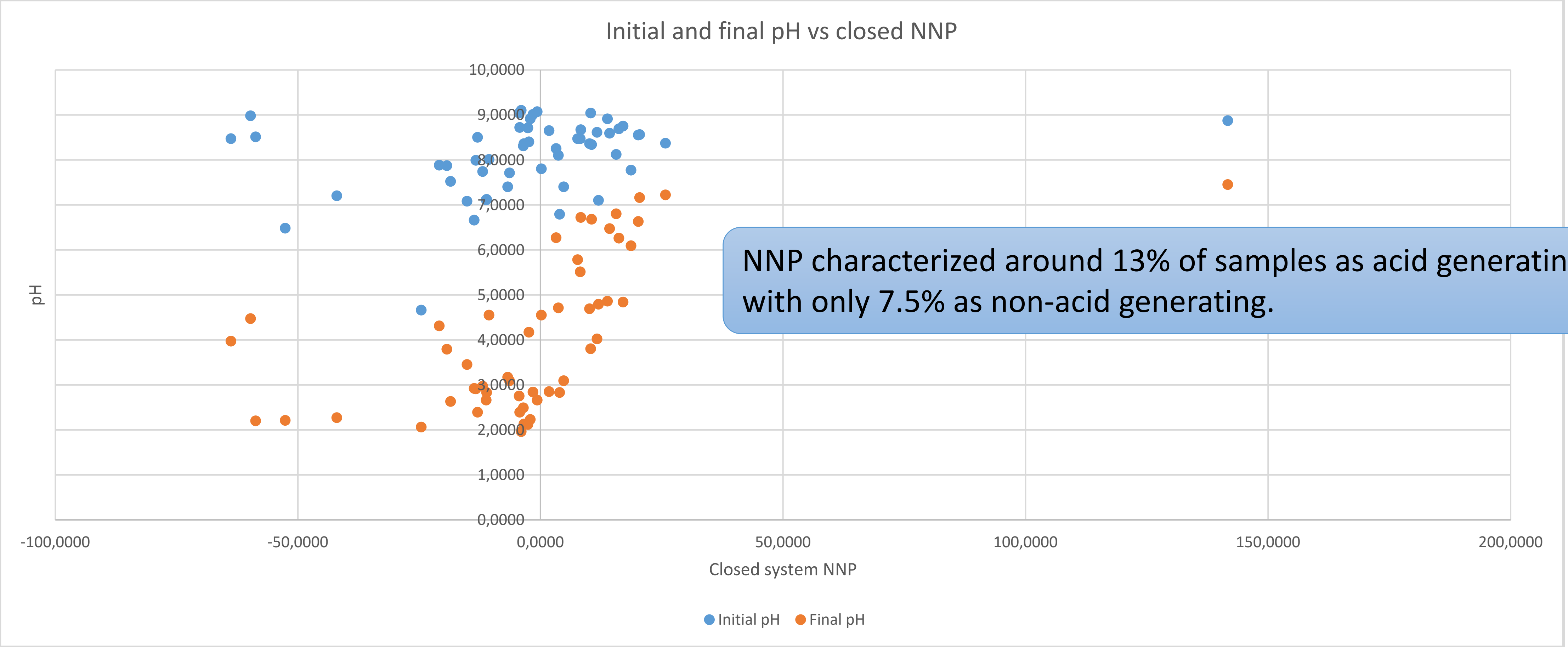
0,10001
0,09001
0,08001
0,07001
0,06001
0,05001
0,04001
0,03001
0,02001
0,01001
0,00001
Zn (Kg\tonne)
0 2 4 6 8 10
pH



0,12001
0,10001
0,08001
0,06001
0,04001
0,02001
0,00001
Cr (Kg\tonne)
0 2 4 6 8 10
pH

Acid base accounting

NNP (net neutralising potential) =NP (neutralising potential) –AP (acid producing potential)

