Geothermal prospecting by geochemical methods in Yemen and the Quaternary volcanic province of Dhamar (central Yemen)

(overview)

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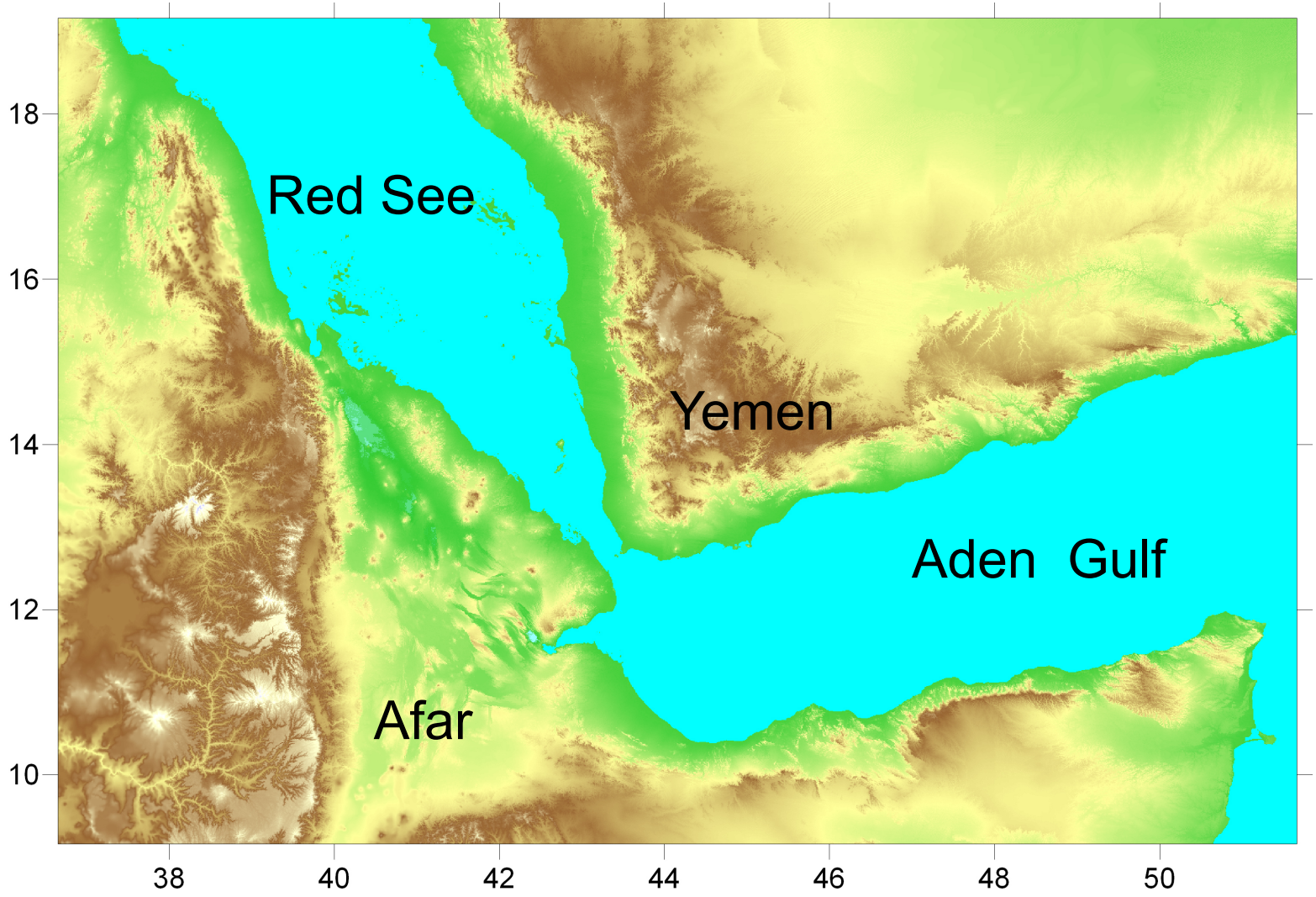
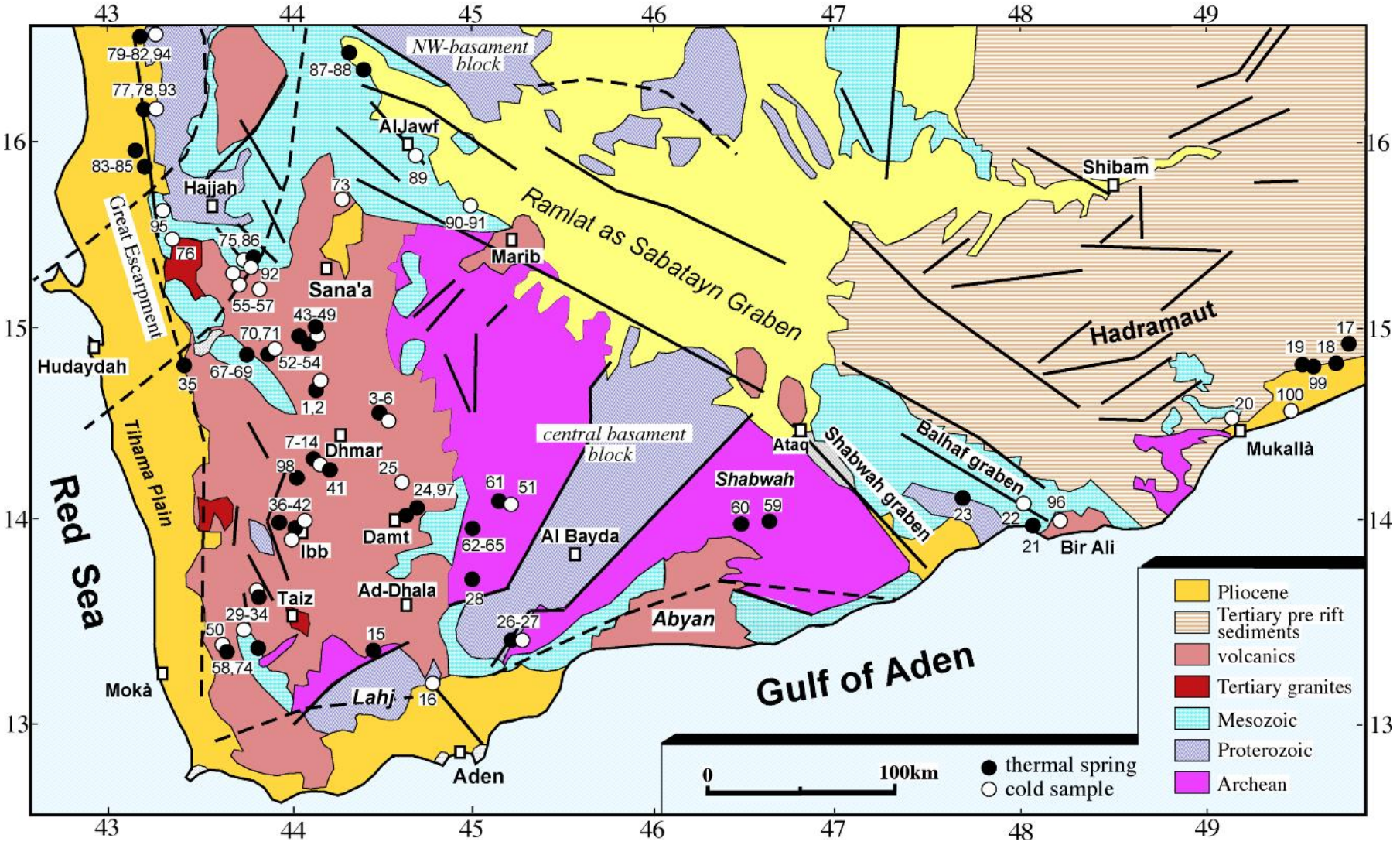

Red See
Yemen
Aden Gulf
Afar
18
16
14
12
10
38
40
42
44
46
48
50

Schematic geology of Yemen and location of thermal springs



Yemen

samples

59 thermal springs
33 cold samples (well, wadi, spring)
3 fumroles
2 boiling pools
19 gas samples (at 9 different areas)

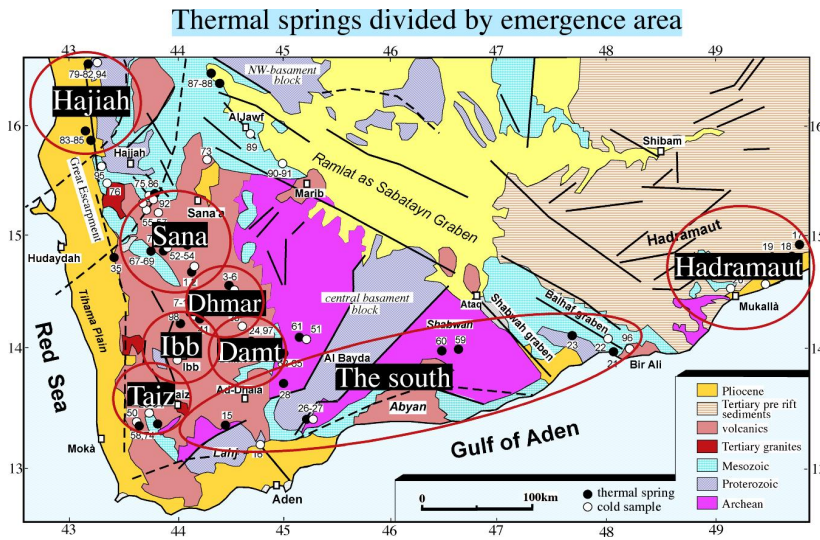
elements in waters

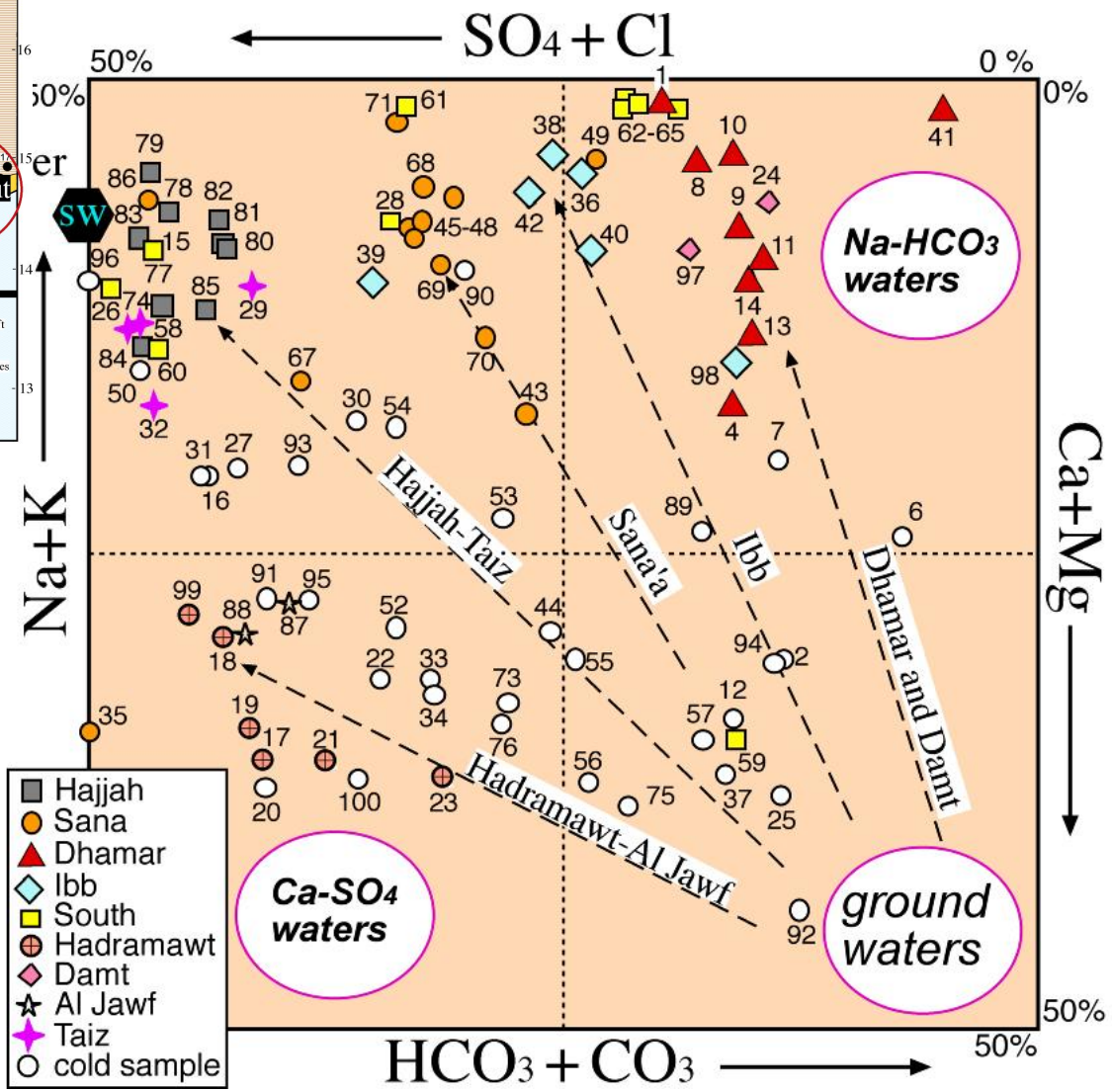
main components
SiO_2, B, Br, F, Li, NH_4, NO_3
$\delta^{18}O$, δD

elements in gases

main components;
He, Ar, Ne, CO, light hydrocarbons;
$\delta^{13}C$ in CO_2, $^3He/^4He$

