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STATE OF KNOWLEDGE OF THE GEOTHERMAL PROVINCES OF REPUBLIC OF DJIBOUTI

ARGEO-C1 Conference
Addis-Ababa, Ethiopia, 24-29 November 2006

JALLUDIN Mohamed
Djibouti, CERD

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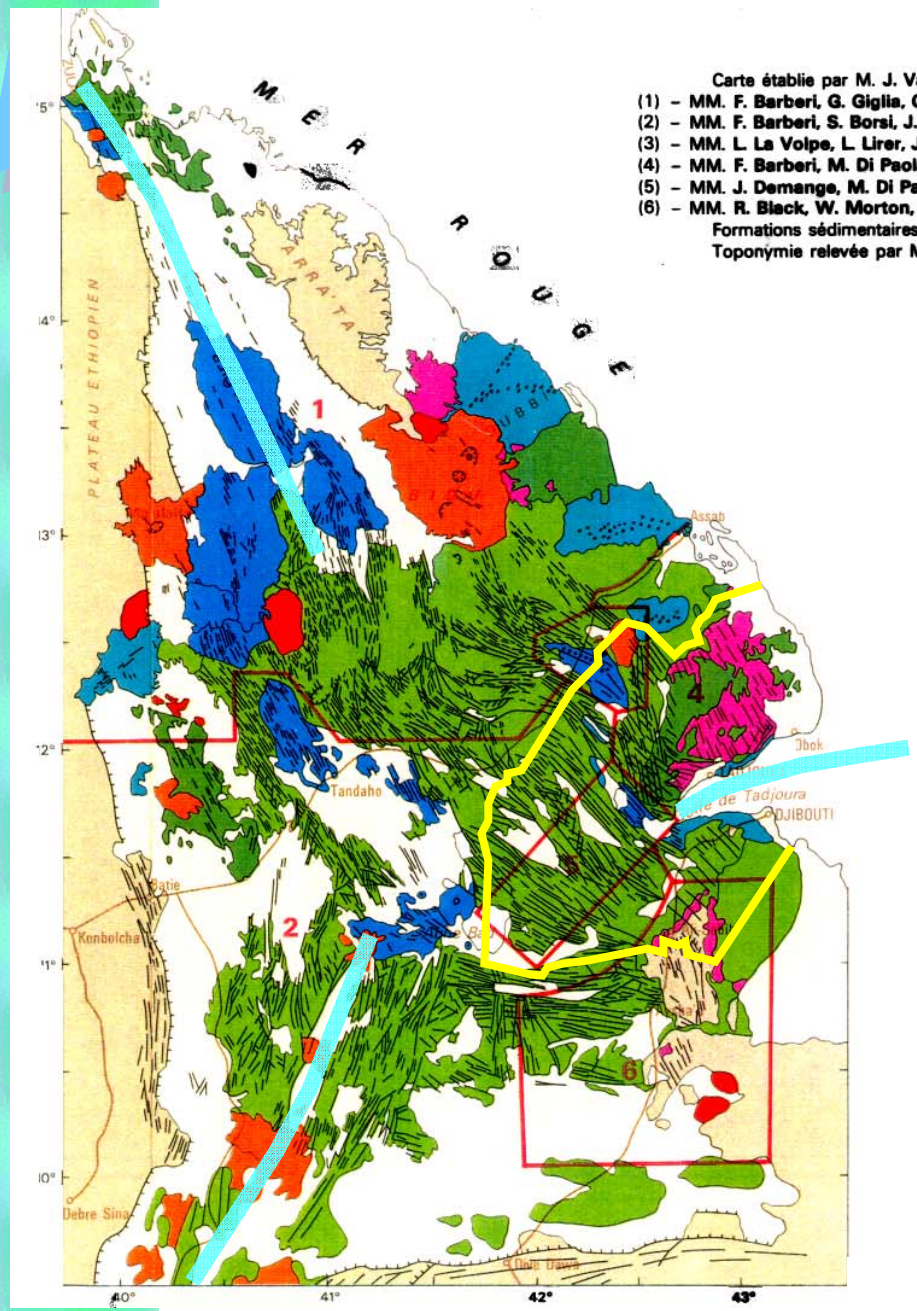
GEOTHERMAL EXPLORATIONS IN DJIBOUTI

- **FIRST PHASE**
  - Preliminary field studies
  - Asal rift geophysical studies
  - First geothermal drillings in Asal Rift geothermal area
  - Nord-Goubhet geophysical studies
- **SECOND PHASE**
  - Hanlé-Gaggadé exploration (field studies and gradient wells)
  - Hanlé geothermal drillings
  - Asal rift new drillings and geophysics
  - Scaling and corrosion study of Asal rift deep reservoir
- **ARGEO PROJECT PHASE**



Carte établie par M. J. Varet à partir des levers géologiques de :
(1) – MM. F. Barberi, G. Giglia, G. Marinelli, R. Santacroce, H. Tazieff, J. Varet et al. (1971)
(2) – MM. F. Barberi, S. Borsi, J.L. Cheminée, G. Giglia, G. Marinelli, R. Santacroce, L. Stieltjes, H. Tazieff, J. Varet
(3) – MM. L. La Volpe, L. Lirer, J. Varet (1973)
(4) – MM. F. Barberi, M. Di Paola, G. Giglia, R. Santacroce, J. Varet
(5) – MM. J. Demange, M. Di Paola, L. Stieltjes (1974) avec compléments de F. Barberi, R. Santacroce et J. Varet
(6) – MM. R. Black, W. Morton, J. Varet (1972)
Formations sédimentaires : MM. F. Gasse (Afar central), M. Taieb (Awash moyen, 1972)
Toponymie relevée par M. E. Chèdeville.

Chaines volcaniques axiales, à tendance tholéiitique
Axial volcanic ranges with tholeiitic tendency.

Centres rhyolitiques des marges
Marginal rhyolitic centres

Alignements volcaniques transverses, d'affinité alcaline.
Transverse volcanic alignements (alkaline affinity).

Série stratoïde de l'Afar (s.l.)
Afar stratoid series

Basaltes du Dalha
Dalha basalts

Rhyolites des Mabla
Mabla rhyolites.

Granite hyperalcalin miocène
Miocene peralkaline granites

"Socle" cristallin et couverture Pré-miocène
Pre-miocene "basement"

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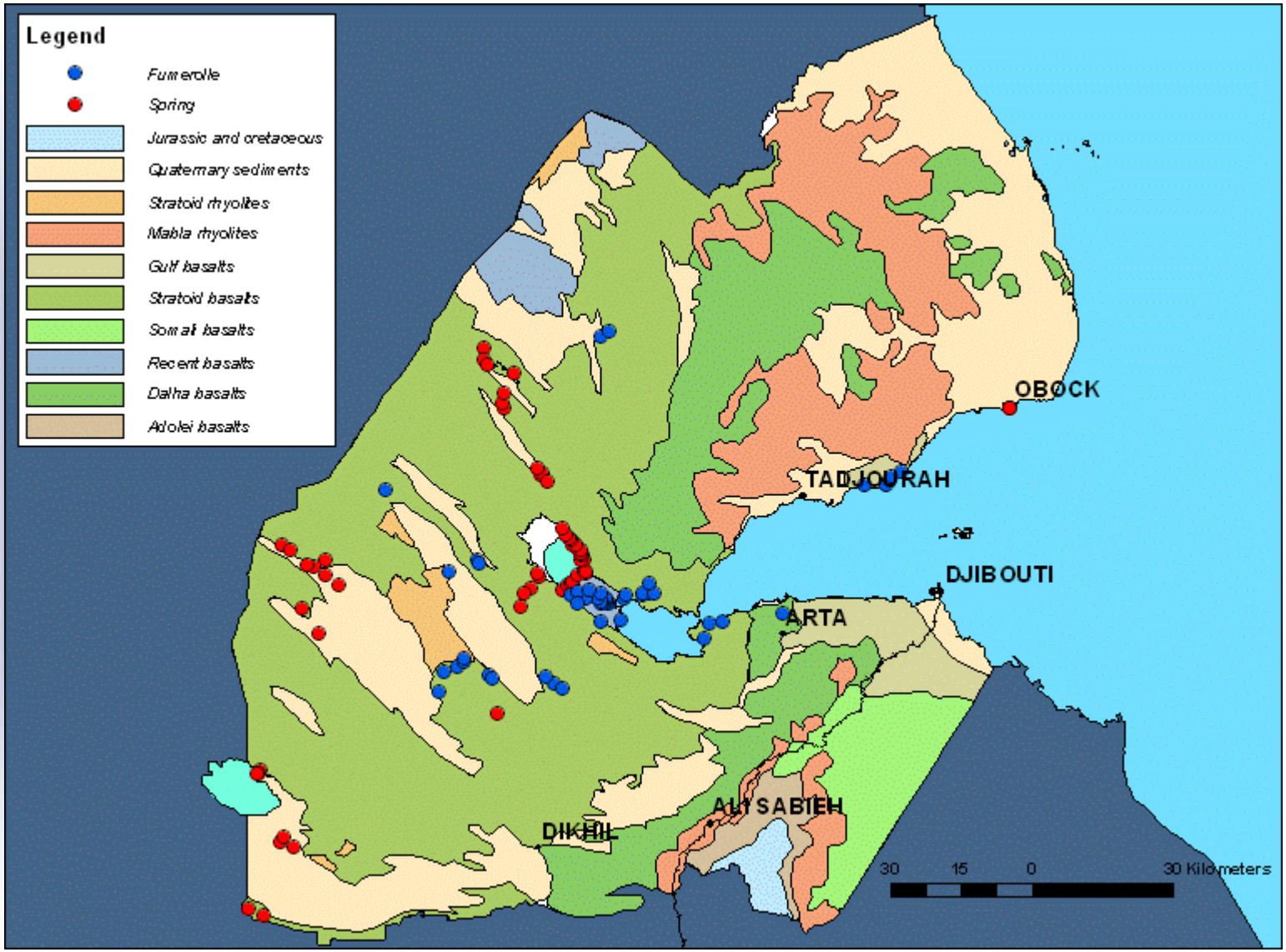
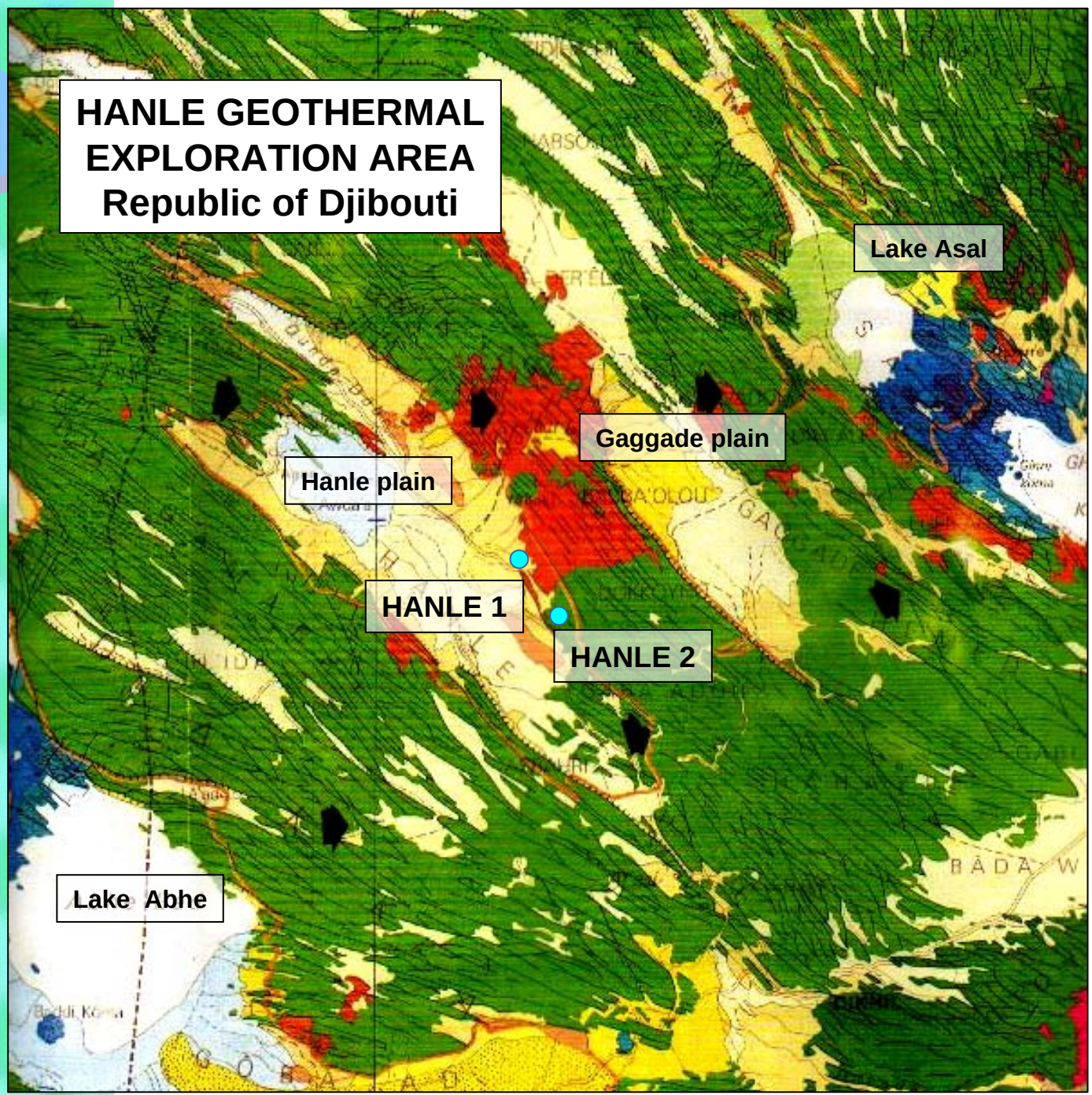
GEOLOGY AND SURFACE MANIFESTATIONS