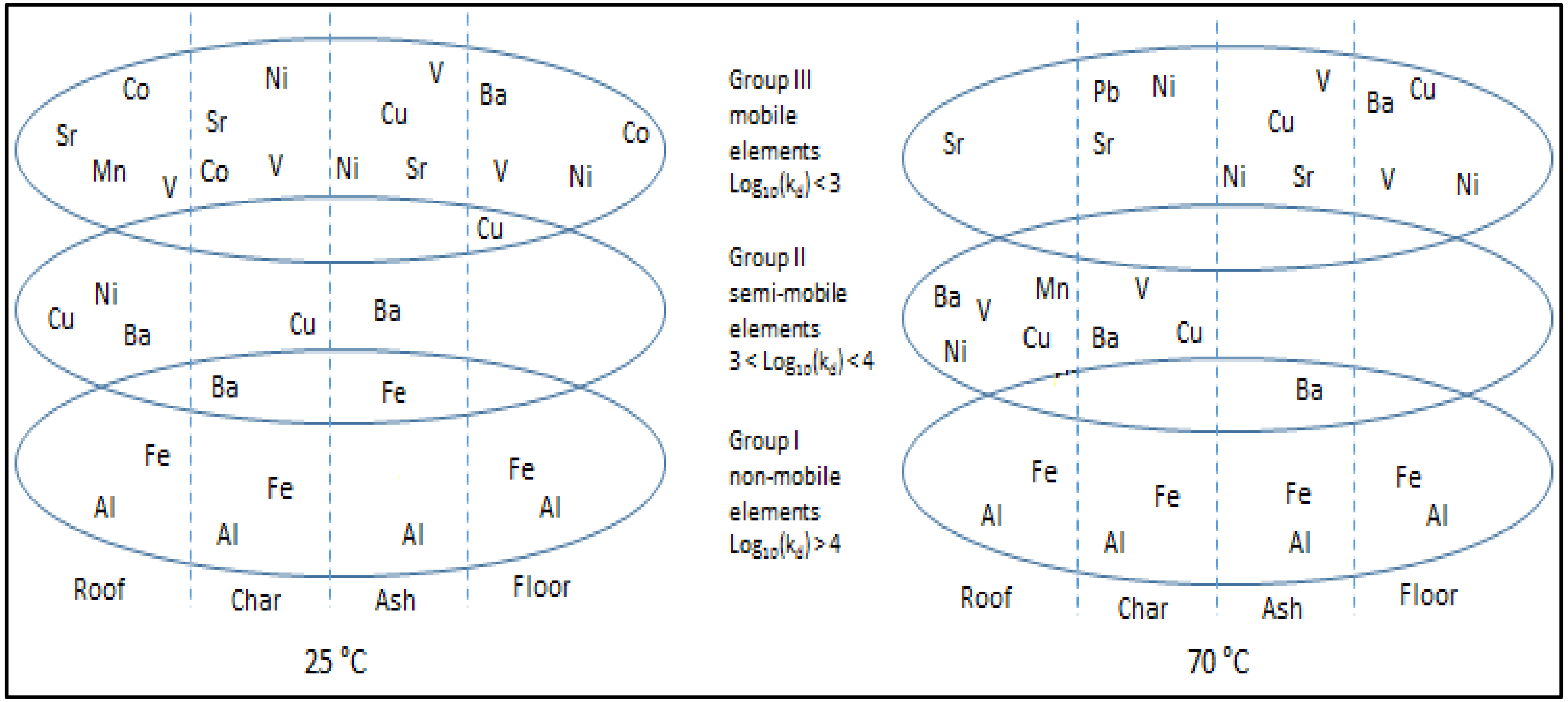


NNP characterized around 13% of samples as acid generating with only 7.5% as non-acid generating.

Mine Water Leaching

- Distribution coefficient (Kd) is the ratio of the amount of contaminant adsorbed on the surface of the solid phase to the dissolved concentration of the contaminant
- Group I - poorly mobile elements where a small quantity is mobilized, $\log_{10}(k_d) > 4$
- Group II - moderately mobile elements, $3 < \log_{10}(k_d) < 4$
- Group III – mobile elements with great affinity for release into solution $\log_{10}(k_d) < 3$

$$K_d = \frac{Ci,s}{Ci,r}$$



Stable isotopes

- The deep aquifer samples are clustered separate from the other aquifers
- Mixing between the intermediate aquifers through the T2 weathered dolerite but not mixing with the deep aquifer

