GEOCHEMICAL AND ISOTOPIC STUDY OF DOFAN-FENTALE GEOTHERMAL PROSPECT

GEOLOGICAL SURVEY OF ETHIOPIA

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Introduction

- The Dofan-Fentale geothermal prospect is located in the northern end of the main Ethiopian Rift Valley where the Rift starts funnelling outwards into the Afar triangle, at about 230km to the NE of Addis Ababa.

- The Tendaho geothermal prospect is located in the Tendaho Graben, which is a N-W trending structural trough in the Afar triangle. It is 650km to the north east of Addis Ababa

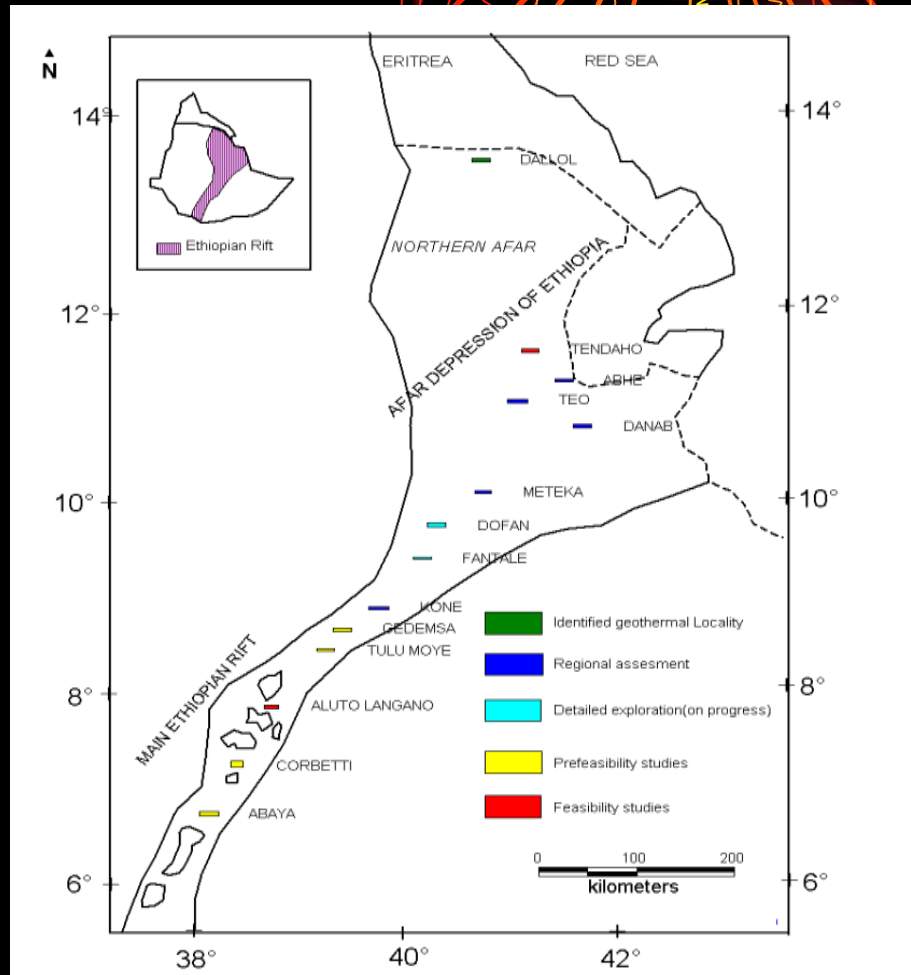


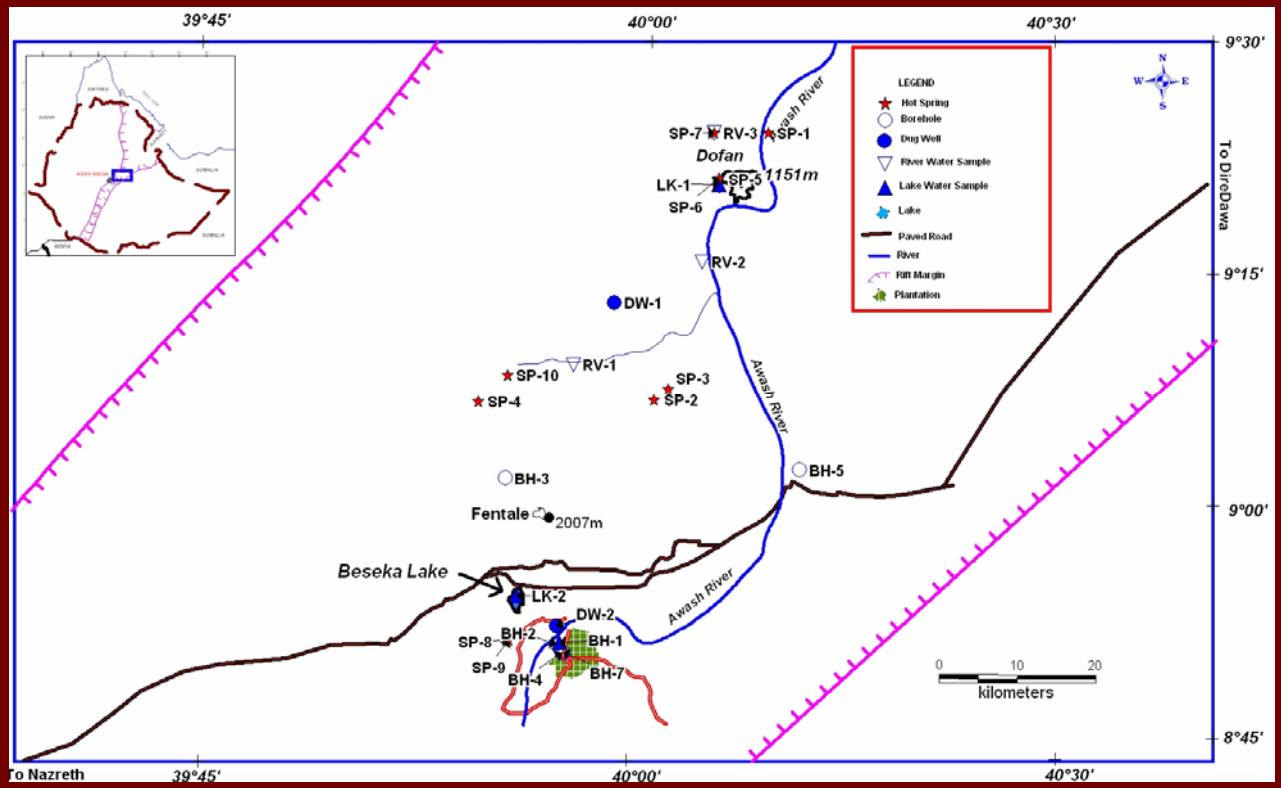
Fig.1 Location Map of the Geothermal Prospect Areas with in the Ethiopian Rift Valley

Methodology

- Pre-field review of previous works
- Field Work
- Data Organization, data processing and interpretation

The sampled features in (Dofan-Fentale)

- Hot springs, boreholes, dug wells, lakes and rivers were sampled.
- Most of the Hsps, have discharge temperature in the range of 48-59°C.