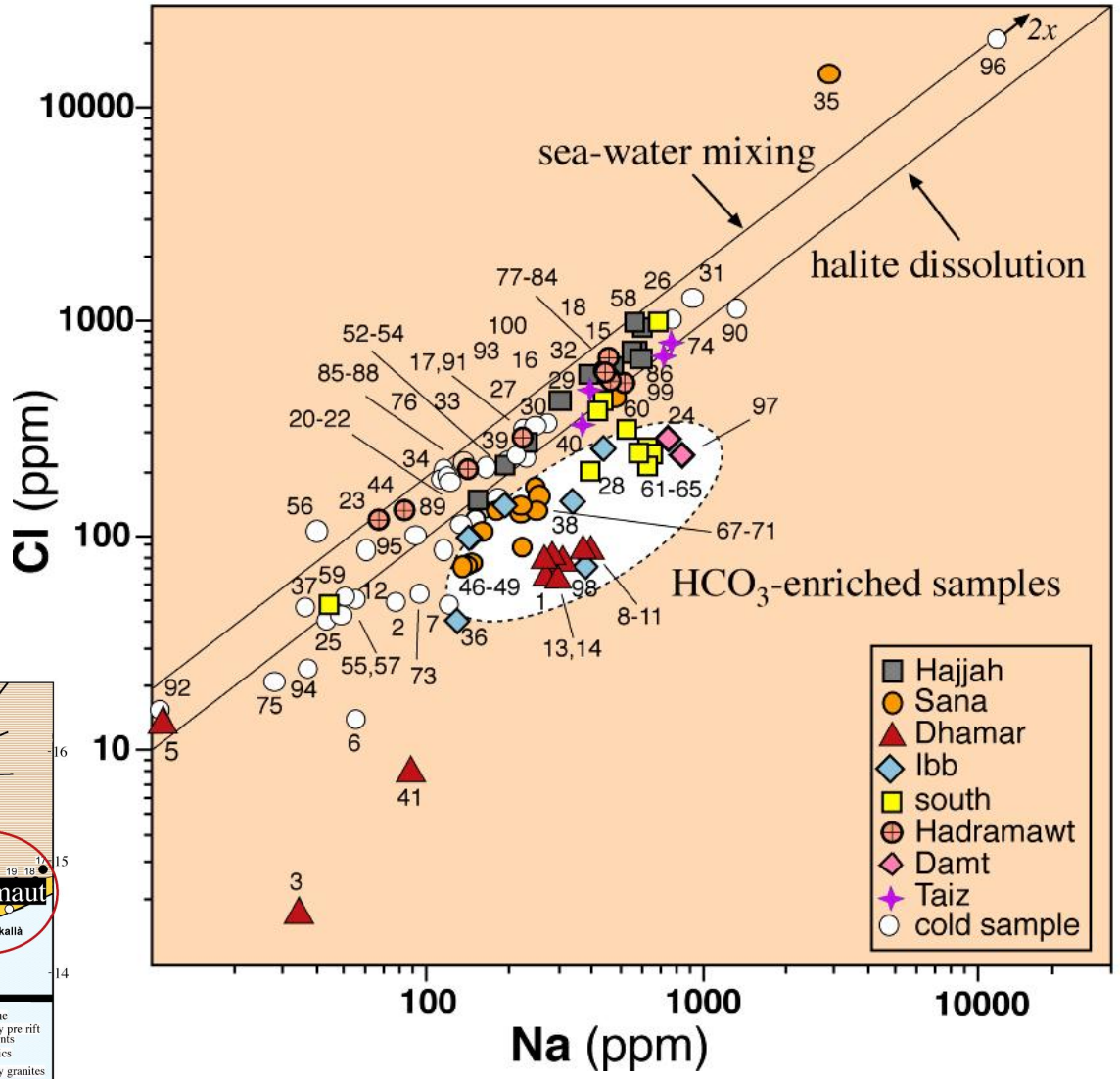
Chemical composition of springs in Yemen



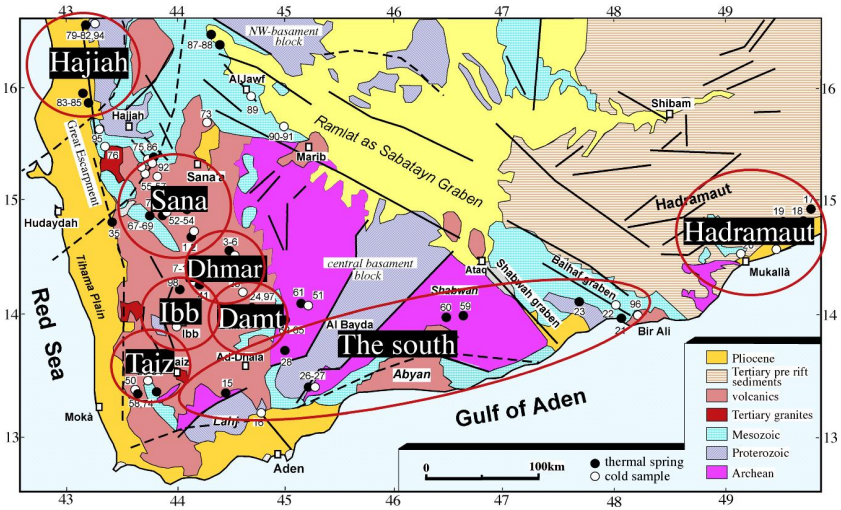


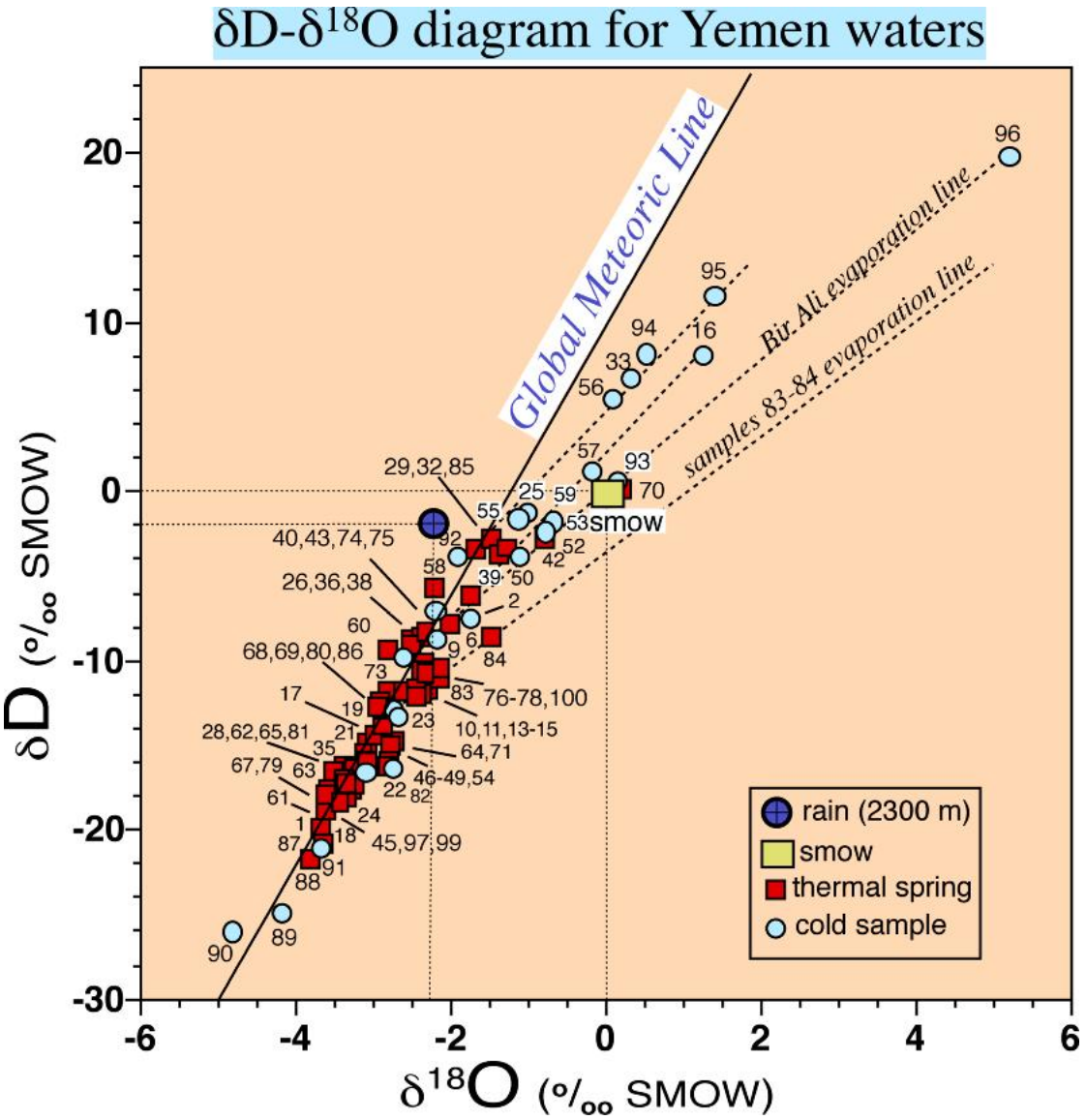
Minissale A., Mattash, M., Vaselli O., Tassi F., Al-Ganad I., Selmo E., Shawki M., Tedesco D., Poreda R., Ad-Dukhain A. & Hazzae M. (**2007**) *Thermal springs, fumaroles and gas vents of continental Yemen: their relation with active tectonics, regional hydrology and country's geothermal potential*. **Appl. Geochem. 22**, 799-820