http://dx.doi.org/10.17159/2411-9717/2018/v118n10a5

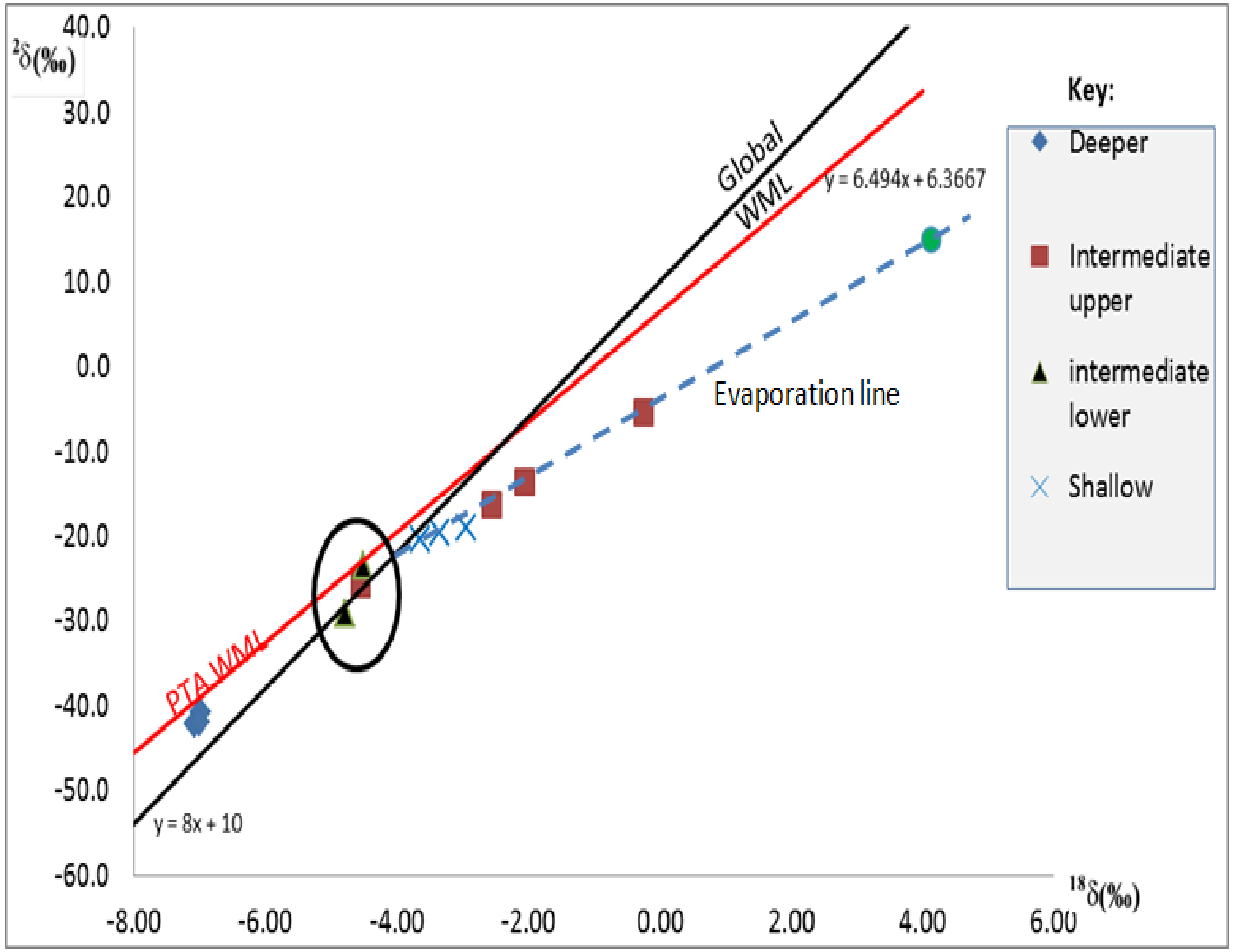
Qualitative hydrogeological assessment of vertical connectivity in aquifers surrounding an underground coal gasification site

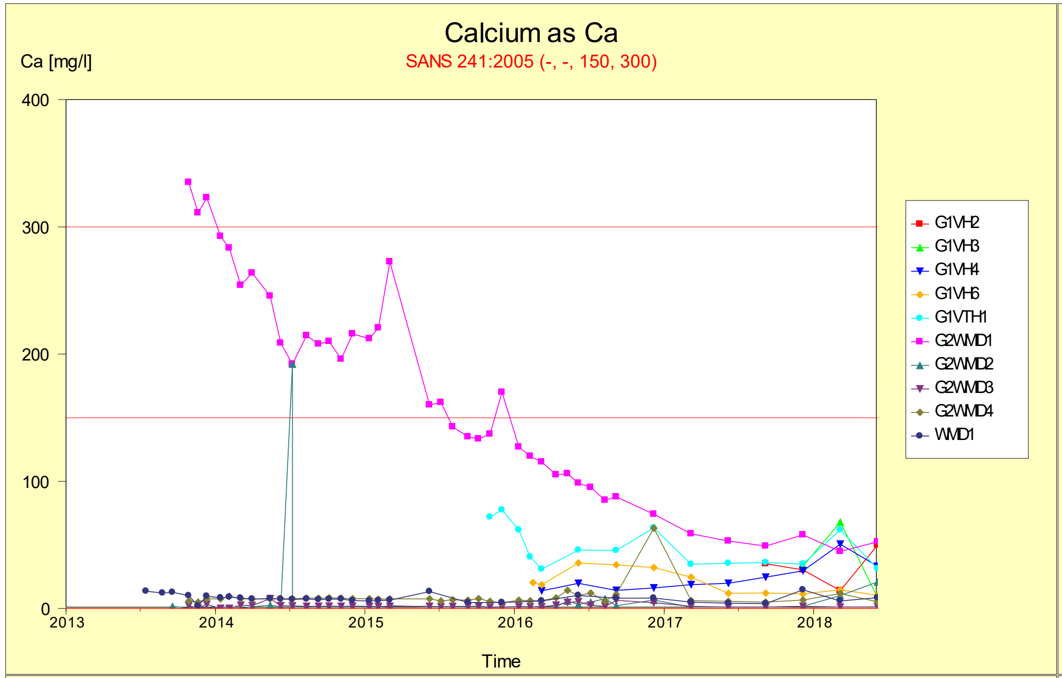
by L.S. Mokhahlane*, G. Mathoho†, M. Gomo*, and D. Vermeulen*