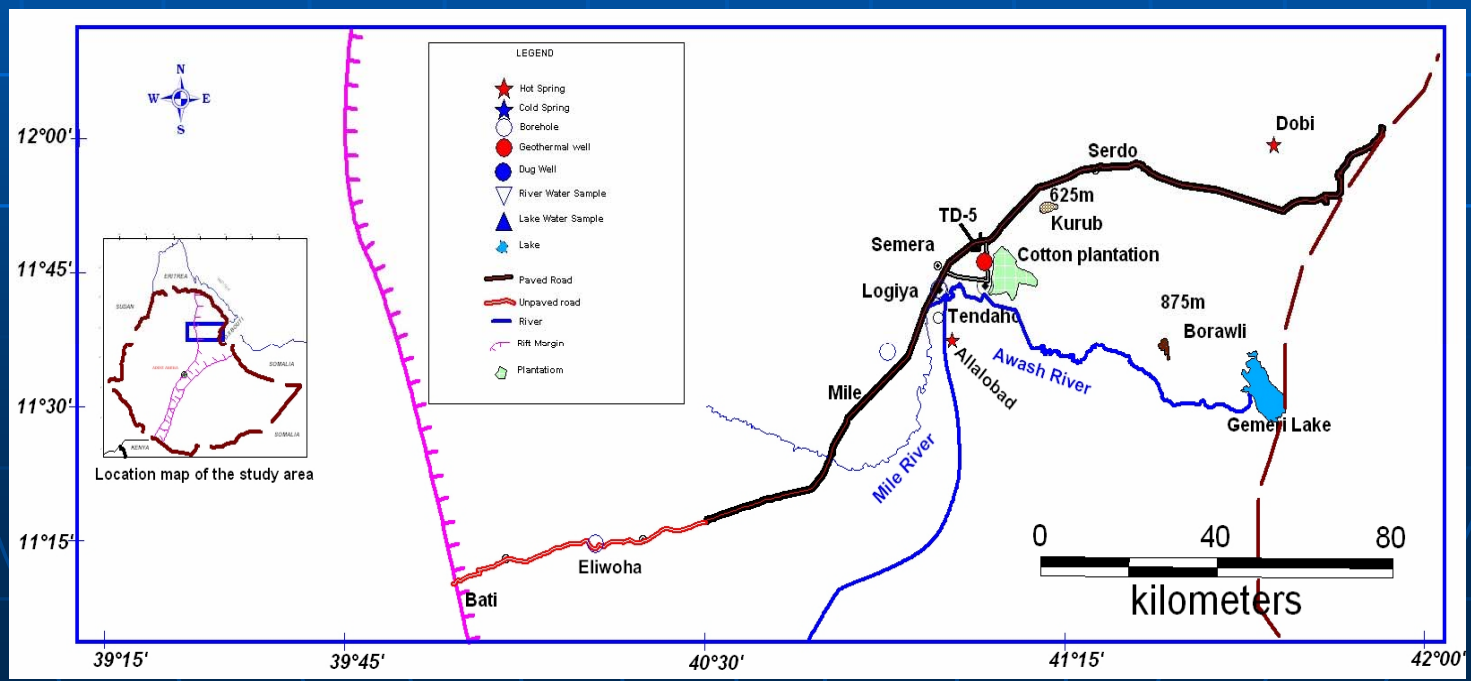


Habilo hot spring

- Habilo is the only spring having dicharge temperature of 82°C in the area. It shows geyseric effect and the water jets up to 1.5 m high. There are siliceous sinter and small fumaroles in the surrounding.

The sampled features in (Tendaho)

- Three hot springs and one geothermal well were sampled.
- The discharge temperature of the hot springs is in the range of 72°C and 100°C .
- Well TD-5 is a two phase flow geothermal system. Separated & weir box water as well as gas samples were collected.