Na *vs* Cl diagram for Yemen waters

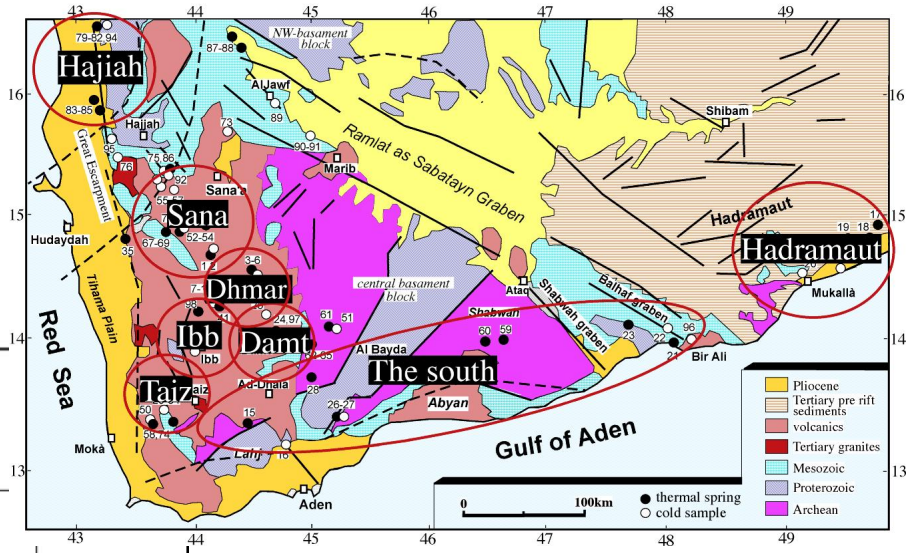


Thermal springs divided by emergence area

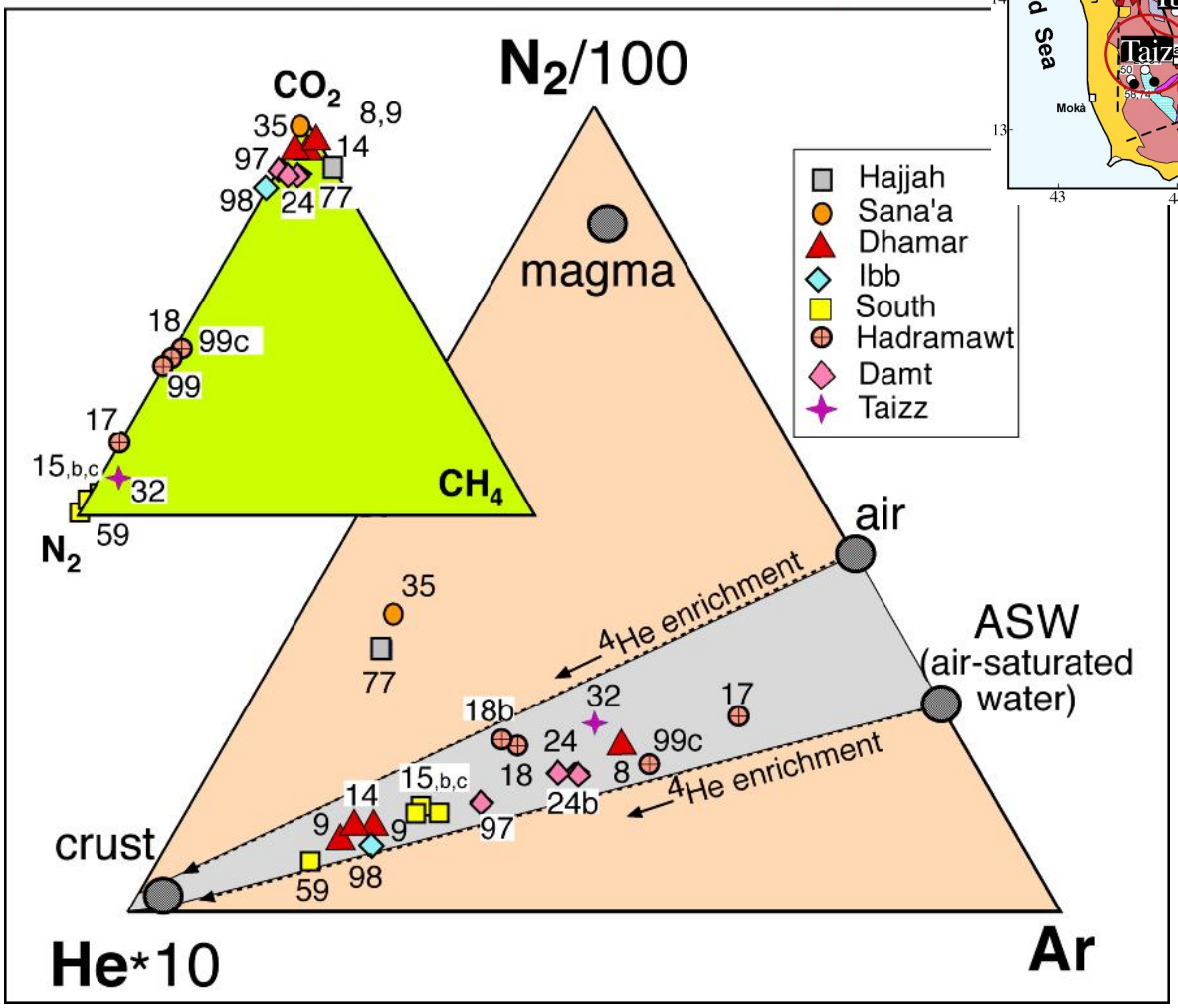



δD-δ18O diagram for Yemen waters
Global Meteoric Line
Bir Ali evaporation line
samples 83-84 evaporation line
smow
rain (2300 m)
smow
thermal spring
cold sample
δD (°/oo SMOW)
δ18O (°/oo SMOW)
20
10
0
-10
-20
-30
-6
-4
-2
0
2
4
6
96
95
94
16
33
56
57
93
70
59
25
55
53
52
42
50
39
2
6
84
83
76-78,100
10,11,13-15
64,71
46-49,54
22
82
24
18
45,97,99
91
88
89
90
87
1
61
63
67,79
35
21
23
19
17
73
9
60
68,69,80,86
58
92
40,43,74,75
26,36,38
29,32,85
28,62,65,81

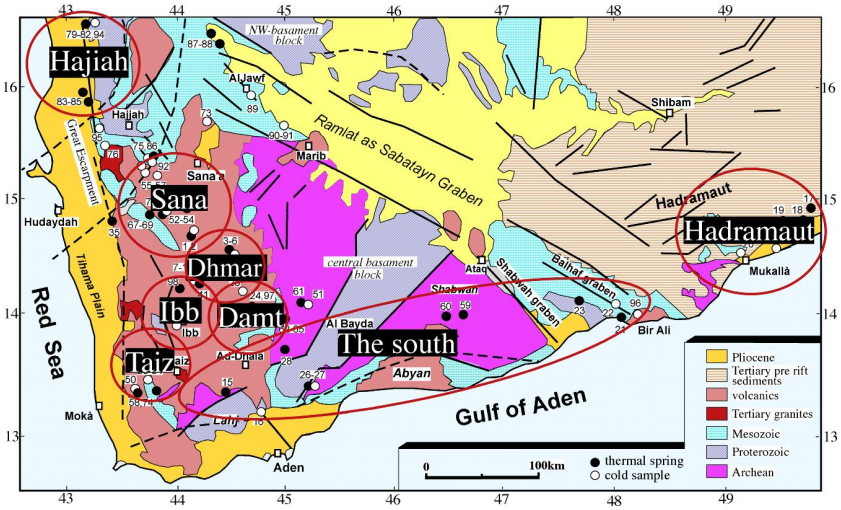
Thermal springs divided by emergence area



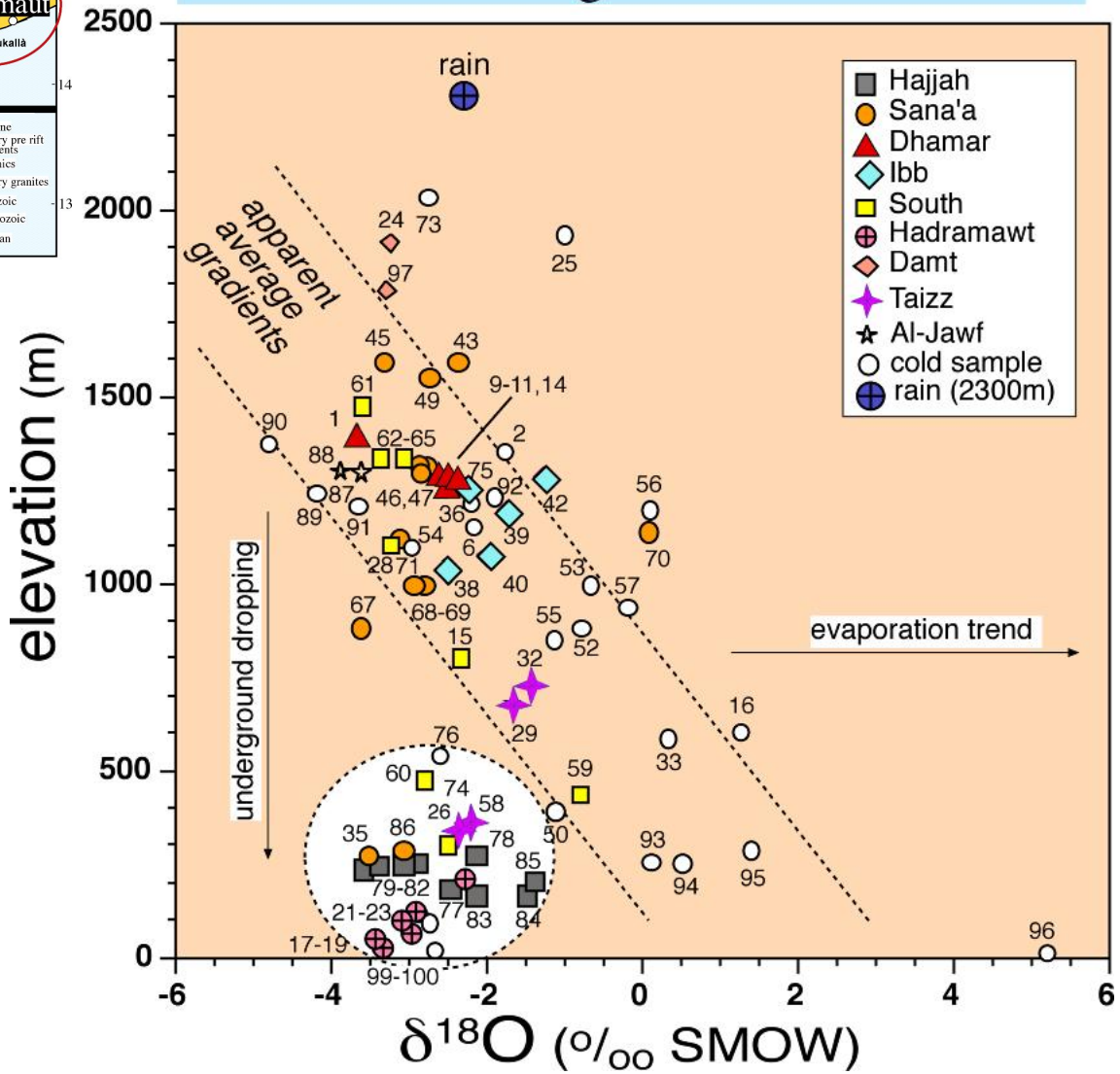
crustal gases of Yemen



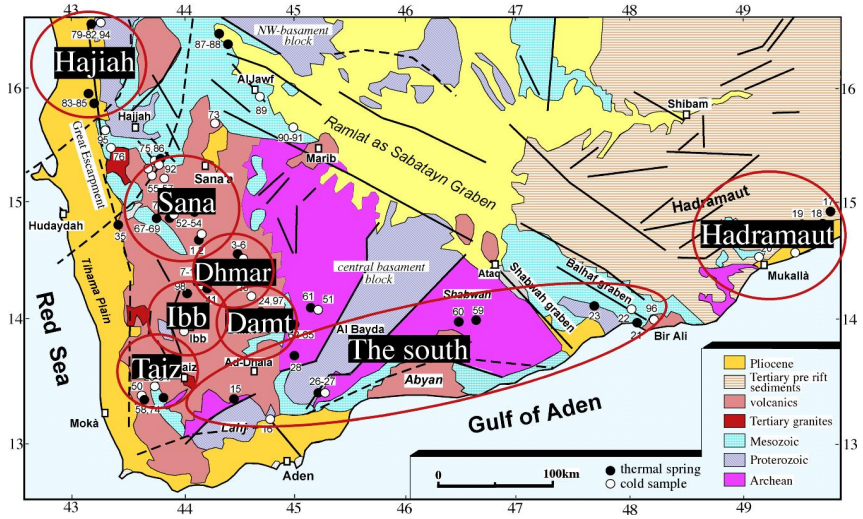
Thermal springs divided by emergence area