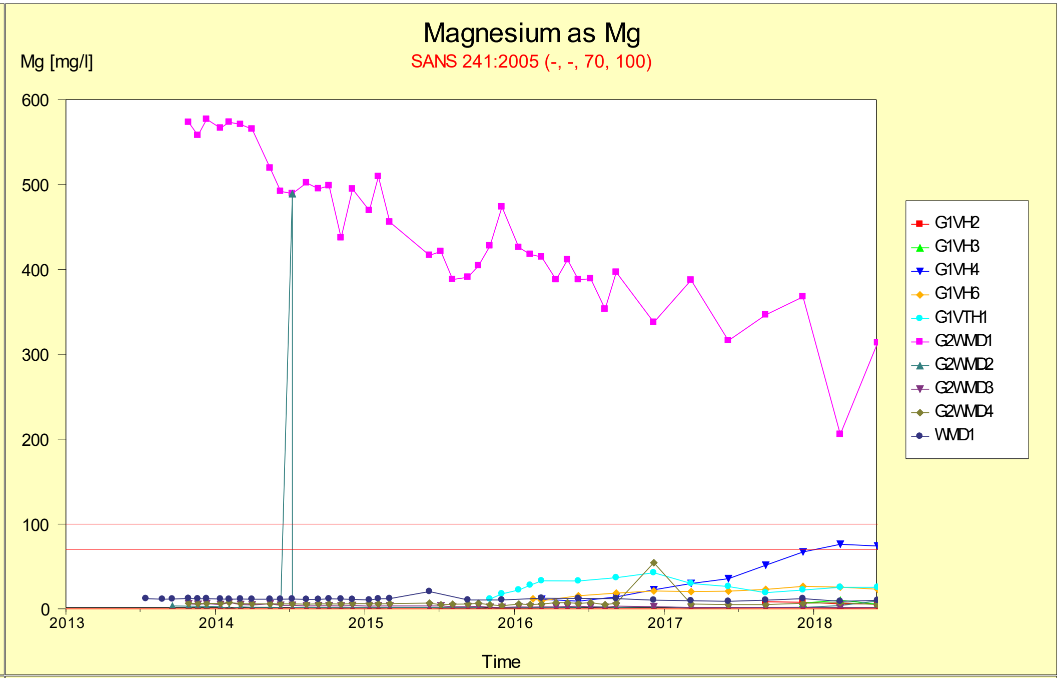
Synopsis

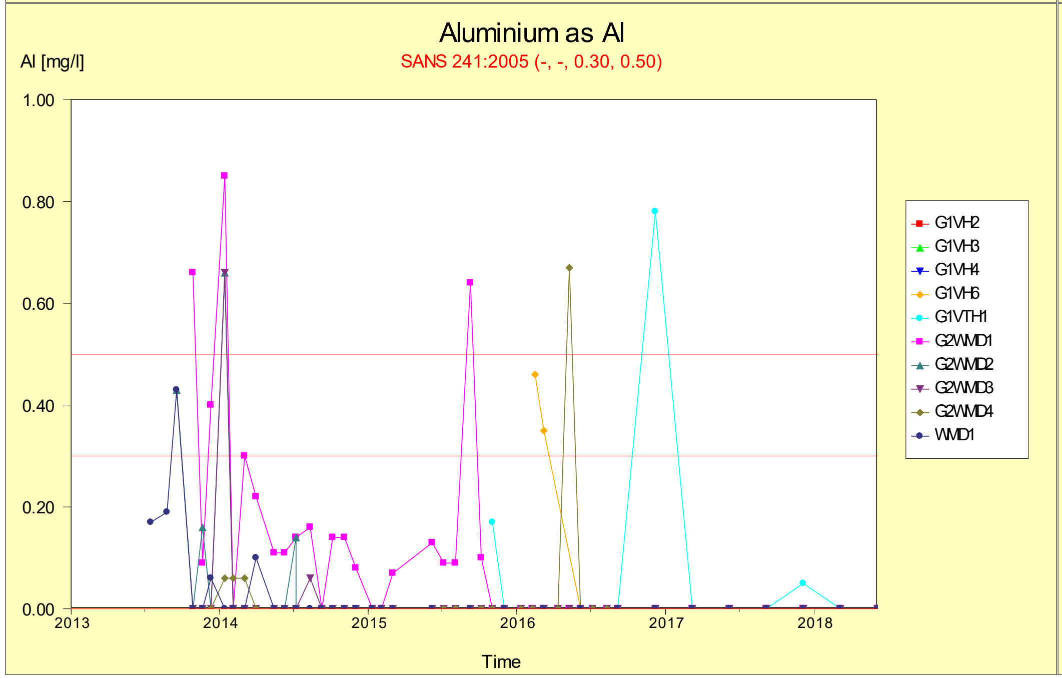
Underground coal gasification (UCG) is the conversion of coal *in situ* into a usable synthetic gas. One of the major environmental concerns with UCG is the possibility of groundwater from the coal seam aquifer contaminating the shallow aquifers via hydraulic connections. The coal seam aquifers are usually confined aquifers but can have hydraulic connections to the shallow aquifers due to faults/fractures or any man-made connections, including boreholes. The aim of this paper is to study groundwater hydraulic connections across various aquifers at the UCG site at Majuba, using hydrochemistry and stable isotope ($\delta^{18}O$ and $\delta^{2}H$) tools. Physical and chemical processes such as diffusion and condensation generate isotopic differentiation in natural waters that can be used to deduce the origins of different waters, and in groundwater the spatial isotopic distribution can be used to deduce hydraulic connections between different aquifers. The