HANLE GEOTHERMAL
EXPLORATION AREA
Republic of Djibouti
Lake Asal
Gaggade plain
Hanle plain
HANLE 1
HANLE 2
Lake Abhe

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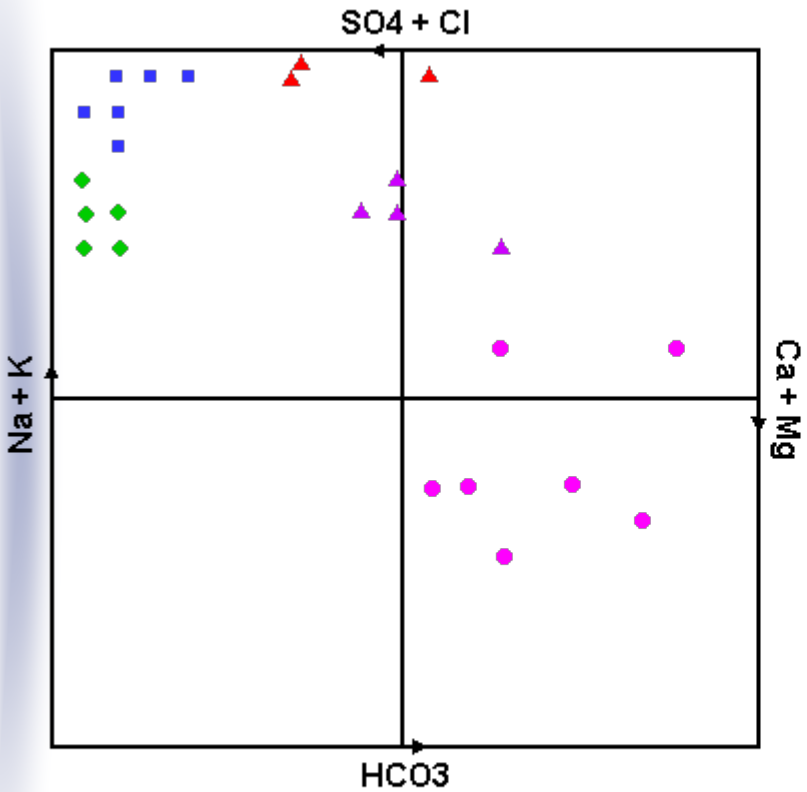
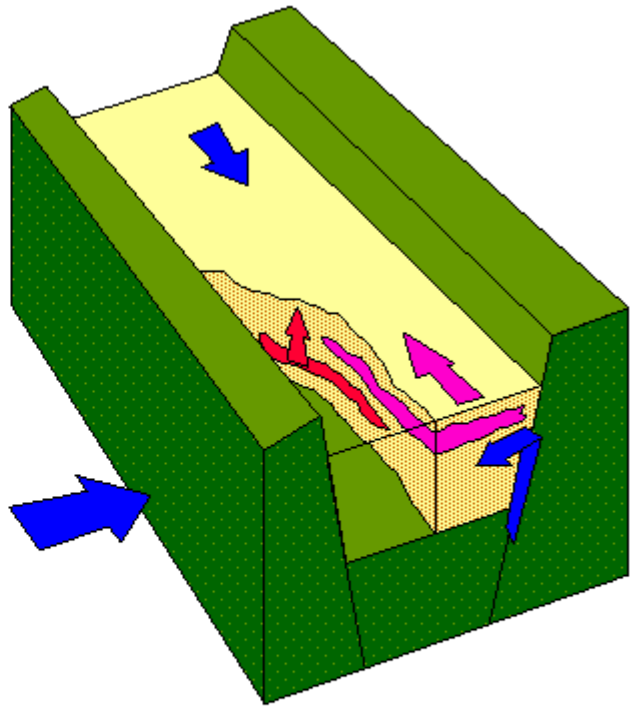
HANLE-GAGGADE GEOCHEMICAL STUDIES (AQUATER-CERD 1983)





- 1. Bicarbonated-earth-alcaline
- 2. Chlorinated-alcaline
- 3. Chlorinated-alcaline-earth-alcaline
- 4. Chlorinated-bicarbonated-sulfated-alcaline
- Mixing of groupe 1 and 4

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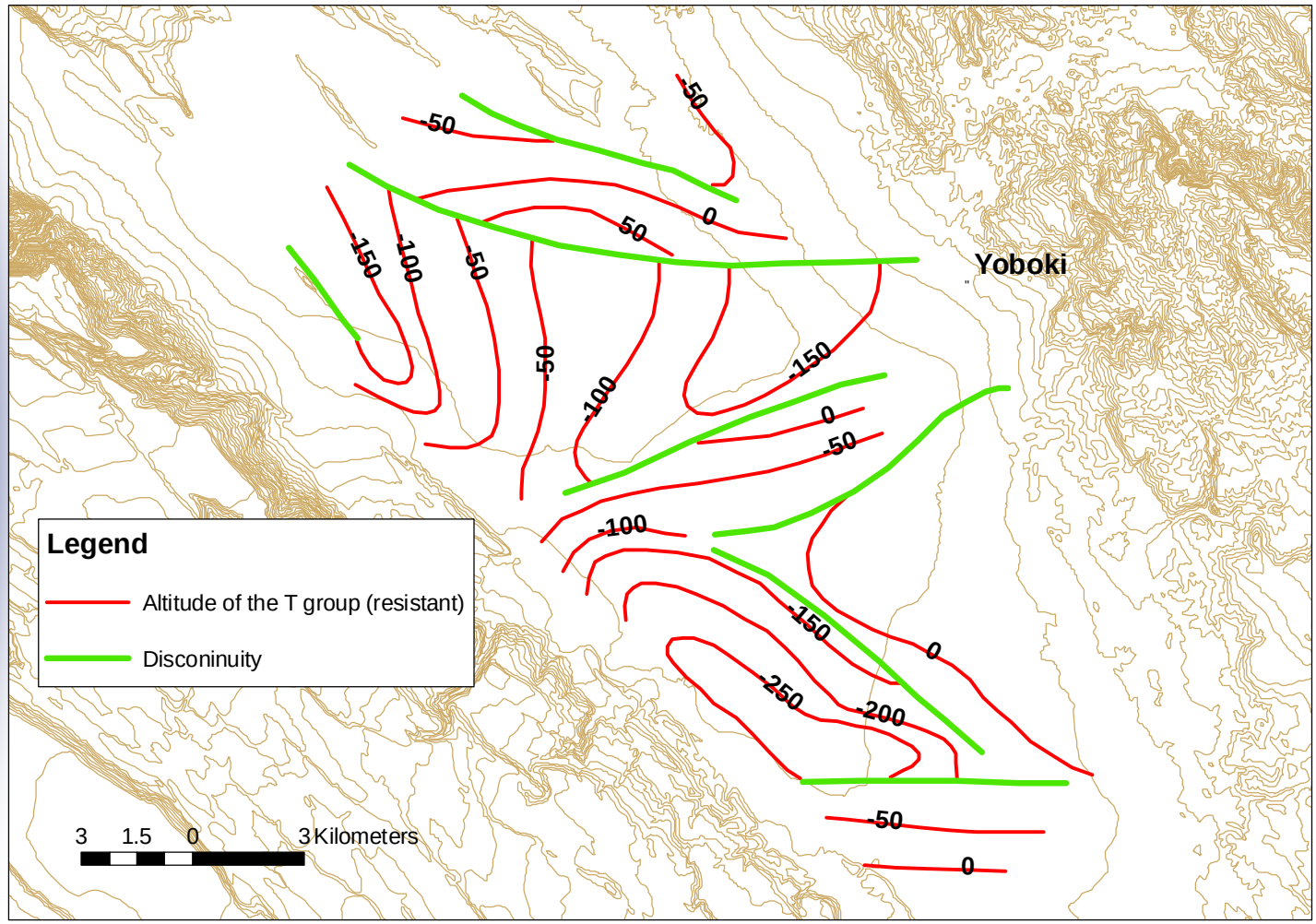
ELECTRICAL SURVEY OF HANLE PLAIN (AQUATER-CERD 1983)