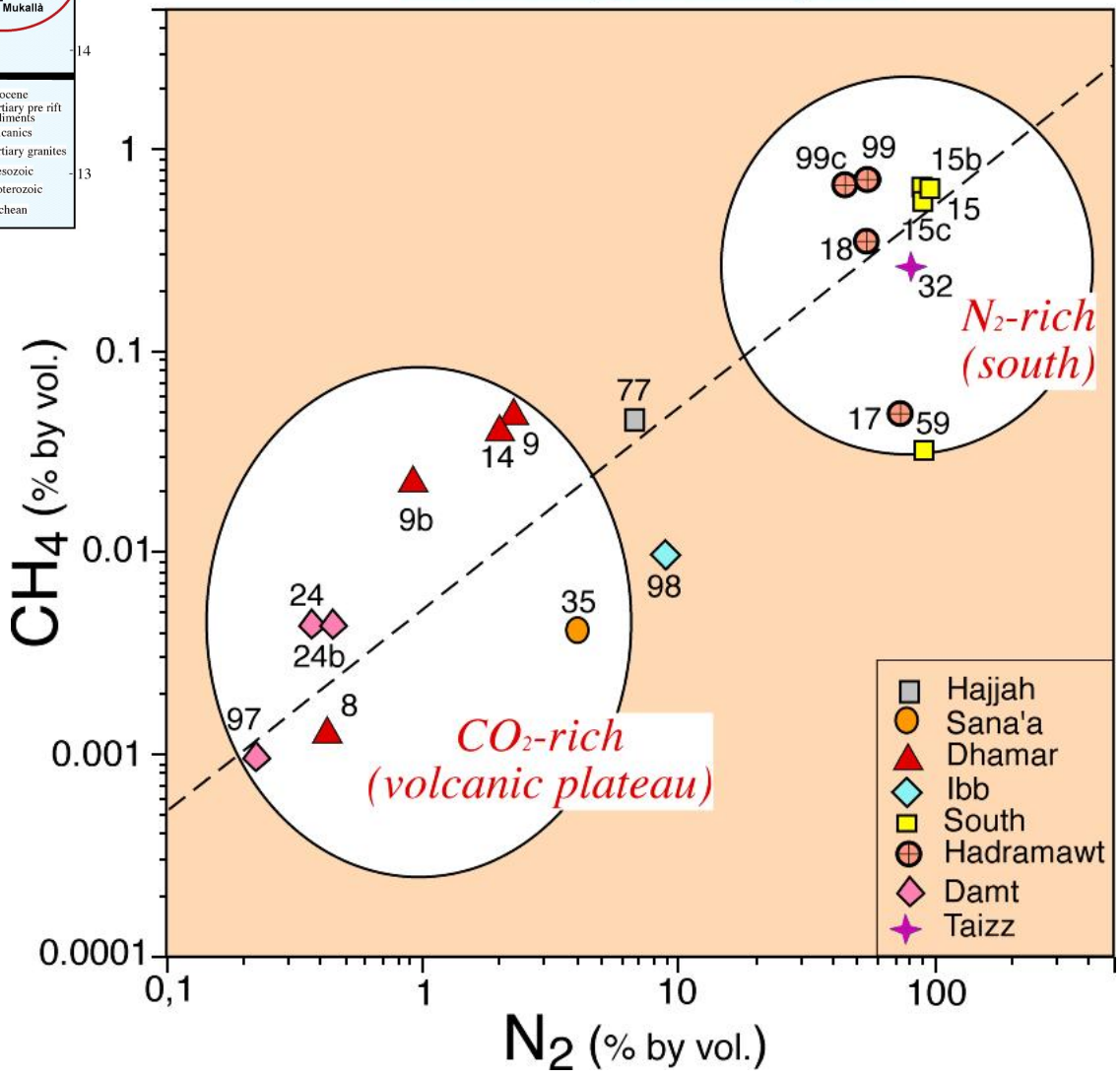
elevation-$\delta^{18}O$ diagram for Yemen waters



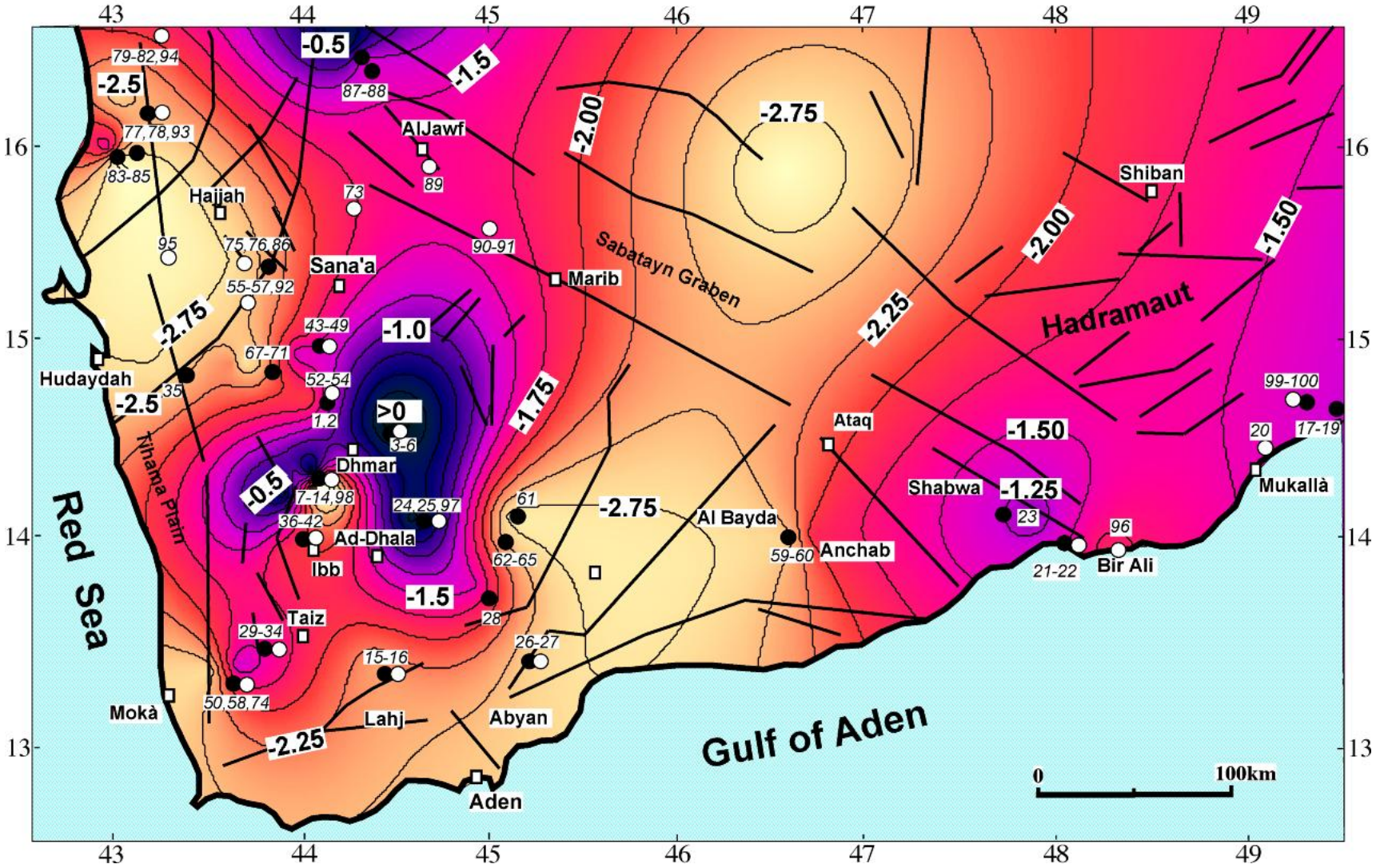
Thermal springs divided by emergence area



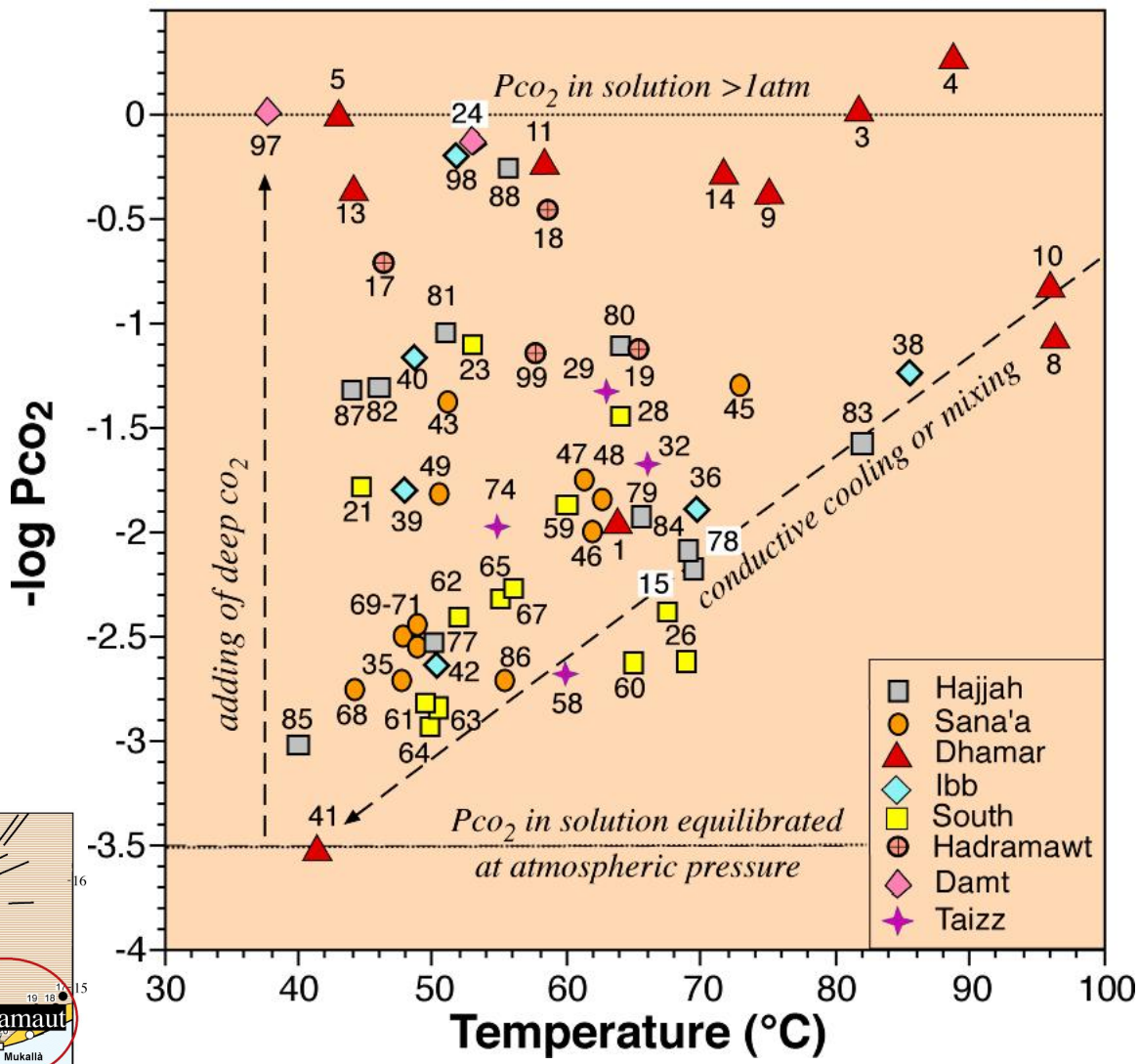
Yemen gas samples



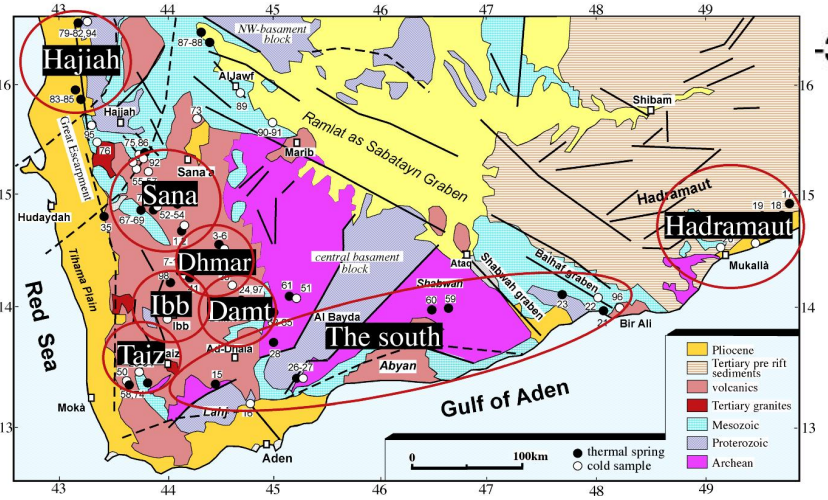
Distribution map of calculated pCO_2 in thermal springs