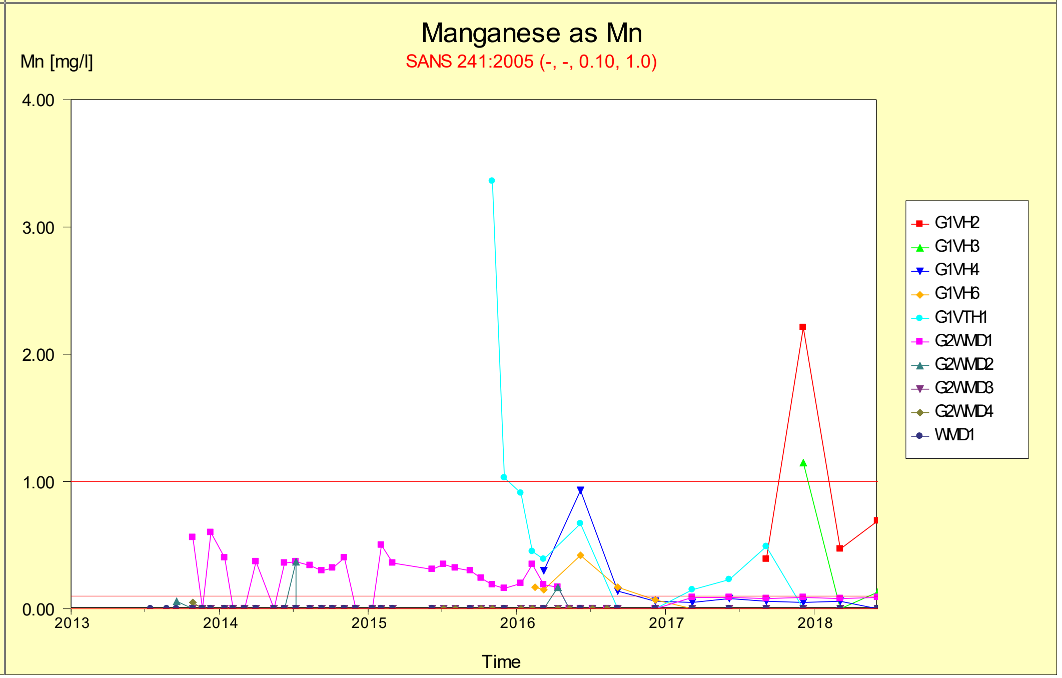
around the gasification zone (Kapusta and Stańczyk, 2015). This is due to the decomposition of coal in the gasification zone, which produces organic pollutants such as benzene, polycyclic aromatic hydrocarbons (PAHs), phenols, and inorganic compounds including ammonia and sulphides (Bhutto, Bazmi, and Zahedi, 2013; Kapusta and Stańczyk, 2011). These contaminants can migrate and penetrate the surrounding aquifers as a result of an outward pressure from the gasification zone if the gasifier is operated at a pressure higher than the hydrostatic pressure in the coal seam aquifer