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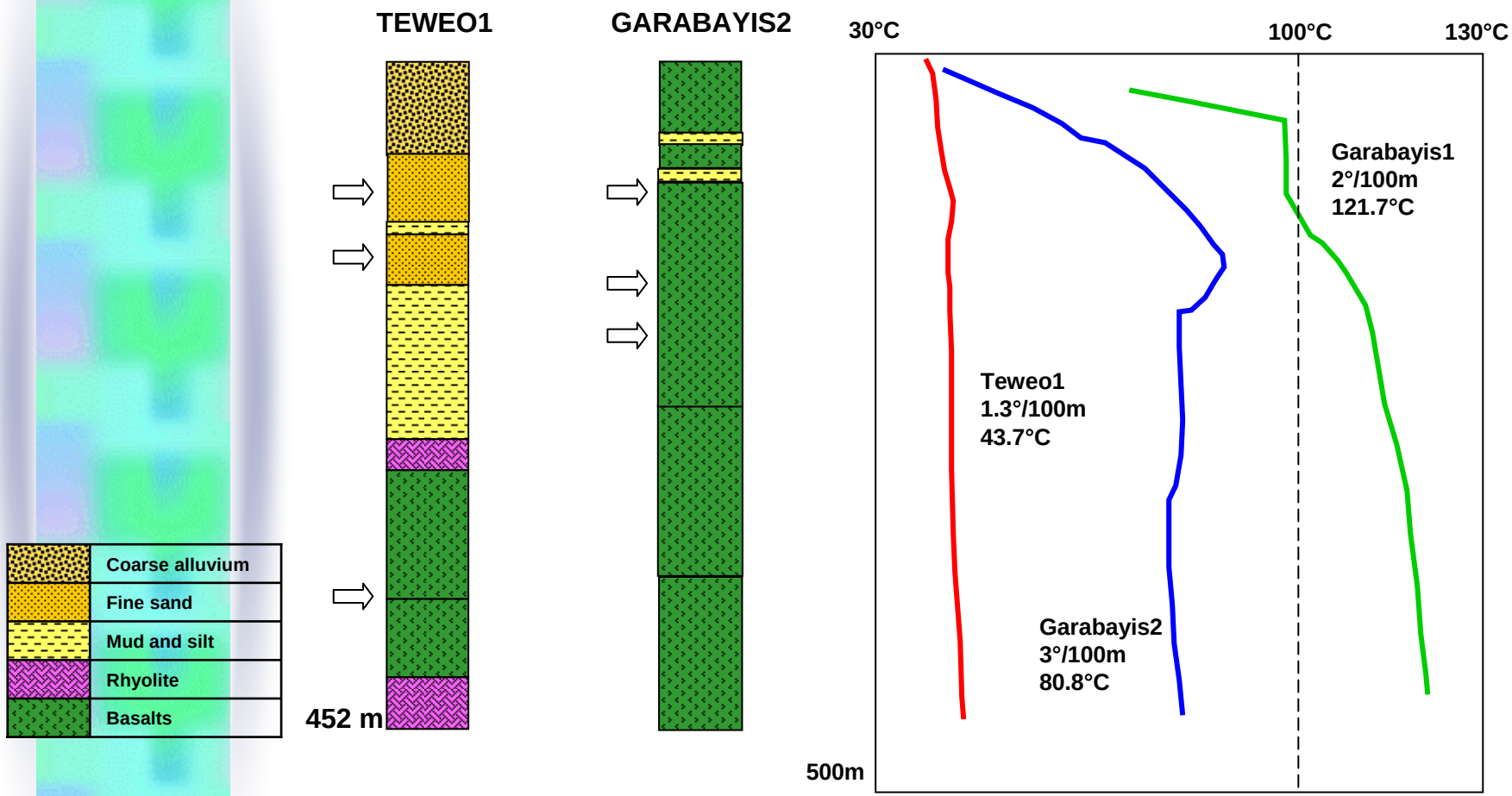
HANLE GRADIENT WELLS



HANLE DRILLINGS

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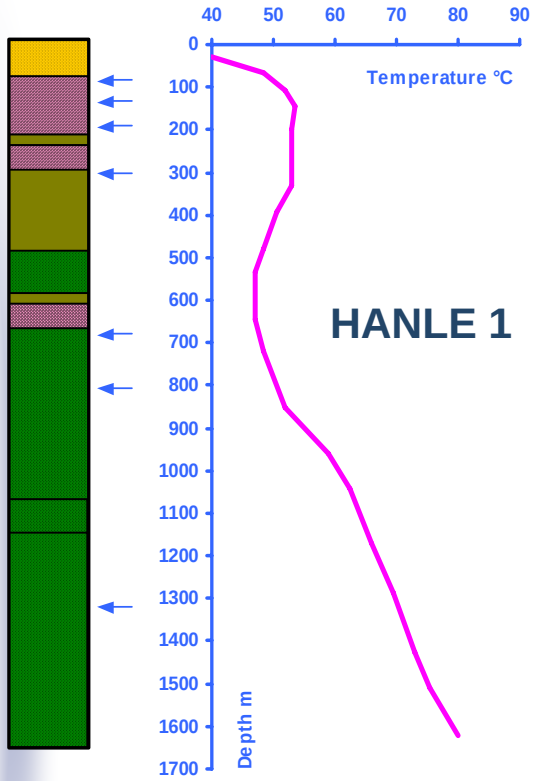
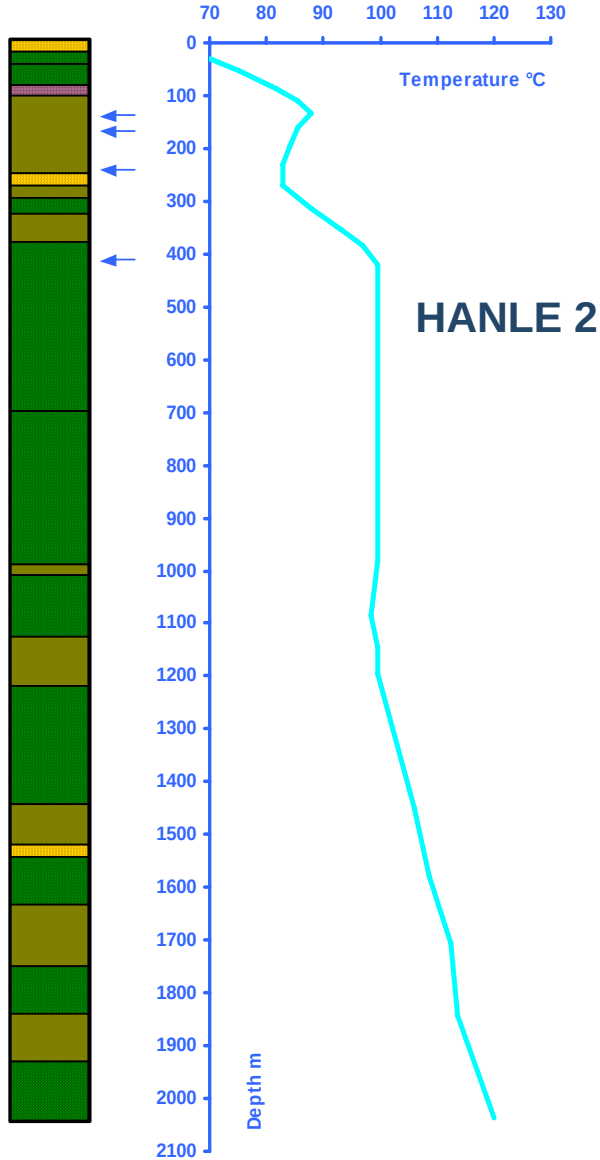


HANLE 1



HANLE 2

Alluviums

Rhyolites

Trachytes

Basalts

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HANLE EXPLORATION OUTCOMES

- Hanlé 1 (1623 m), 72 °C at 1420 m
- Hanlé 2 (2038 m), 124 °C at 2020 m
- Permeability
  - Hanlé 1: rhyolites, contact rhyolites-basalts, scoriae, dry below 800 m
  - Hanlé 2: basalts, scoriae, dry below 450 m
- Bottom hole core of Hanlé 2: 18.8 My
- Thick crust with 24 °C/km to 36 °C/km

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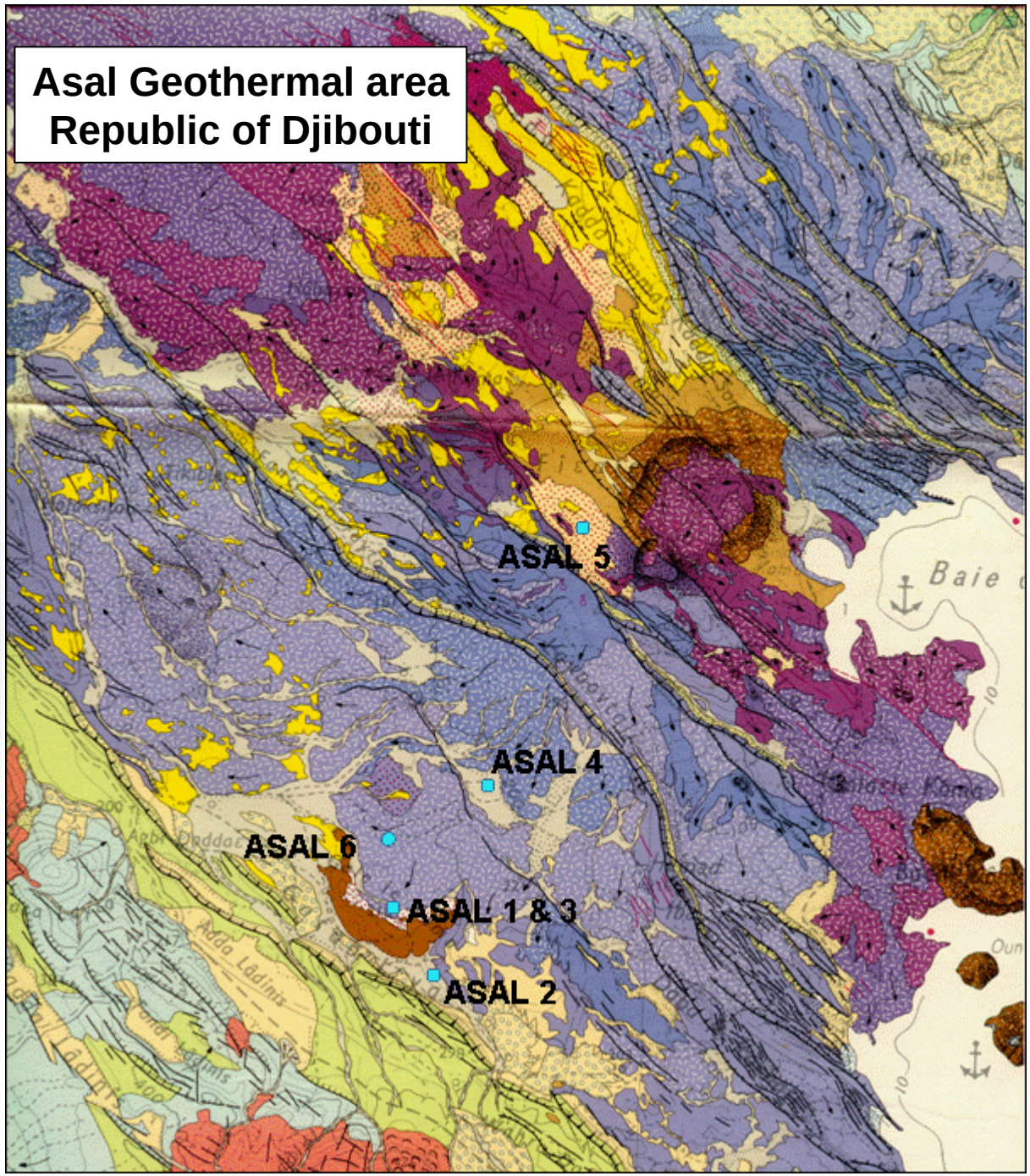
Asal Geothermal area
Republic of Djibouti
ASAL 5
ASAL 4
ASAL 6
ASAL 1 & 3
ASAL 2
Baie