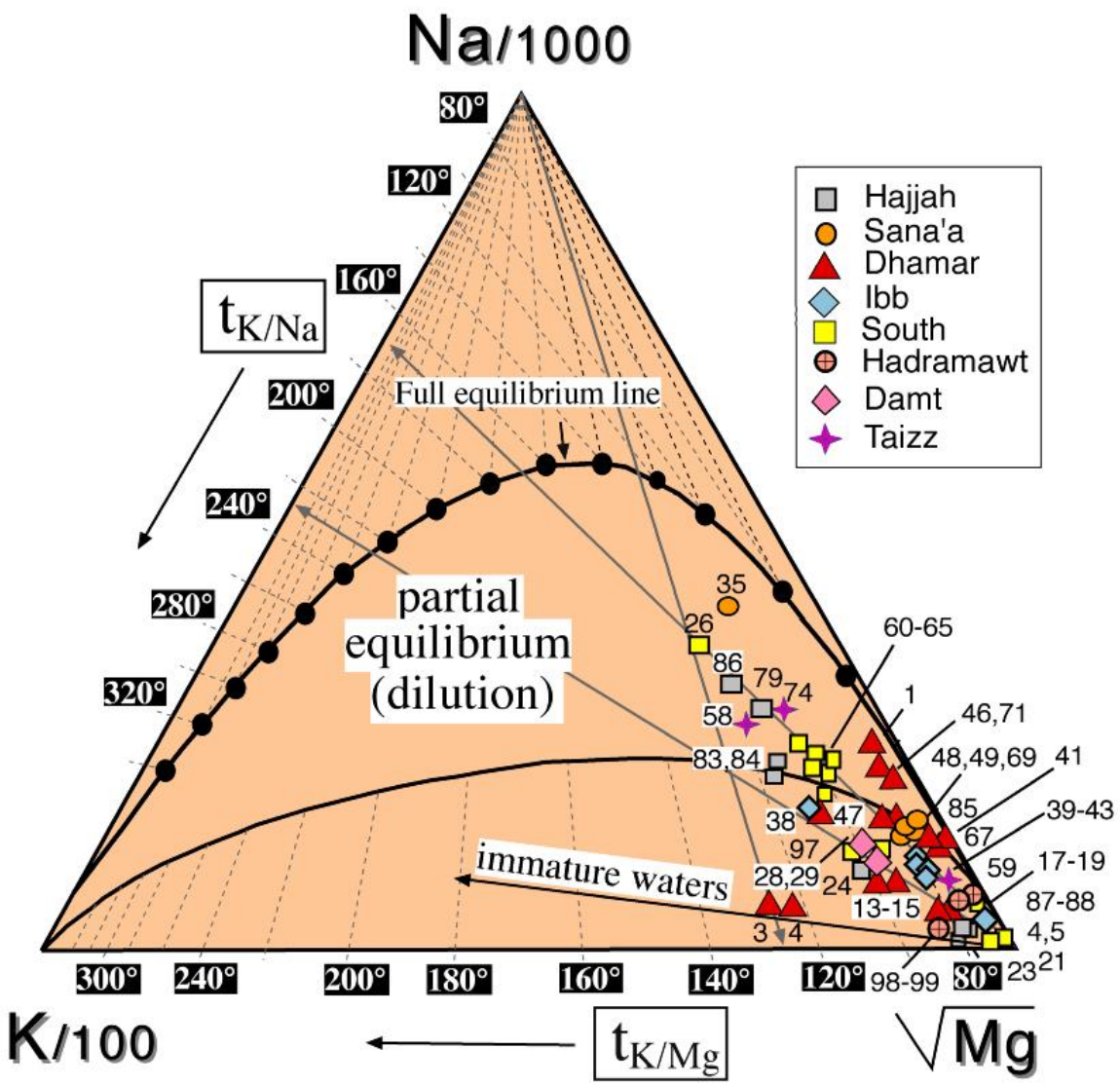
temperature-pCO_2 in Yemen springs



Thermal springs divided by emergence area



Evaluation of Na-K-Mg temperature

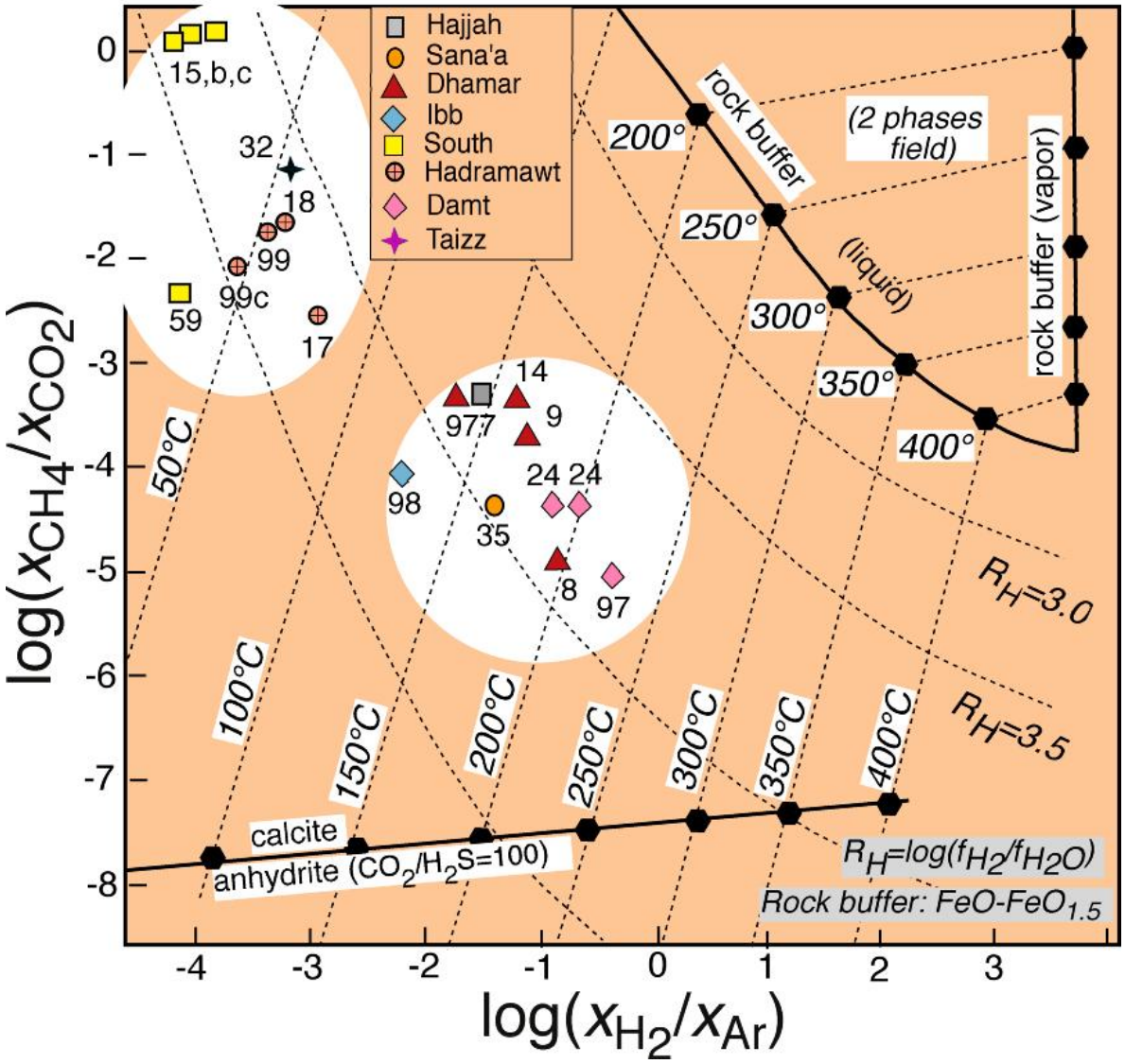


K-feldspar+Na^+ = Na-feldpar + K^+

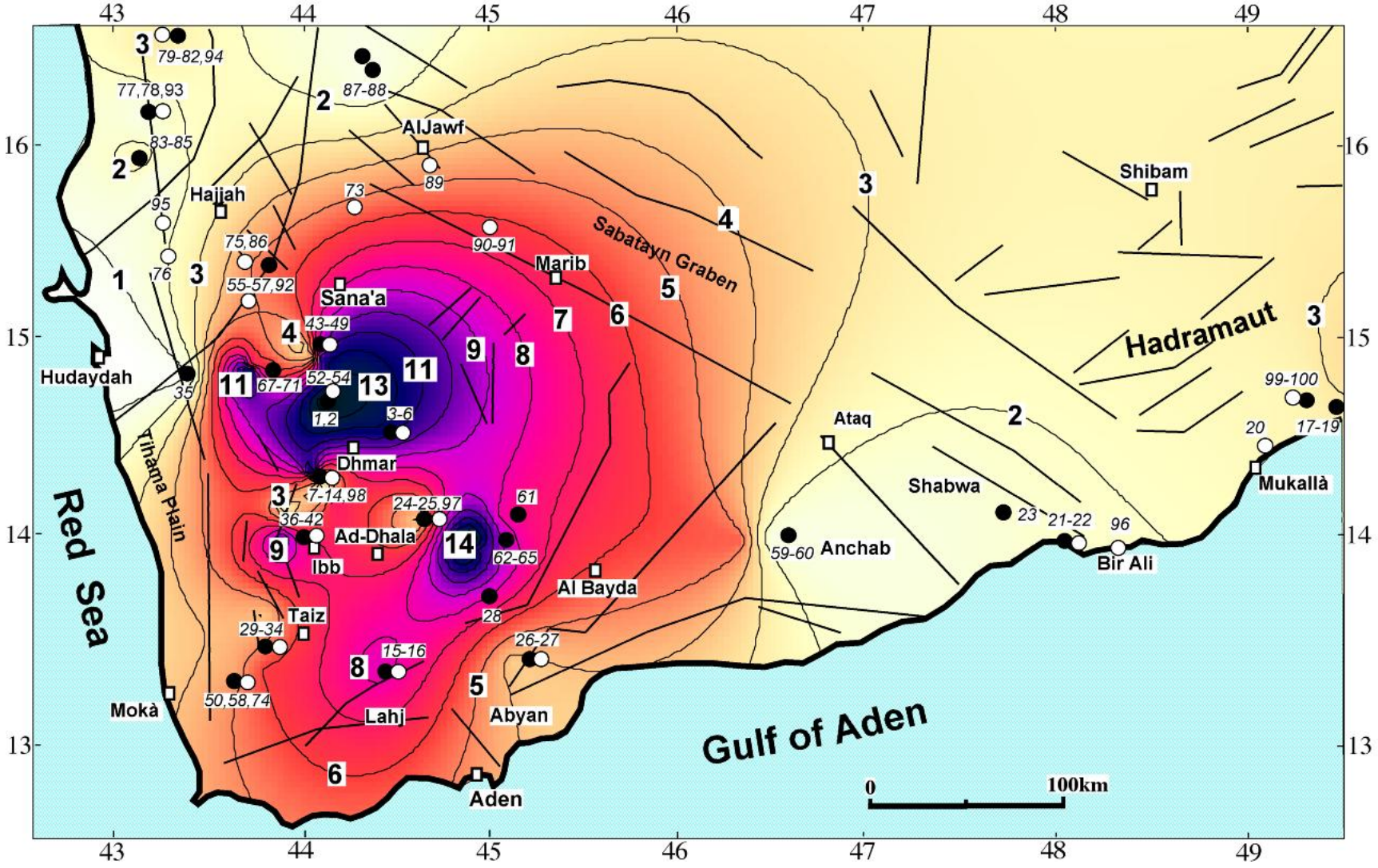
0,8muscovite+0,2chlinoclore+5,4SiO_2+2Na^+ = 2albite+0.8 K-feldspar+1.6 H_2O+Mg^{++}

0,8muscovite+0,2chlinoclore+5,4SiO_2 +2K^+ = 2.8 K-feldspar+1.6 H_2O+Mg^{++}

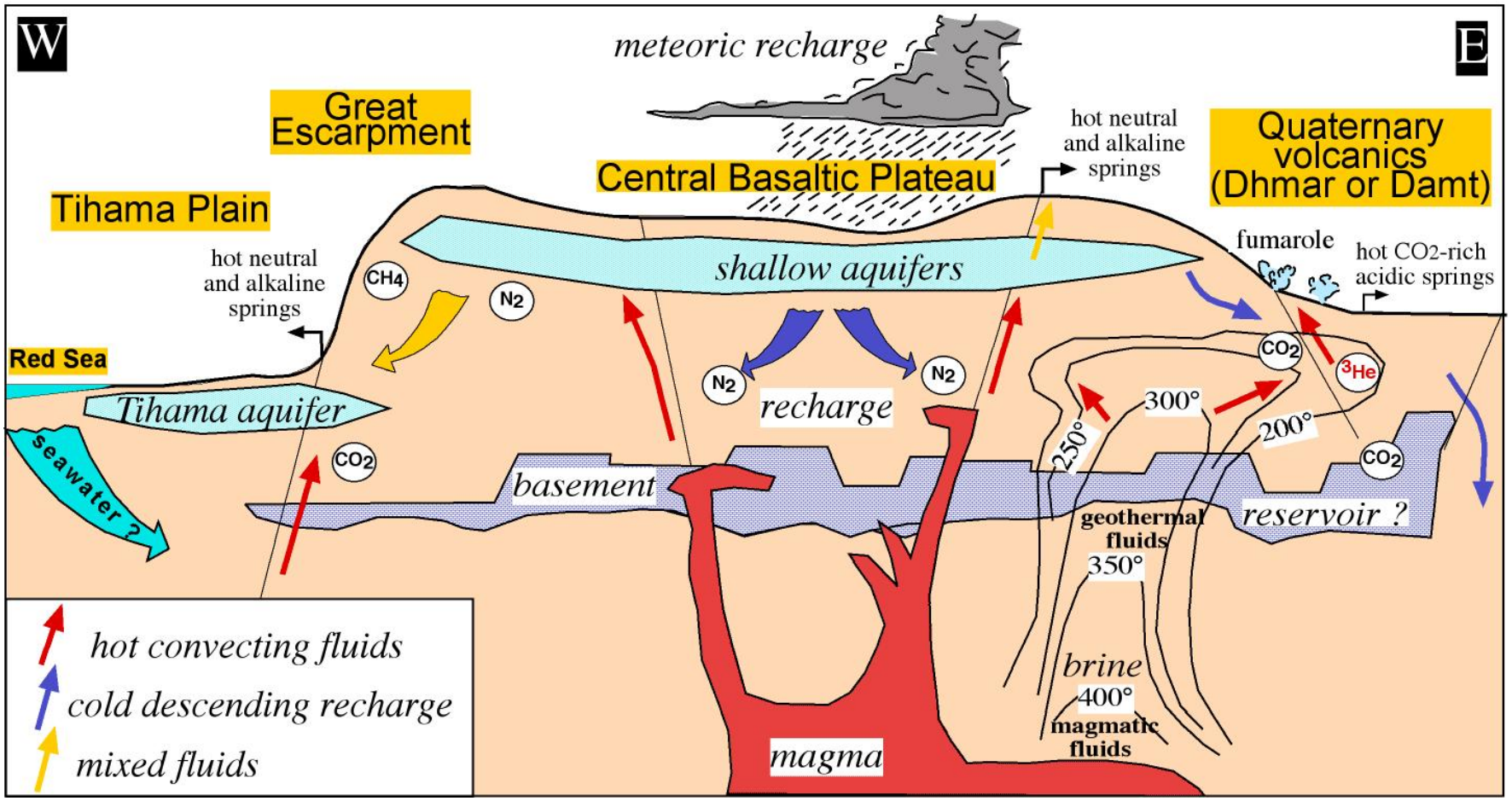
Evaluation of equilibration gas temperatures



Distribution map of fluorine concentration in thermal springs



West-East 100 *km* section across Yemen



Conclusions

- Yemen dispalys typical thermal features of active plate boundaries.