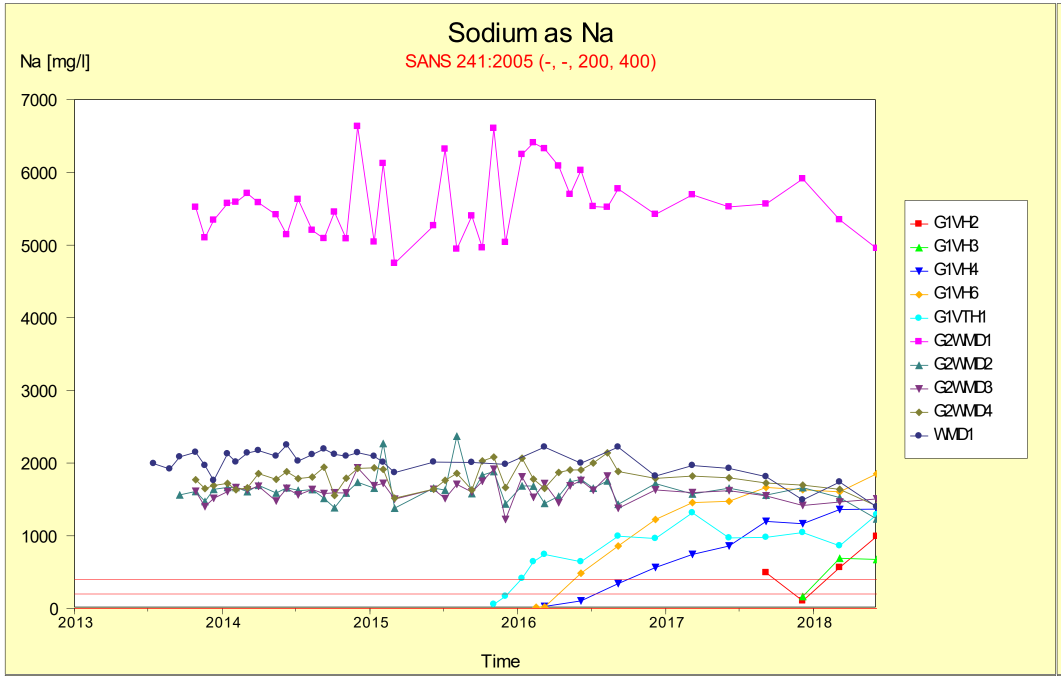


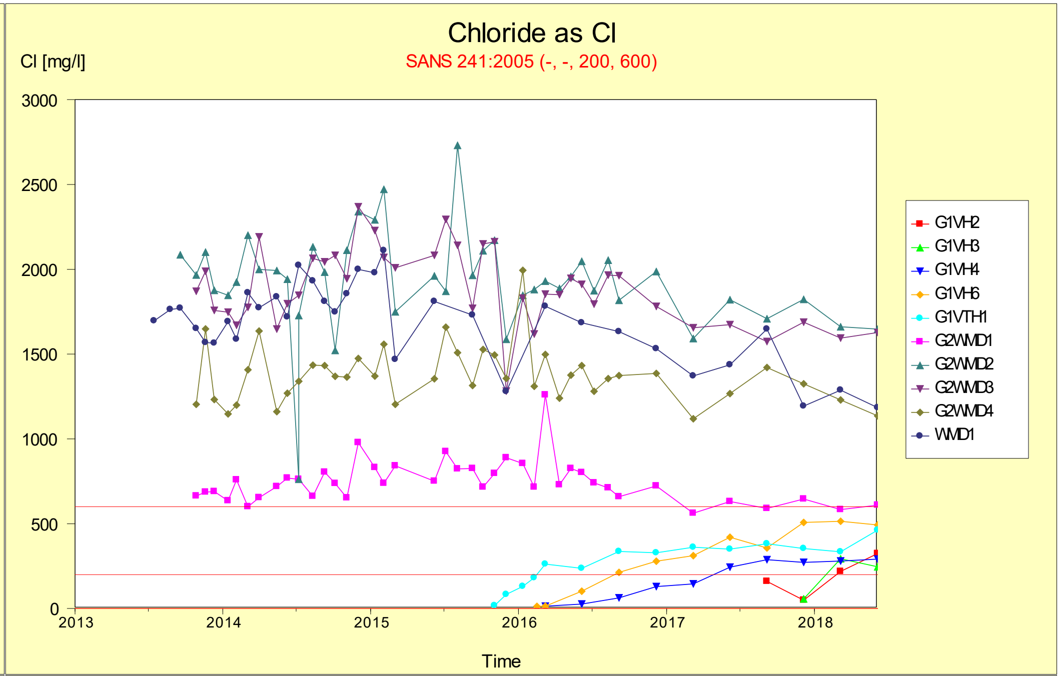

Calcium as Ca
Ca [mg/l]
SANS 241:2005 (-, -, 150, 300)
400
300
200
100
0
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1