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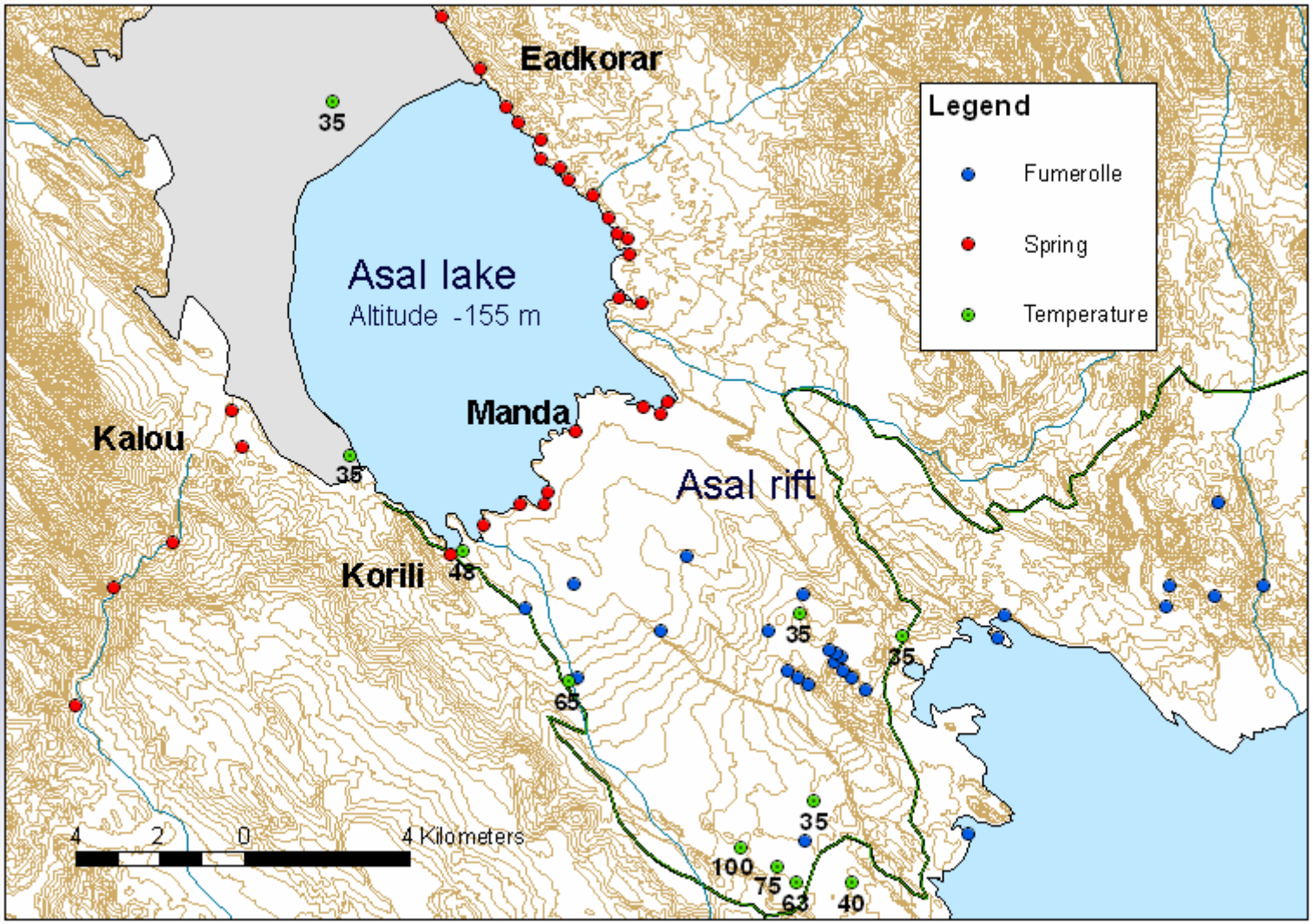
SURFACE MANIFESTATIONS AND GRADIENT WELLS. ASAL RIFT (BRGM-CERD 1973)



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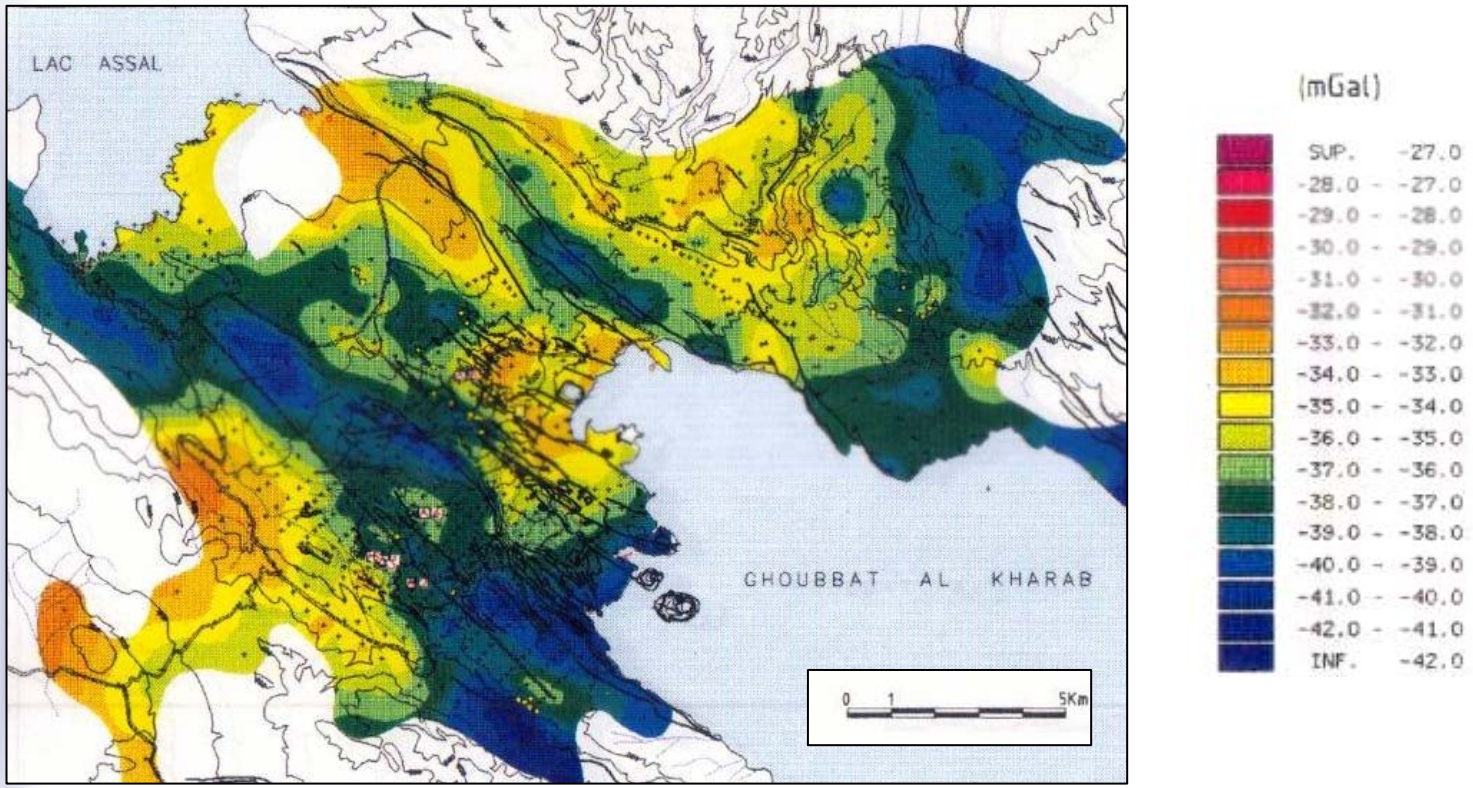
GRAVIMETRIC SURVEY. BOUGUER ANOMALY (BRGM 1993)



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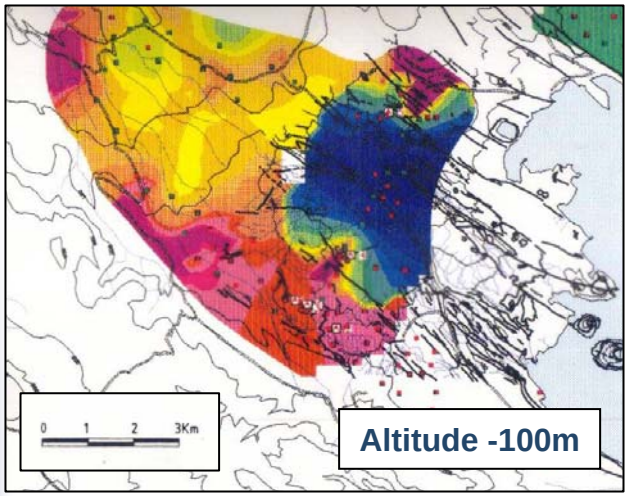
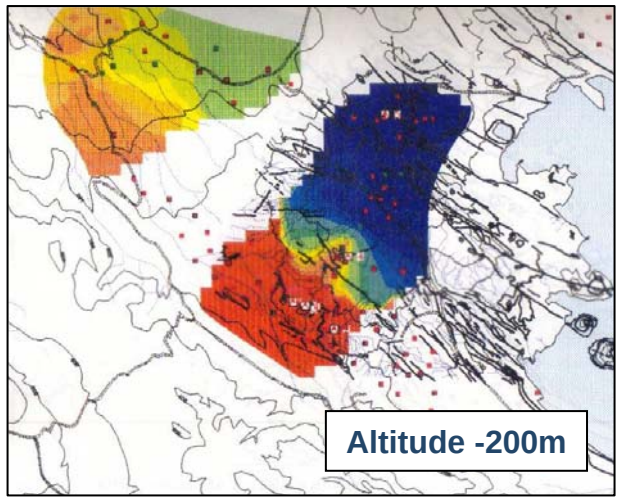
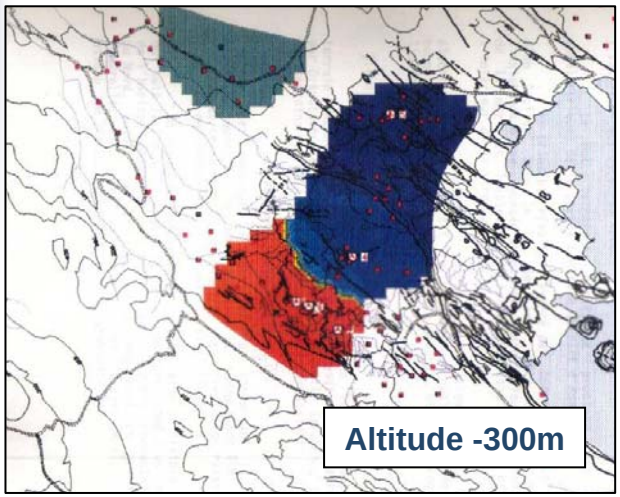
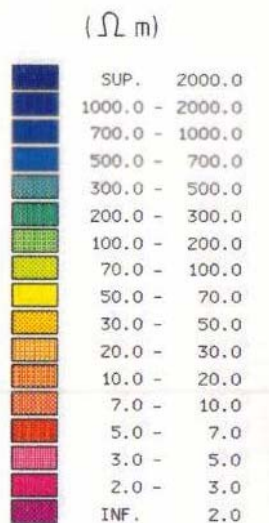
AMT SURVEY OF THE ASAL RIFT (BRGM 1993)









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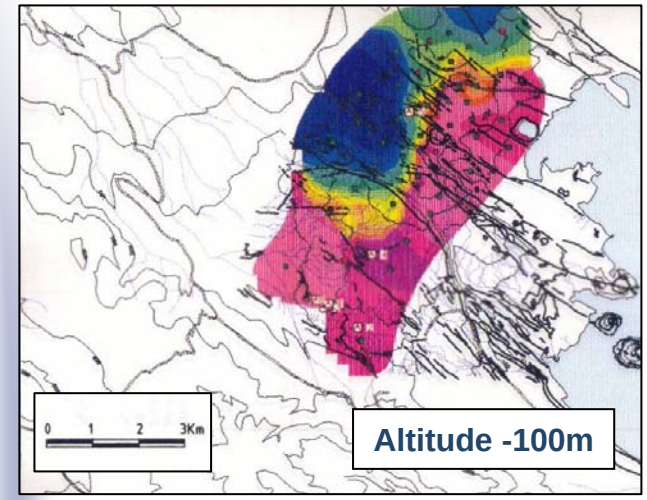
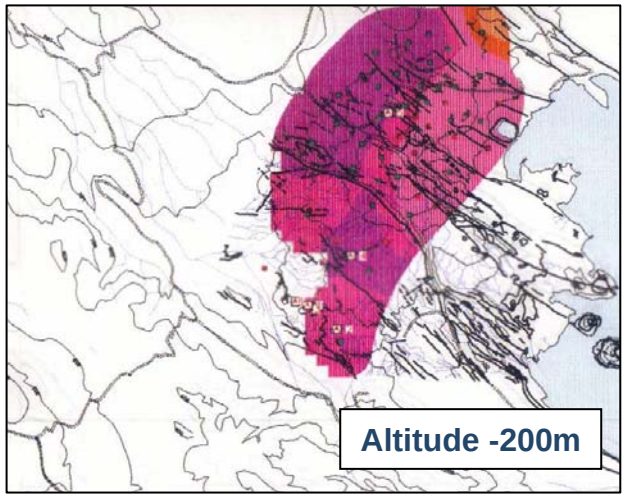
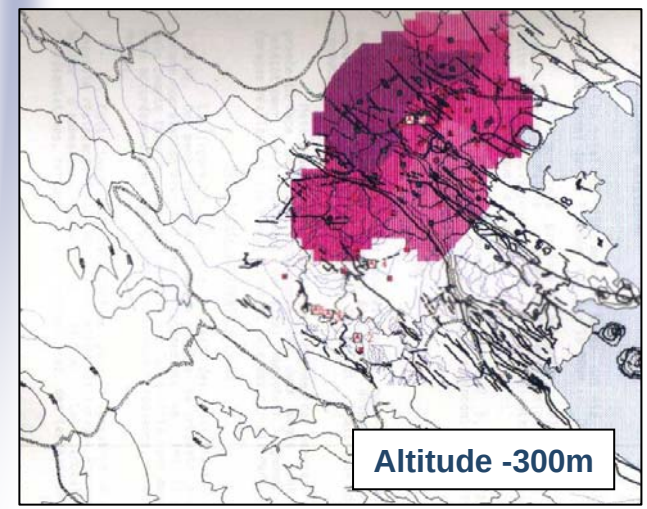
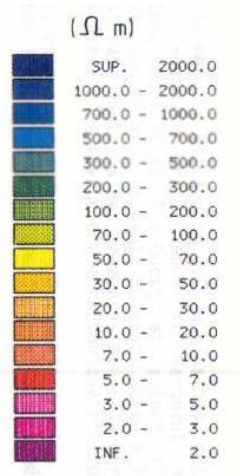
EM SURVEY OF THE ASAL RIFT (BRGM 1993; ORKUSTOFNUN 1988)