- The central volcanic plateau hosts active hydrothermal systems (skarns ?) producing CO_2.

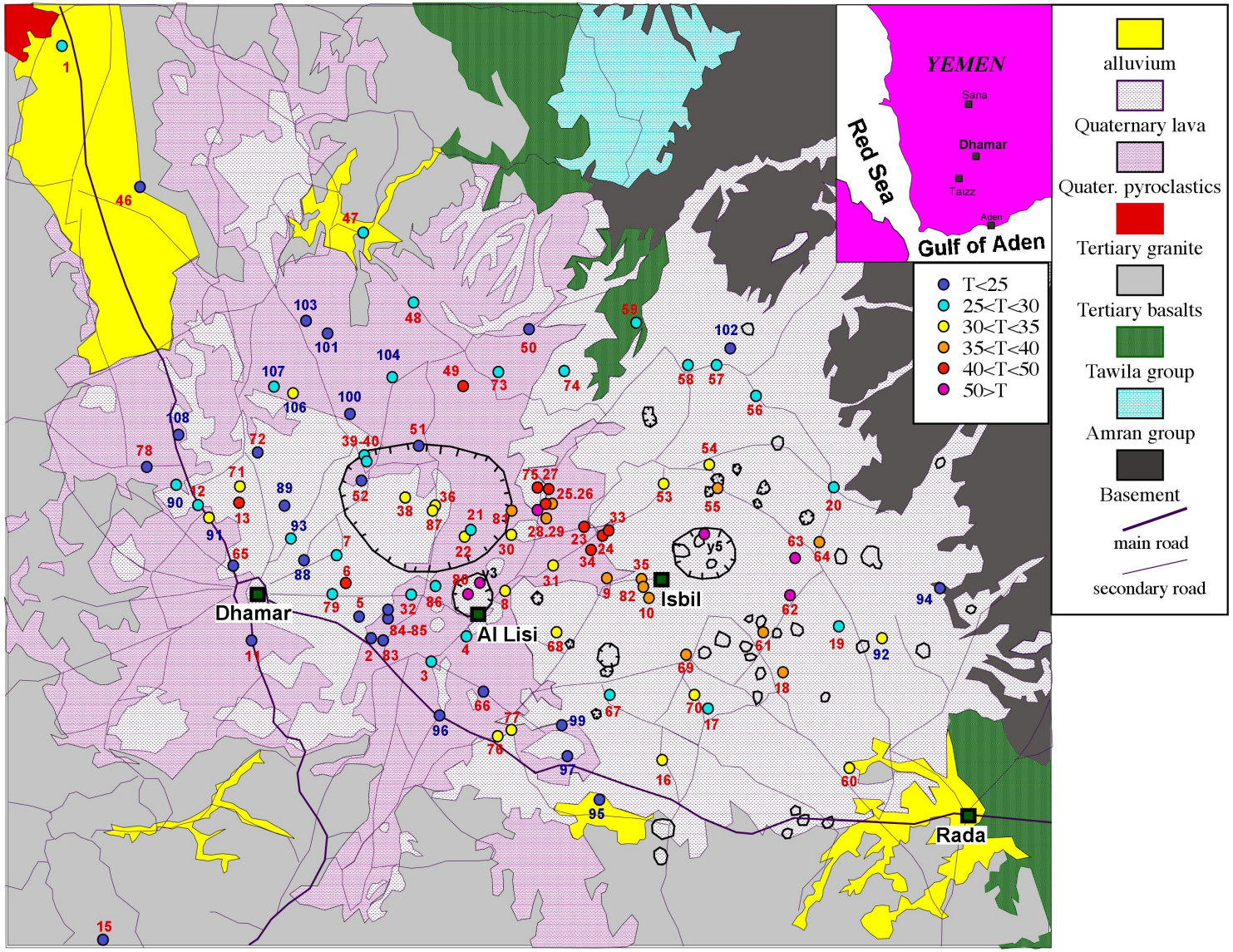
- The presence of ^3He suggests active mantle degassing in Dhmar and Damt areas.

- Equilibration deep temperatures >200 °C are possible below the central volcanic plateau (limestone reservoirs ?).

The reason why the Al Lisi and Isbil area has always been considered a primary choice for geothermal exploration is because of the recent eruption in the 20th century and because volcanics products are <u>Rhyolites</u>

BUT THIS IS DEFINITELY NOT SUFFICIENT

Geology of the Dhamar-Al Lisi-Isbil area and sampled wells



The prospecting method adopted was bases on the assumption that:

if there is a leak of: steam, condensates, gases, from a deep hydrothermal reservoir in the shallow aquifer,

THAN,

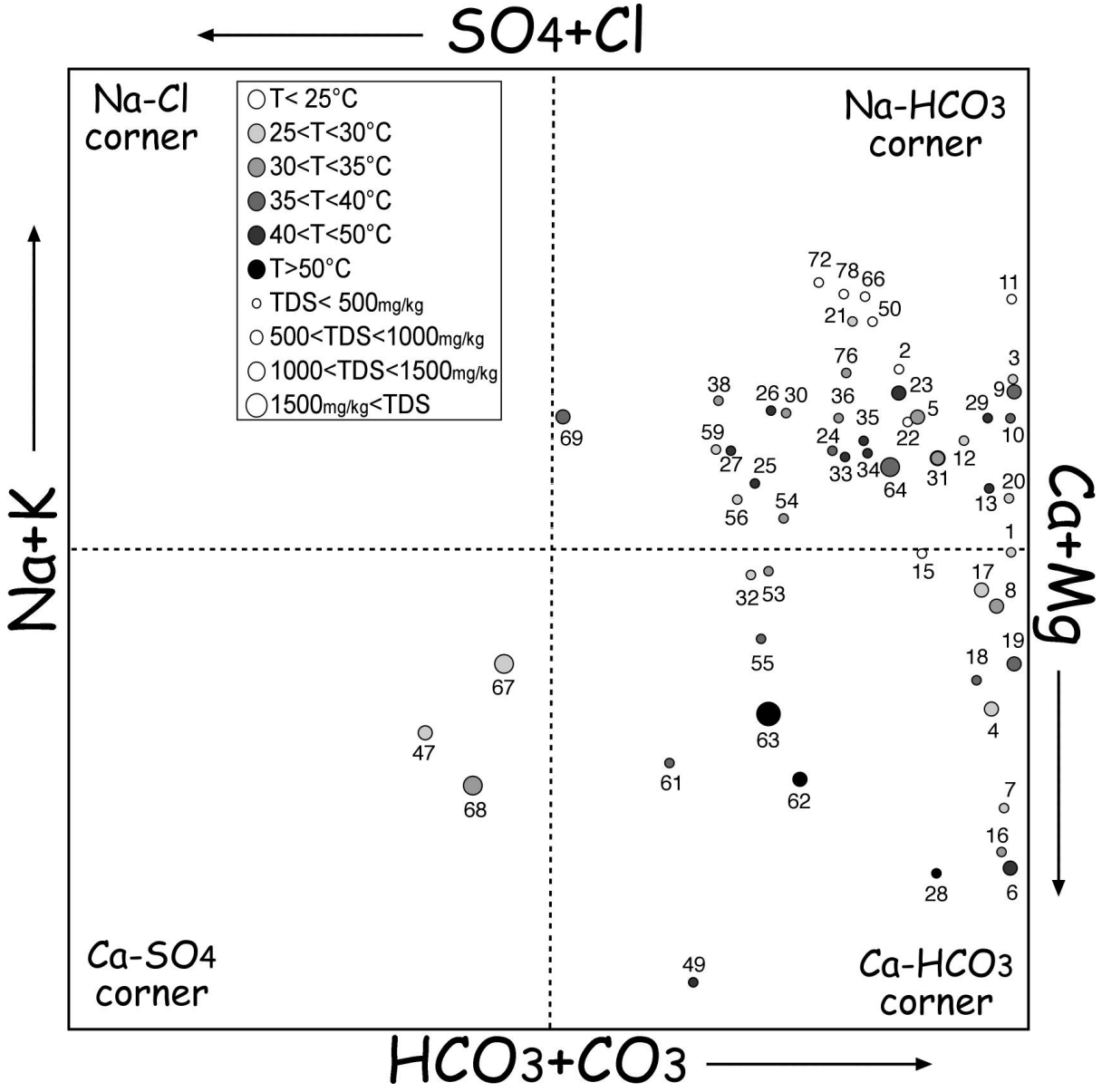
there must be anomalies (T, NH_4, CO_2..etc) recorded.

Measurements in the field on well water samples:

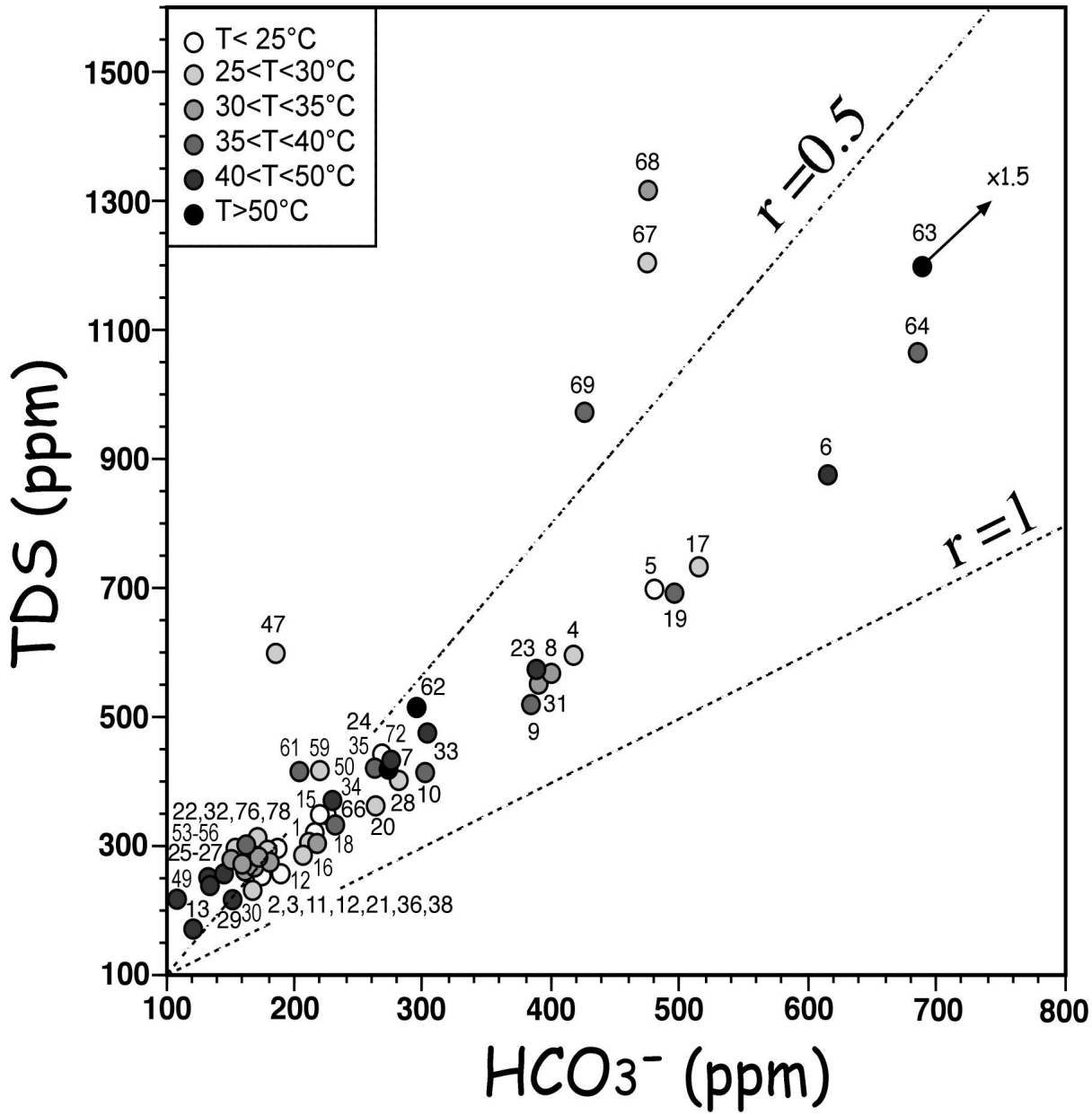
1) Temperature
2) pH
3) Electrical conductivity
4) Ammonia (NH_4)
5) Silica (SiO_2)
6) Asking well's depth
7) Elevation