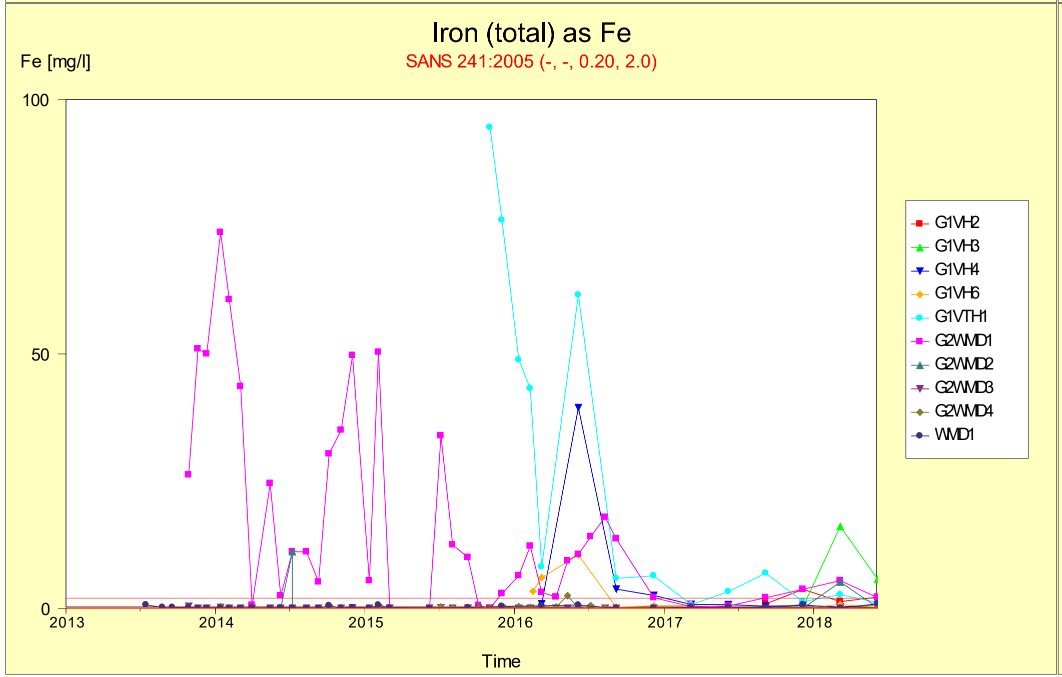

Magnesium as Mg
Mg [mg/l]
SANS 241:2005 (-, -, 70, 100)
600
500
400
300
200
100
0
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1

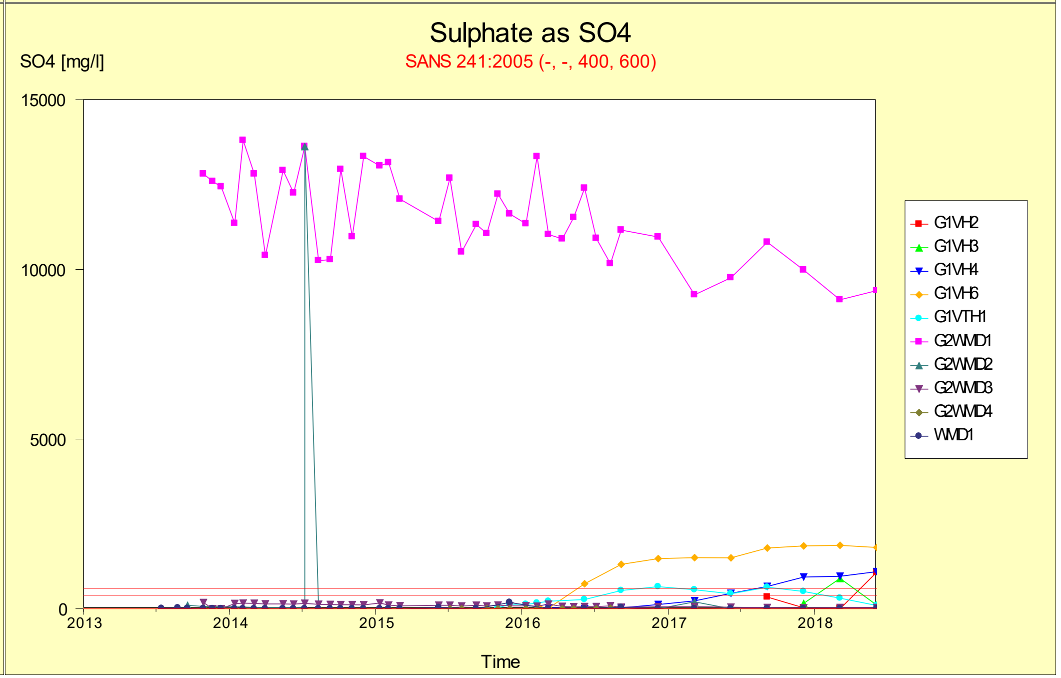

Aluminium as Al
Al [mg/l]
SANS 241:2005 (-, -, 0.30, 0.50)
1.00
0.80
0.60
0.40
0.20
0.00
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1


Manganese as Mn
Mn [mg/l]
SANS 241:2005 (-, -, 0.10, 1.0)
4.00
3.00
2.00
1.00
0.00
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1


Sodium as Na
Na [mg/l]
SANS 241:2005 (-, -, 200, 400)
7000
6000
5000
4000
3000
2000
1000
0
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1