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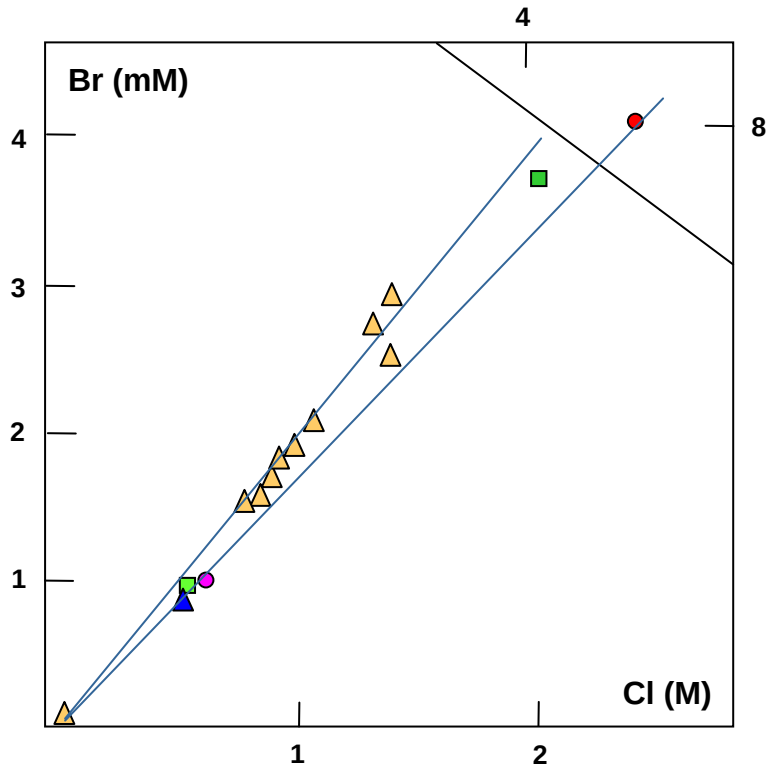
Br VERSUS Cl IN ASAL RIFT ZONE



●	Lake Asal
●	Sea water
■	Deep reservoir
■	Shallow reservoir
▲	Korili spring
△	Other springs

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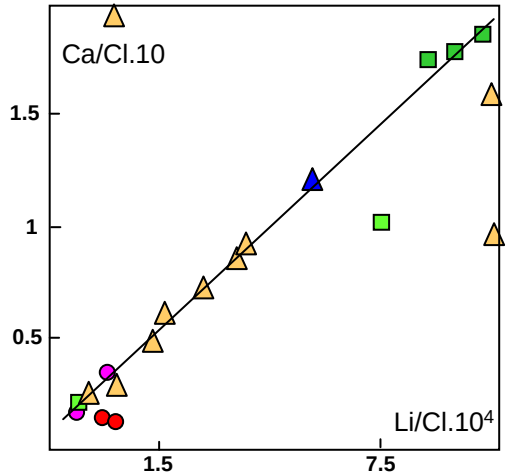
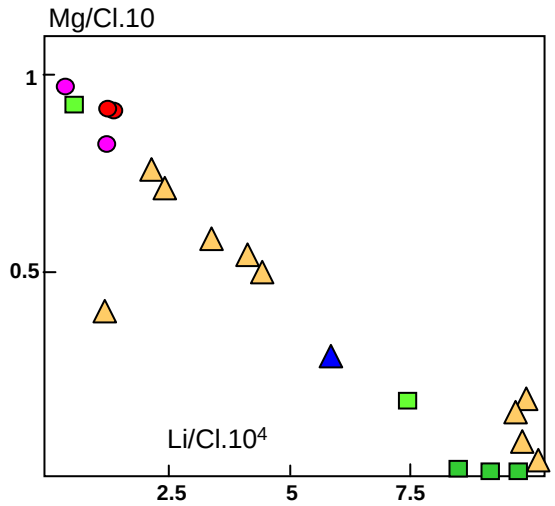
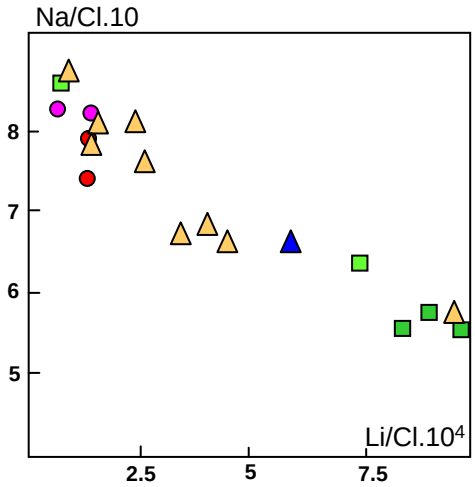
MAJOR ELEMENTS VERSUS Li (San Juan et al. 1990)







●	**Lake Asal**
●	**Sea water**
■	**Deep reservoir**
■	**Shallow reservoir**
▲	**Korili spring**
△	**Other springs**

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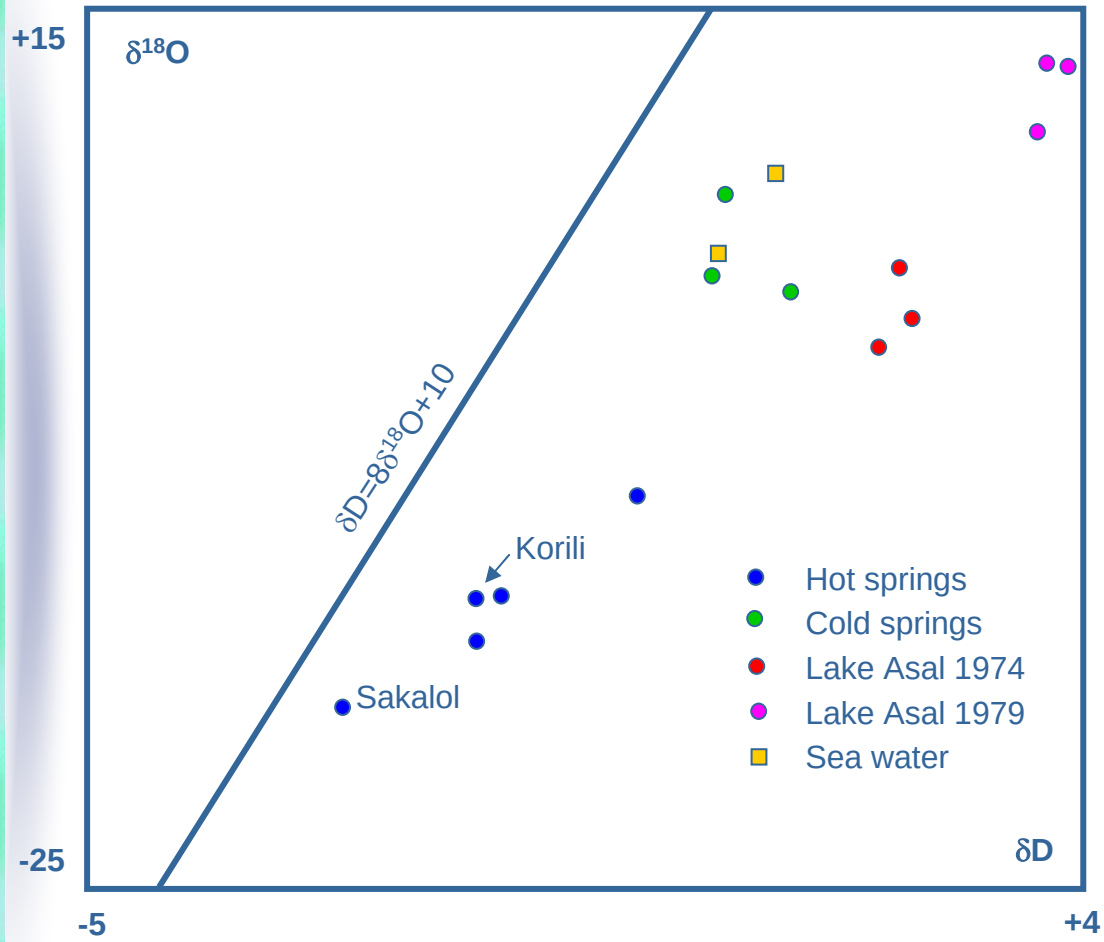
$\delta^{18}O$ VERSUS δD IN ASAL RIFT AREA



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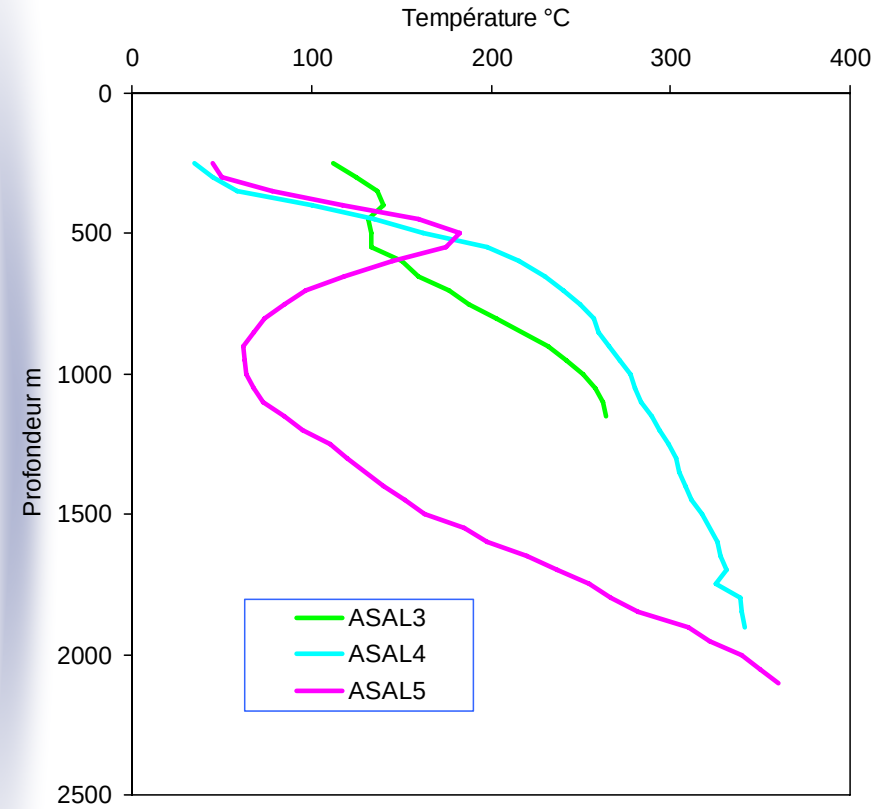
Temperature profiles – Asal geothermal area