Measurements in the laboratory:

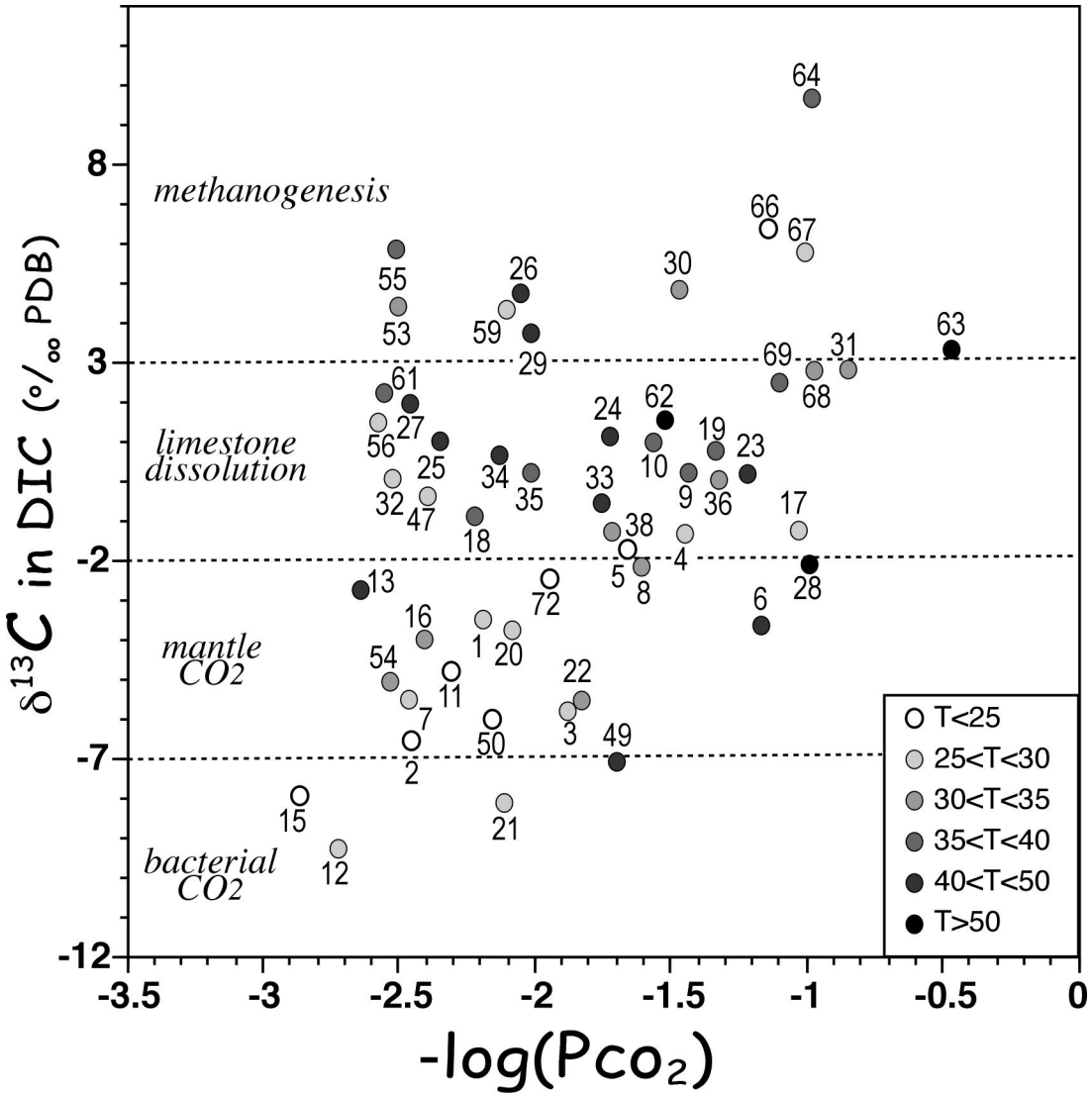
1) Main components (Na,K,Mg,Ca,HCO_3,SO_4,Cl)
2) Some trace elements (B, Br, NO_3, Li, F)
3) $^{18}O/^{16}O$ and $^{2}H/H$ ratios in water
4) $^{13}C/^{12}C$ in DIC (dissolved inorganic carbon)



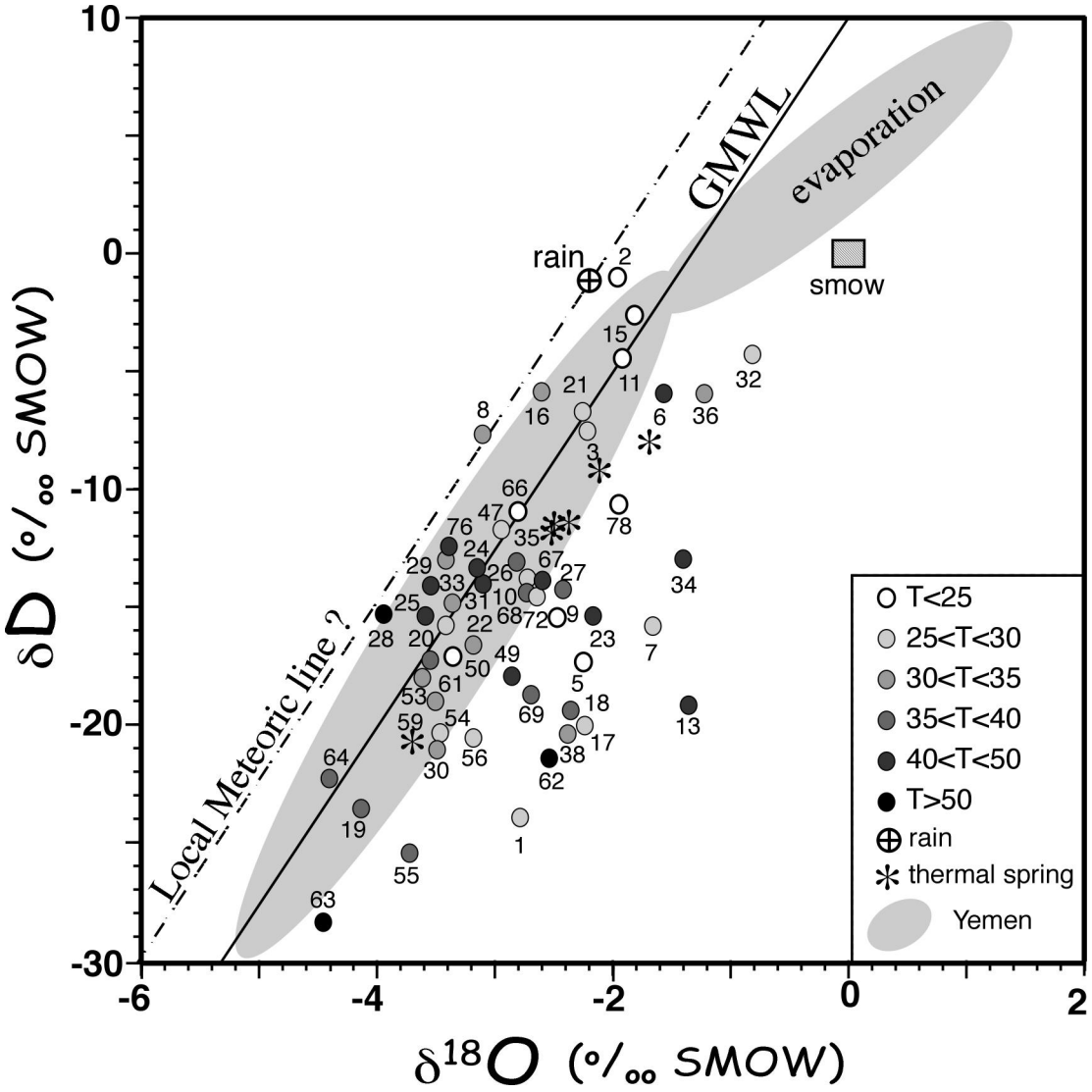
Langelier-Ludwig diagram



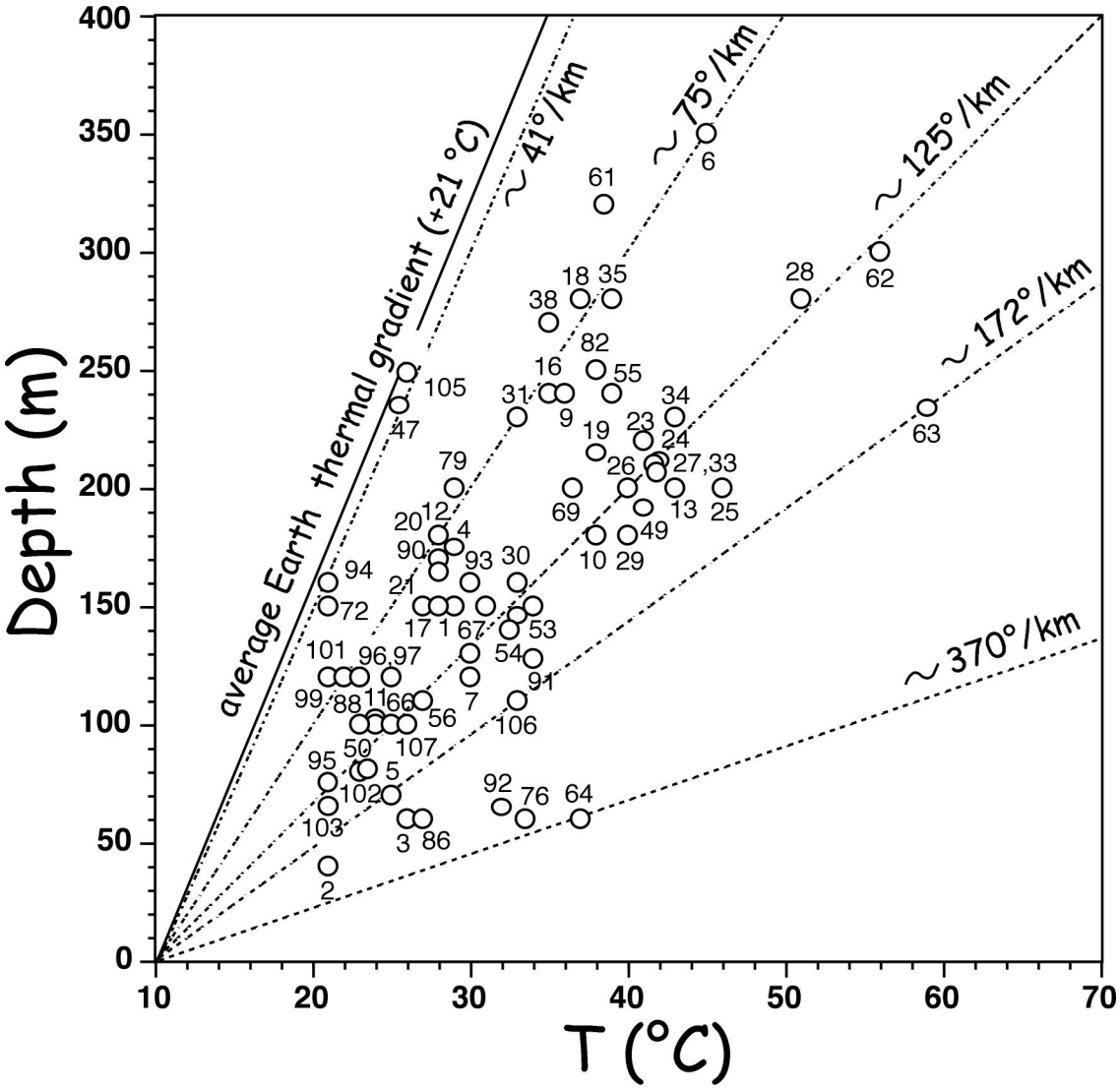
bicarbonate composition means shallow origin



most $^{13}C/^{12}C$ ratios suggest that CO_2 derives from limestone dissolution (metamorphism ?) and not bacteria



some ^{18}O shifts are present in Dhamar



Thermal gradients have been calculated according to the depth of wells (not the water level) by subtracting 21°C (the lower temperature found and coinciding with the temperature of a single rainfall taken in Taiz in 2002)