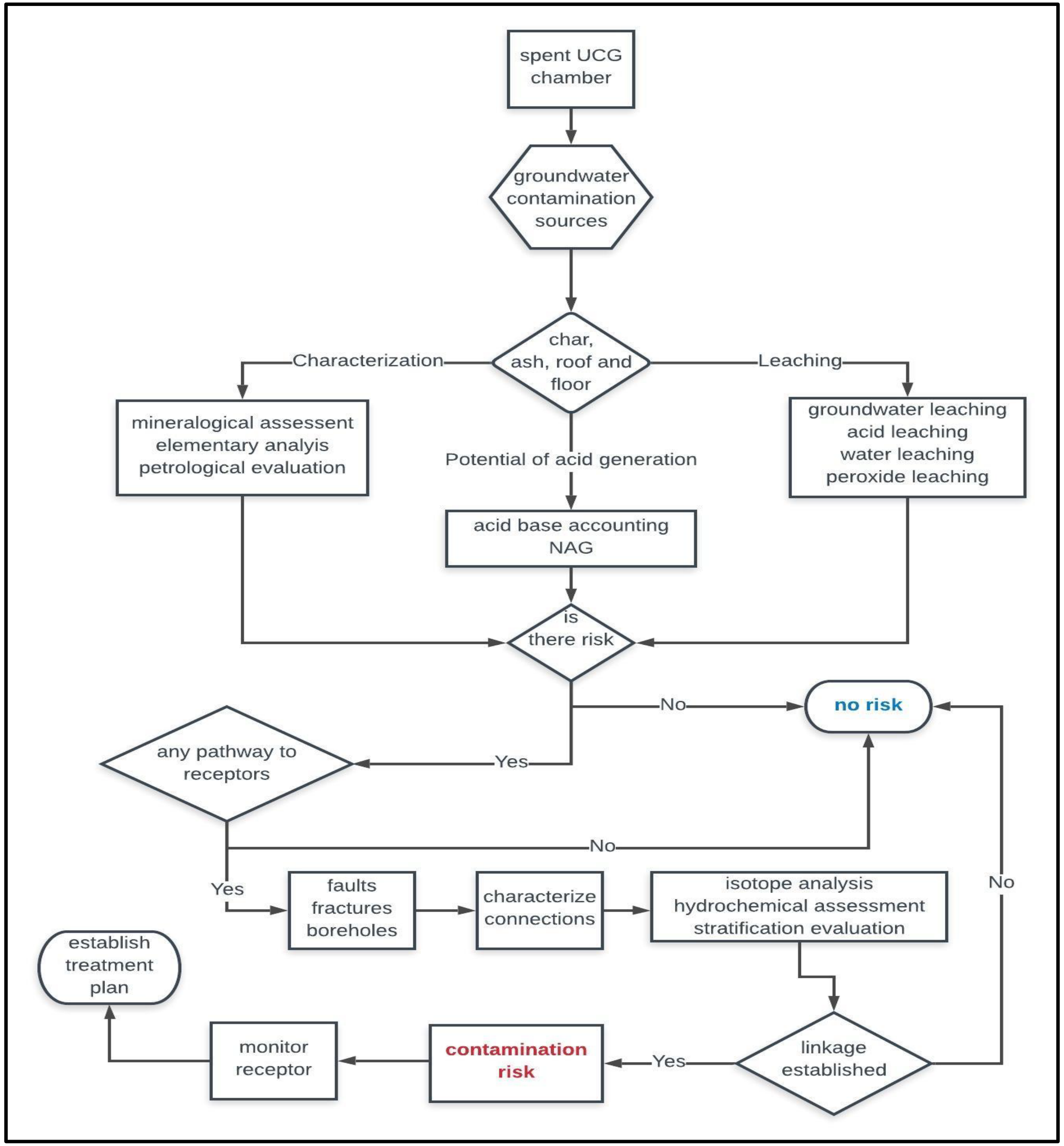

Chloride as Cl
Cl [mg/l]
SANS 241:2005 (-, -, 200, 600)
3000
2500
2000
1500
1000
500
0
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1


Iron (total) as Fe
Fe [mg/l]
SANS 241:2005 (-, -, 0.20, 2.0)
100
50
0
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1


Sulphate as SO4
SO4 [mg/l]
SANS 241:2005 (-, -, 400, 600)
15000
10000
5000
0
2013
2014
2015
2016
2017
2018
Time
G1VH2
G1VH3
G1VH4
G1VH6
G1VTH1
G2WMD1
G2WMD2
G2WMD3
G2WMD4
WMD1

Conclusions

- The mineralogy analysis show that a spent UCG geo-reactor is composed of complex mineral phases and the incoming groundwater will interact with ash, char, glass and pyrometamorphosed rocks
- All of these materials are potential sources of groundwater pollution
- The integrated groundwater risk assessment model can be used to determine risk to groundwater contamination for UCG sites



Thank you,
Kea leboha.