Well	Depth (m)	Temp. Max (°C)	Temp. Gradient (°C/100m)
A1	1145	261	18
A2	1554	235	14.3
A3	1316	280	15.51
A4	2013	345	15.2
A5	2105	360	15.2
A6	1761	280	12.75

Interpretative cross section of Asal rift Geothermal area

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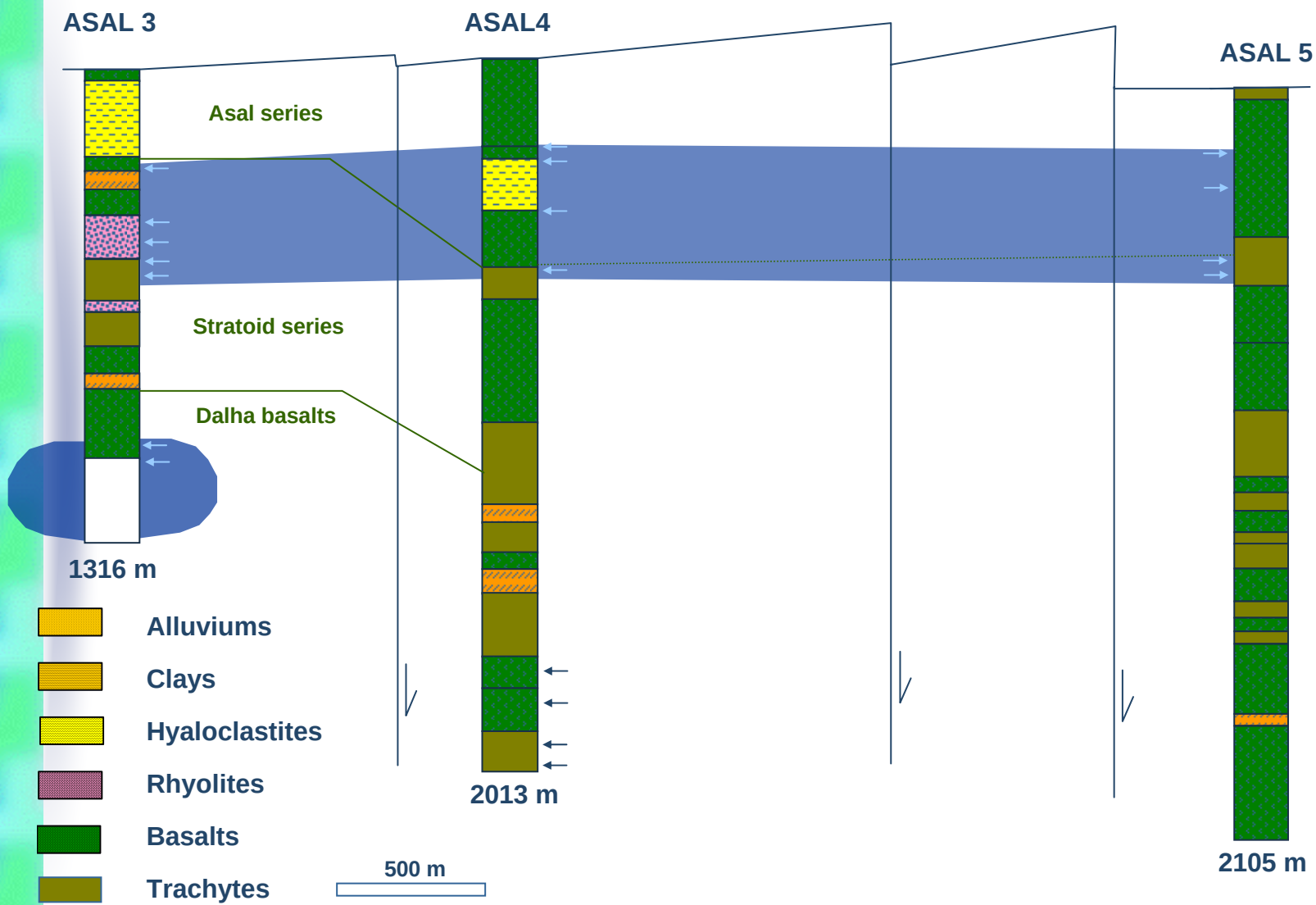

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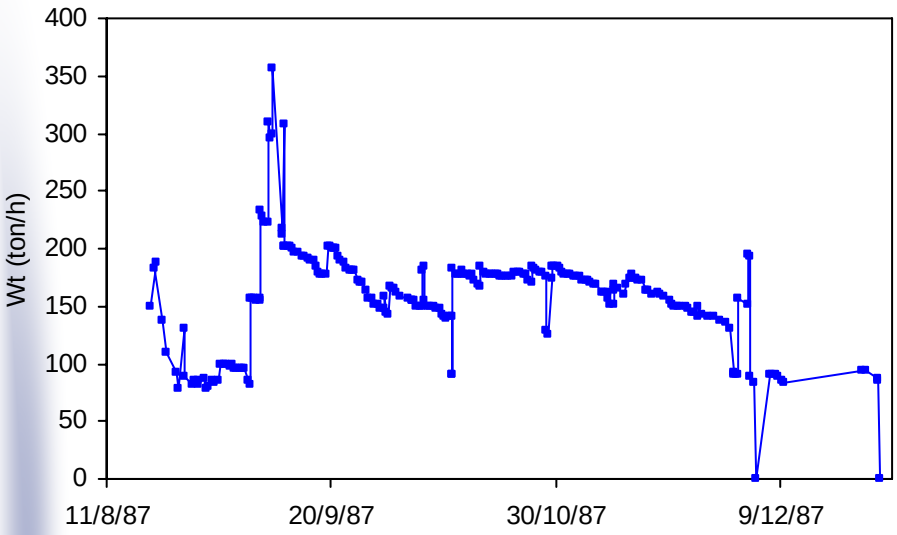
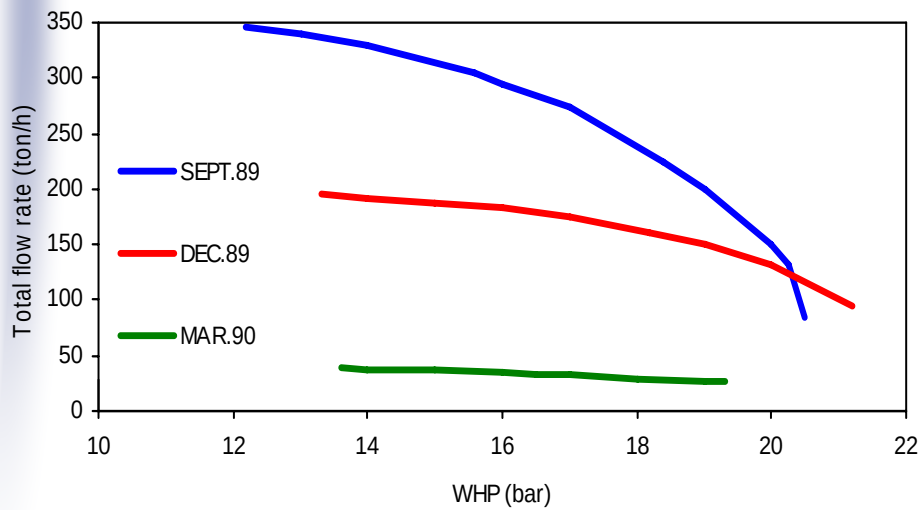
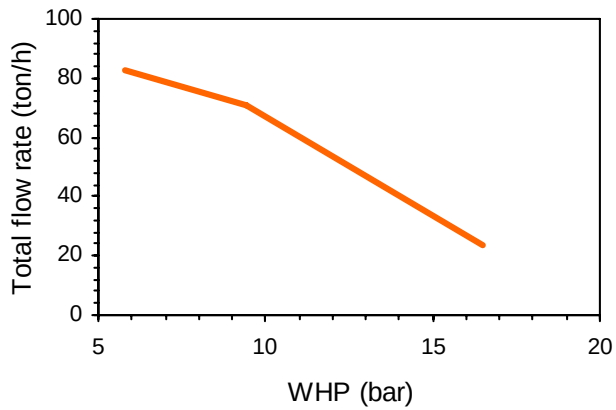
Production curves of ASAL 3





Production curve of ASAL 1



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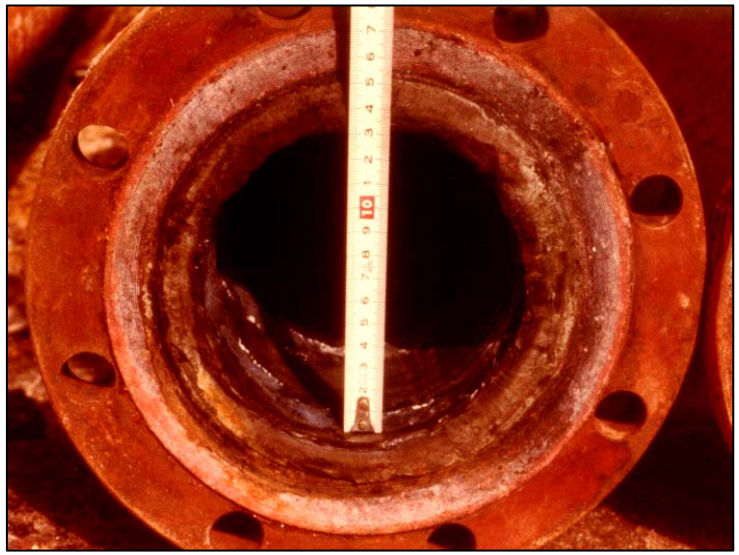
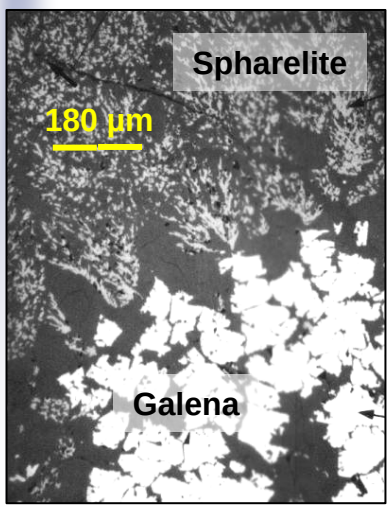
Scale deposits in 6 inches production line
Asal 1 geothermal well (BRGM-CERD 1981)





Sulphide deposits 300 m depth

Baryte x3000 Silencer deposits

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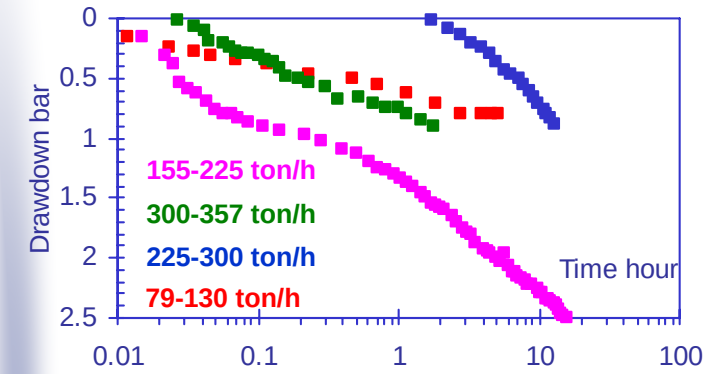
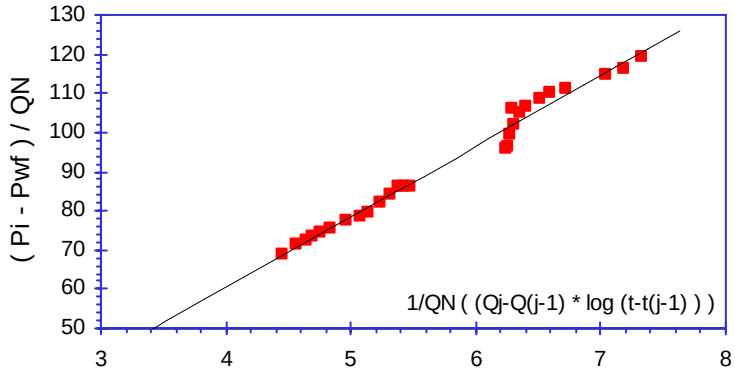
Asal 3 well testing data