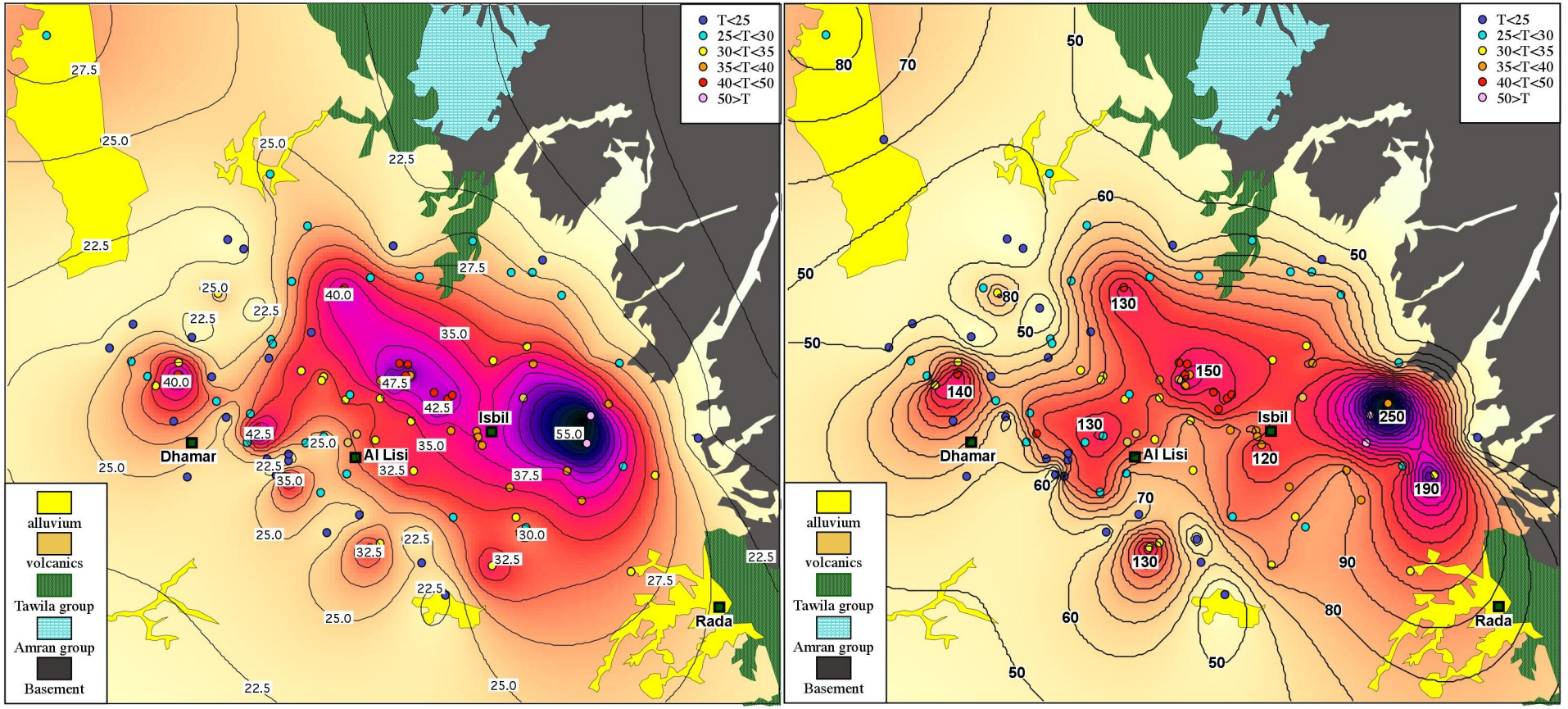
Thermal gradient can be extrapolated up to
a potential reservoir (Tawila-Amran Groups ?)

Thermal gradients can be affected (lowered)
by infiltration of surface cold water

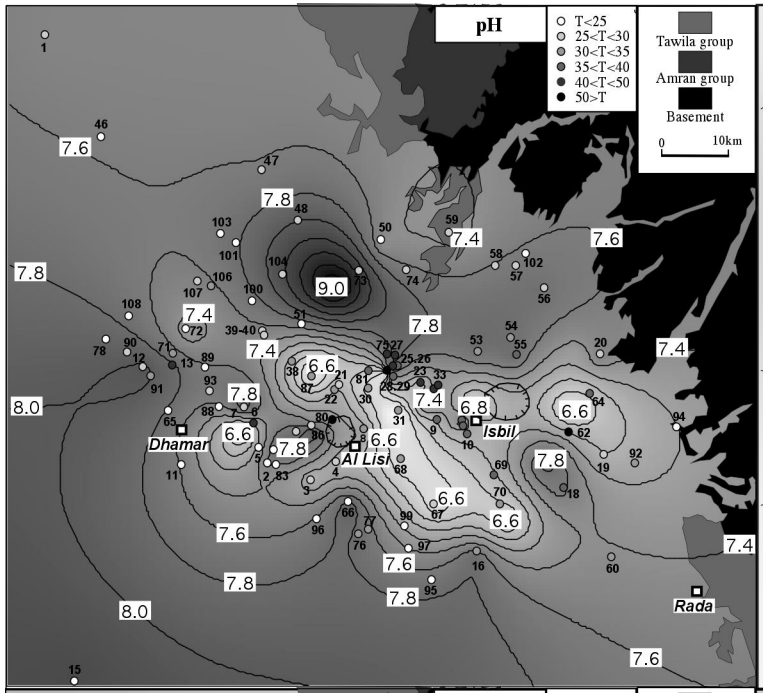
Thermal gradients can be affected (increased)
by hot acquifers at intermediate depth

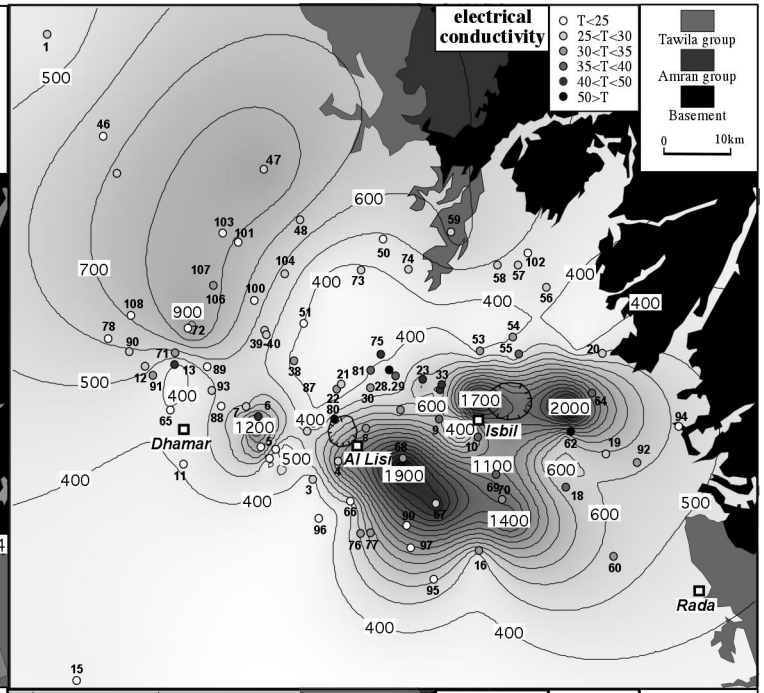
Dhamar: measured temperature

Dhamar: calculated temperature at 1000m)



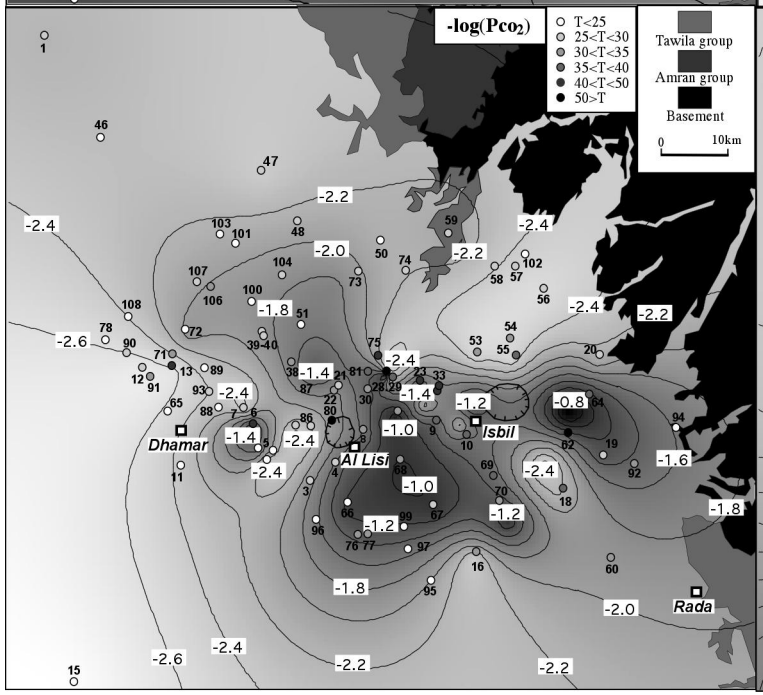
*p*H

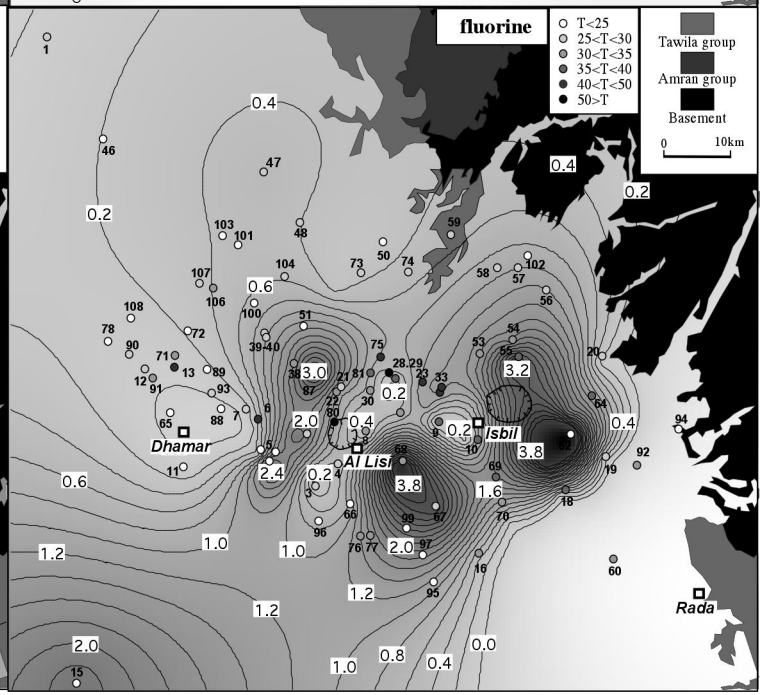

pH
T<25
25<T<30
30<T<35
35<T<40
40<T<50
50>T
Tawila group
Amran group
Basement
0 10km
Dhamar
Al Lisi
Isbil
Rada


electrical conductivity
T<25
25<T<30
30<T<35
35<T<40
40<T<50
50>T
Tawila group
Amran group
Basement
0 10km
Dhamar
Al Lisi
Isbil
Rada

Ω

pCO_2


-log(Pco2)
T<25
25<T<30
30<T<35
35<T<40
40<T<50
50>T
Tawila group
Amran group
Basement
0 10km
Dhamar
Al Lisi
Isbil
Rada


fluorine
T<25
25<T<30
30<T<35
35<T<40
40<T<50
50>T
Tawila group
Amran group
Basement
0 10km
Dhamar
Al Lisi
Isbil
Rada

F^-

CONCLUSIONS

1) In Dhamar there is a clearly closed thermal anomaly
2) The anomaly is paralleled by several chemical closed anomalies (pCO_2, pH, F..etc.)
3) Calculated thermal gradients vary from 40°C/km to >300°C/km.
4) Potential reservoir in the Tawila and/or Amran group(s)