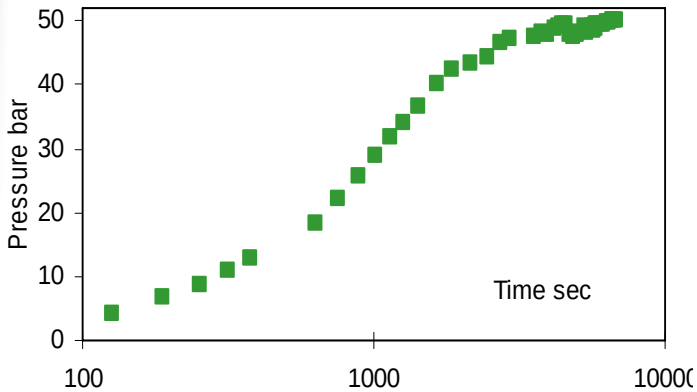
Drawdowns. ASAL3



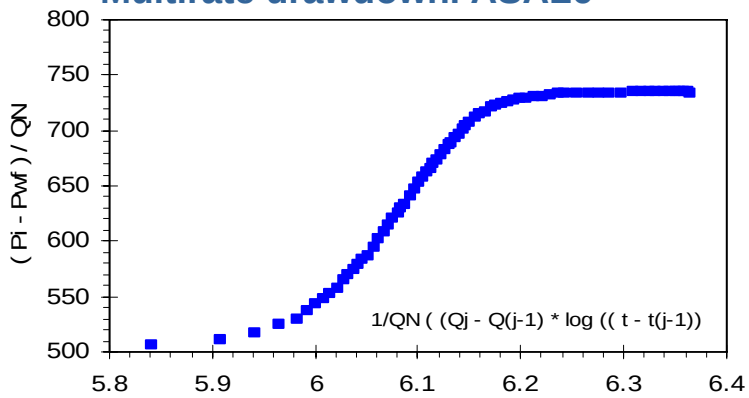
Multirate drawdown. ASAL3



Injectivity test. ASAL4



Multirate drawdown. ASAL6



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HYDRODYNAMIC PROPERTIES OF THE DEEP RESERVOIR IN ASAL RIFT ZONE

ASAL3 Drawdown tests

		Semilog	Bilog	
Wt ton/h	ΔQ ton/h	kh dm	skin	kh dm
79 - 130	51	15.6	- 5	15.6
Multiple		15.9		
155 - 225	70	15.7 5.7	- 5 - 5	16 6
225 - 300	75	6		
300 - 357	57	13.4	- 5	13.4

ASAL3 recovery tests

Wt ton/h	ΔQ ton/h	kh dm
357 - 0	357	7.3
87 - 0	87	5.8

ASAL4 injectivity test

		Semilog	Bilog
	Q m3/h	kh dm	kh dm
Injectivity	70	0.6	0.7
After injection		0.28	

ASAL6 Drawdown tests

		Semilog	Bilog	
Wt ton/h	ΔQ ton/h	kh dm	skin	kh dm
Multiple		4.11		
Multiple		6.4		
65.2 - 78.3	13.1	6.9	10	3.7

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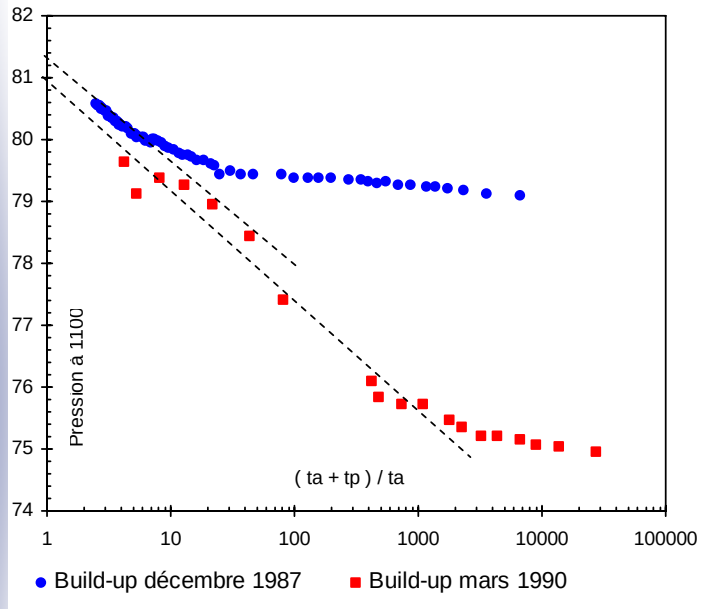
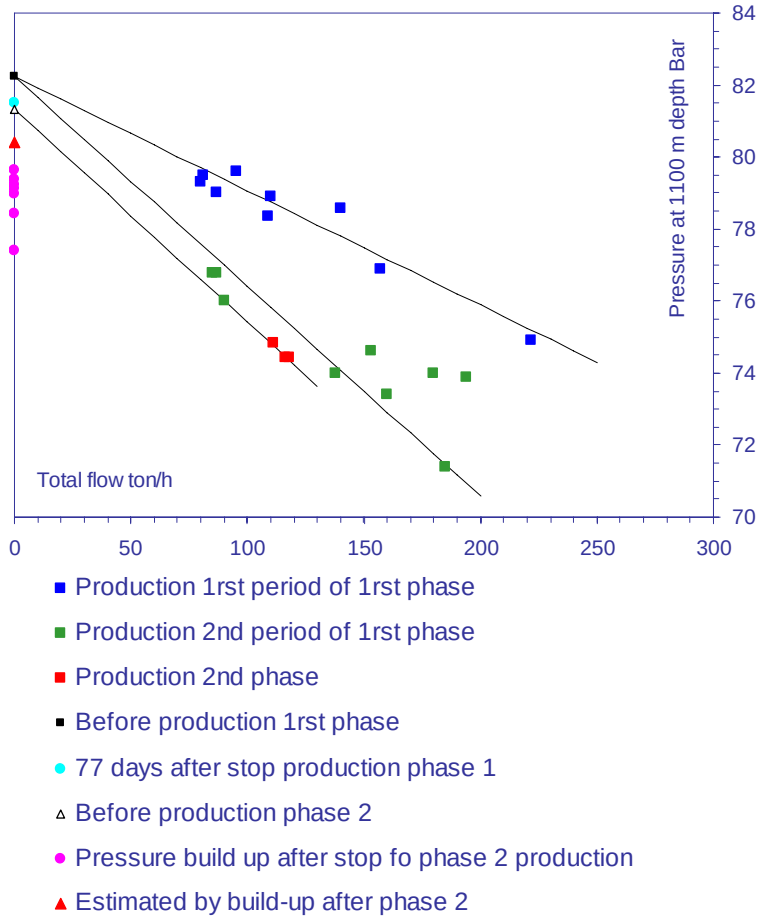
PRESSURE BUILD-UP MEASUREMENTS. ASAL3





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DEEP RESERVOIR RESULTS IN ASAL

- Reservoir recognized by ASAL1, ASAL3 and ASAL 6 in the same area
- Temperature 260 °C to 280 °C
- Reservoir: Dalha basalts (9 - 4 My), 1050 m to 1300 m
- ASAL 3 production:

  Initial characteristics: total mass flow 360 t/h for 12.5 WHP
  Kh: 6.3 dm
  TDS in the reservoir: 116 000 ppm
  Scaling in the well (6 to 10 mm): sulphides (PbS, ZnS)
  Scaling in surface equipment: amorphous Si with Fe and Mn
  Severe decrease of the production rate
  Decrease of the bottom hole pressure: 3.5 bars

ASAL INTERMEDIATE RESERVOIR

- Recognized on all Asal geothermal wells but not yet studied
- Reservoir: Top of Stratoid series and the bottom of Asal series
- Located between 300 m and 600 m
- Temperature 130 °C to 190 °C
- TDS : 50 g/l

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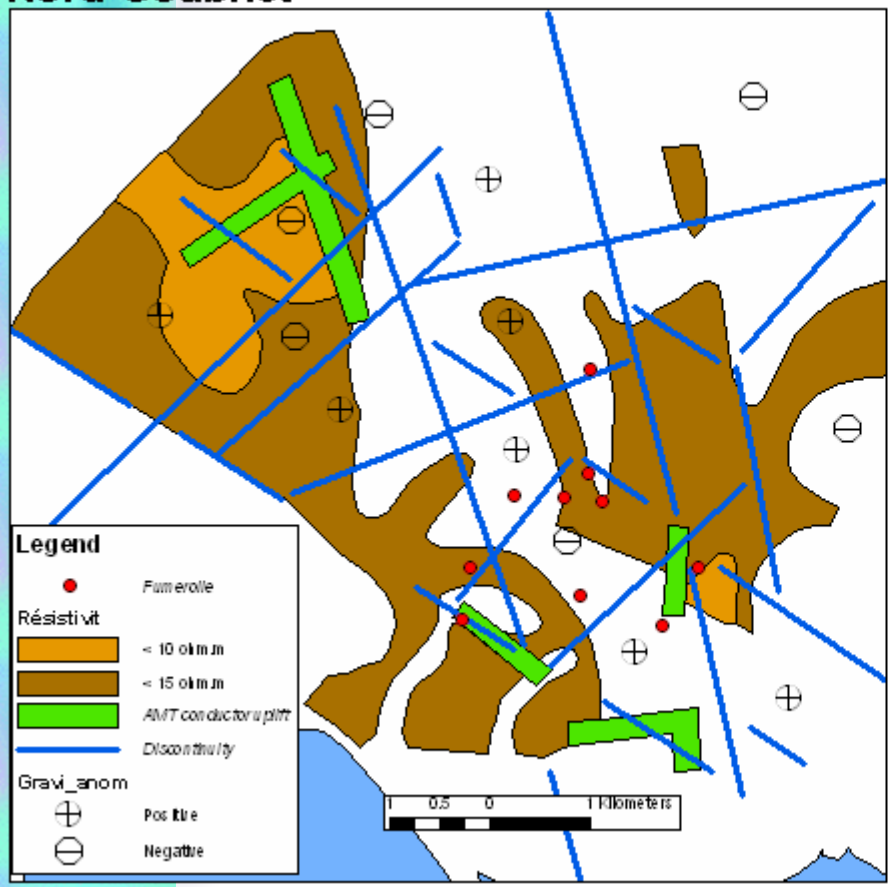
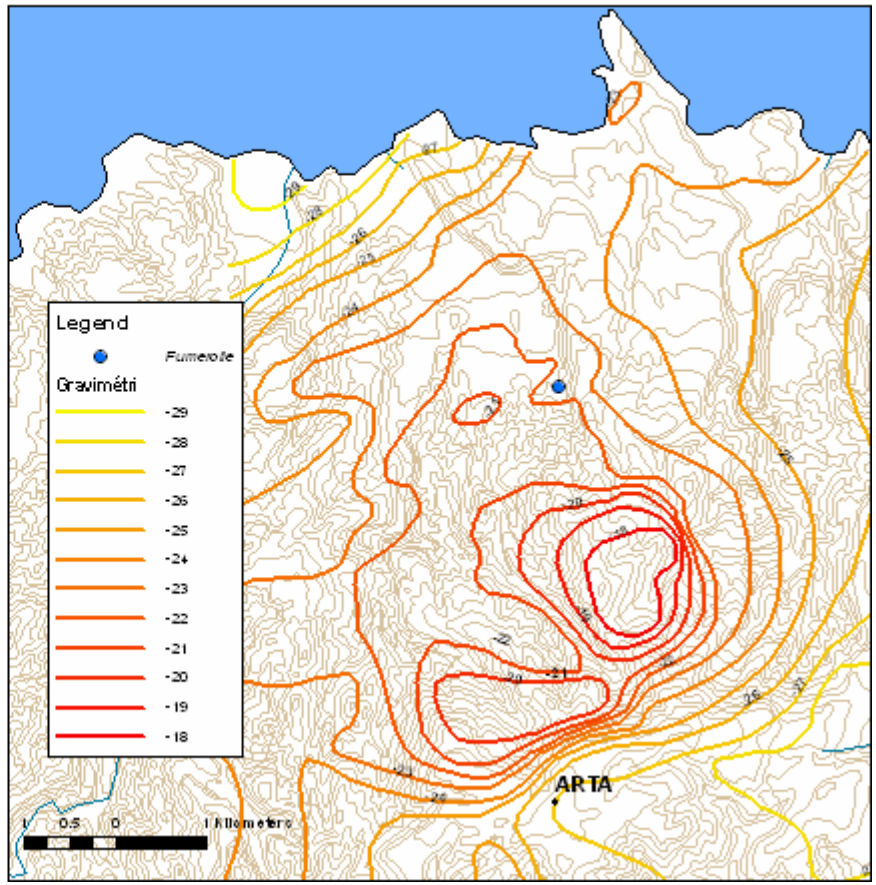
NORD-GOUBHET AND ARTA GEOPHYSICAL SURVEYS (BRGM 1983; GEOTHERMICA 1982)

Nord-Goubhet



Arta



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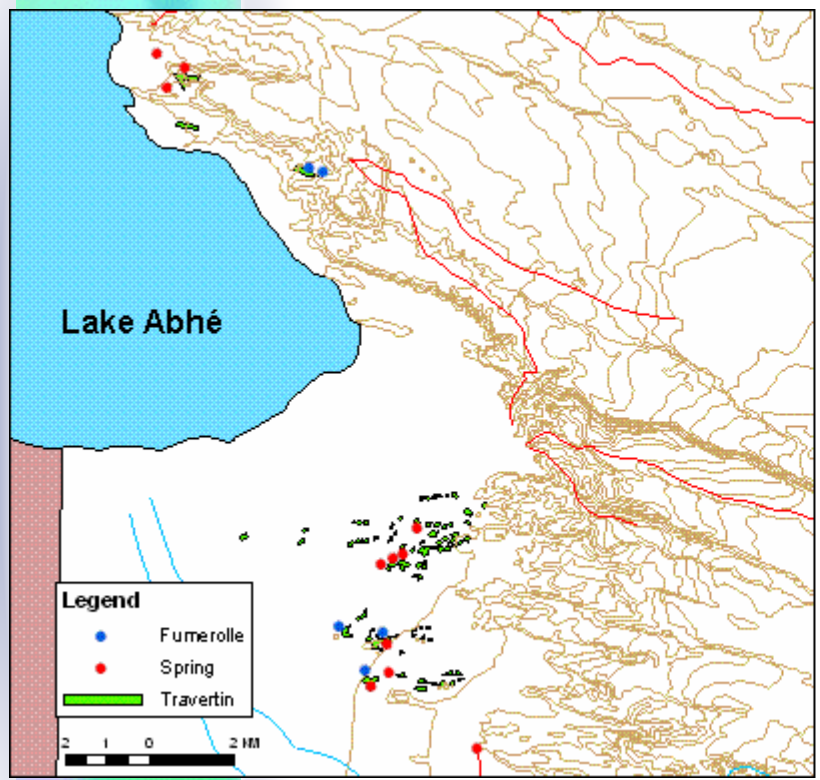
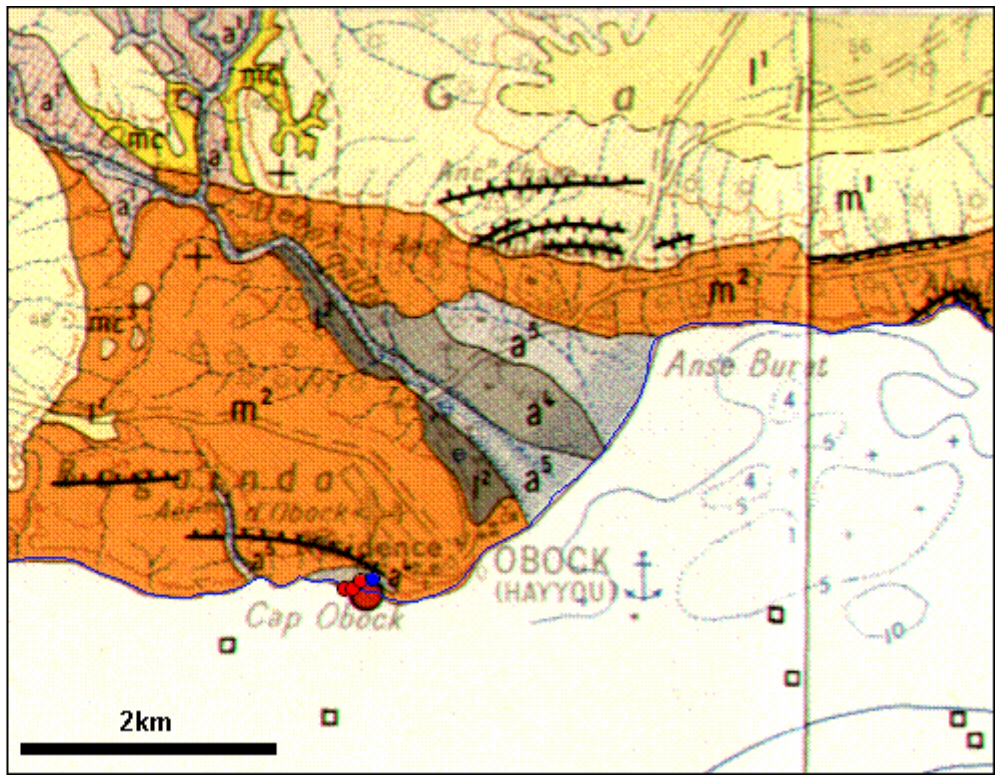
LAKE ABHE AND OBOCK GEOTHERMAL PROSPECTS





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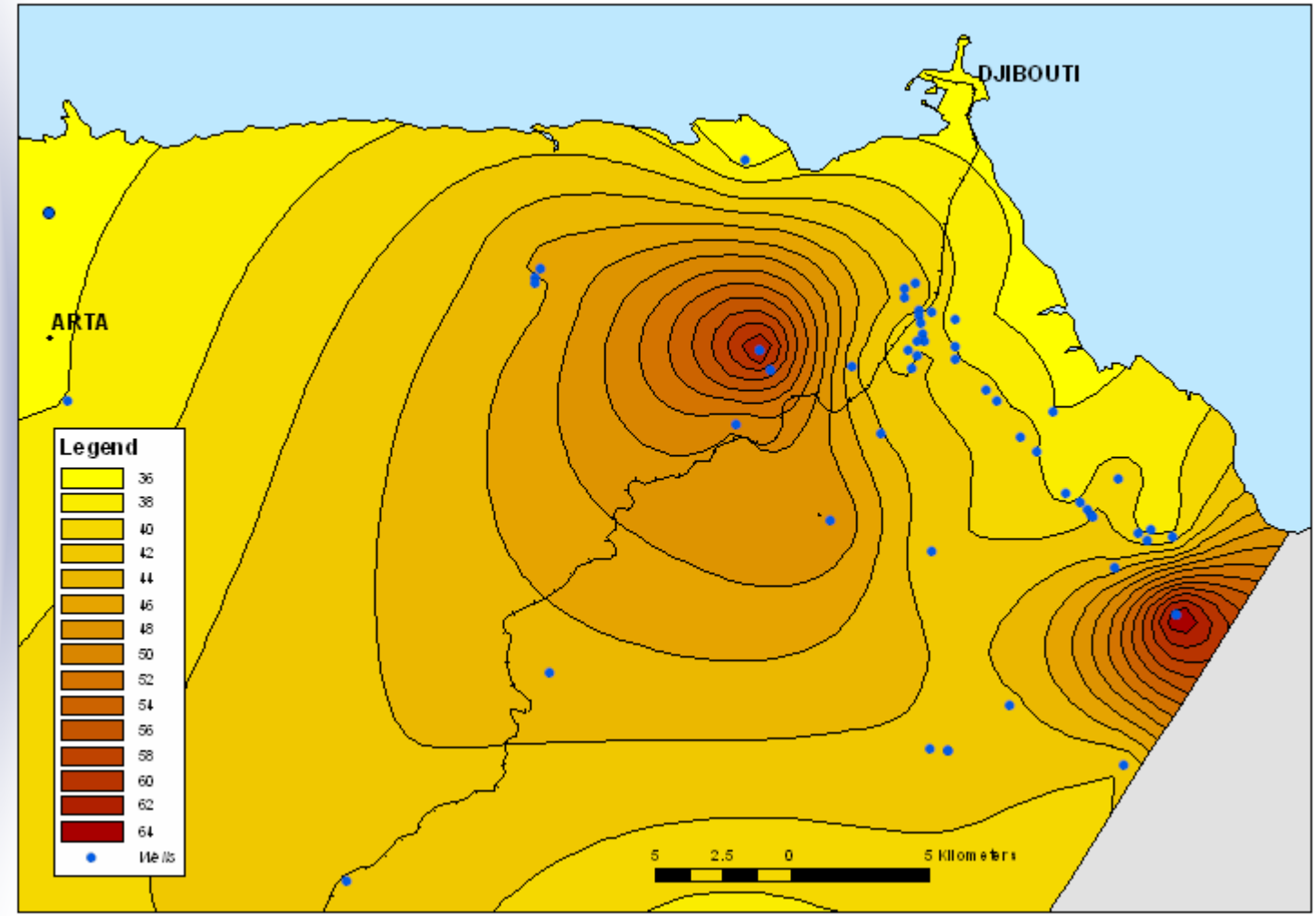
GROUNDWATER THERMAL ANOMALIES
DJIBOUTI AQUIFER



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CONCLUSIONS

- **HANLE-GAGGADE BASINS ZONE**
  Drilling results not conclusive in Hanle basin
  Exploration by drilling not completed
  Need for new geophysical surveys as EM, AMT
  Reevaluate possibility of new drillings

- **ASAL RIFT ZONE**
  Deep reservoir of high enthalpy demonstrated in ASAL1 area
  Lateral extension of deep reservoir not yet evident
  Permeability and circulations controled by fractures
  Major problem of scaling still to resolve
  Geophysical surveys describe complex structures of reservoirs
  Fairly good understanding of fluids origins based on geochemistry and isotopes

  Shallow reservoir medium enthalpy preliminary significant results
  Shallow reservoir likely to have good extension

CERD

PERSPECTIVES FOR GEOTHERMAL DEVELOPMENT

- **ASAL RIFT ZONE**
  - Complete exploration for the deep reservoir extension
  - Solutions for the scaling problem of the deep reservoir
  - Complete EM survey of Asal rift zone
  - Study faisability of the mineral extraction from the deep reservoir high TDS fluid
  - Realize exploration with drillings in the shallow reservoir
  - Develop both reservoirs for electricity production

- **OBOCK ZONE**
  - Realize geophysical surveys with EM and AMT methods
  - Realize geochemical and isotopic studies on the hydrothermal manifestations
  - Exploration drillings
  - Faisability study

- **LAKE ABHE AND GAGGADE ZONES**
  - Realize geophysical surveys with EM and AMT methods
  - Realize geochemical and isotopic studies on the hydrothermal manifestations
  - Exploration drillings
  - Faisability study


Thank you