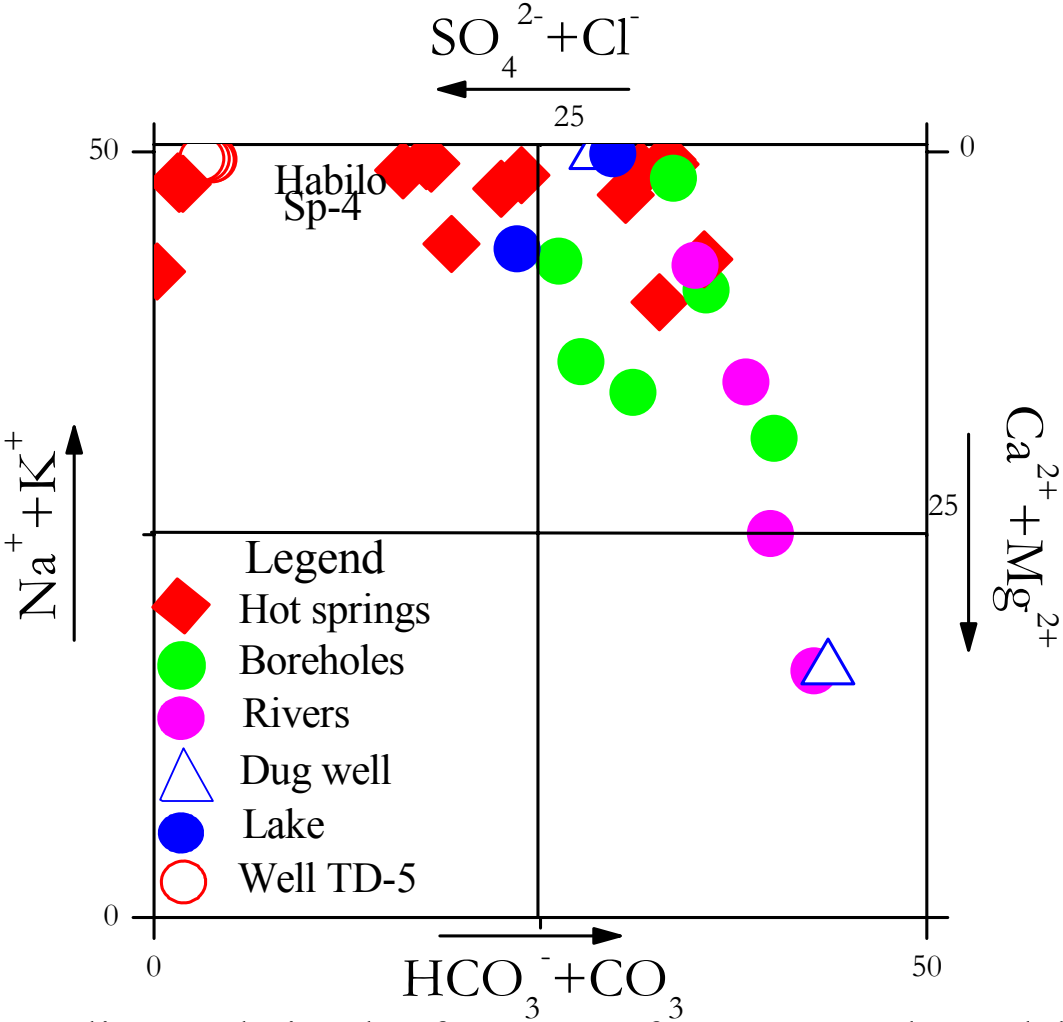
Analytical results of water samples from Dofan-Fentale and Tendaho geothermal prospects (mg/l)

Feature Name	Code	pH/ 25°C	Cond µS/25°C	Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	NO_3	F	SiO_2	B
Filoa	Sp-1	8.5	1886	383	20	4.3	2.0	8.5	735	150	89	2.7	5.2	63	1.0
Filoa	Sp-2	8.6	2115	428	21	8.8	1.3	14	762	194	98	2.9	7.1	70	1.0
Melka	Sp-3	8.2	1751	360	24	15	6.0	-	662	173	100	5.2	5.2	143	1.2
Habilo	Sp-4	7.5	2649	560	67	12	0.5	-	310	429	285	3.6	11	343	4.0
Hubicha	Sp-5	8.6	1716	284	19	49	1.7	19	627	119	108	6.3	6.3	74	0.7
Hubicha	Sp-6	8.5	1670	338	19	2.0	1.5	15	612	113	98	6.0	6.5	82	0.4
Dofan	Sp-1	8.5	1769	319	15	6.0	2.0	10	422	167	159	0.4	8.0	123	0.8
Dofan	Sp-2	7.7	1850	320	20	5.0	5.0	-	381	213	190	0.5	9.0	105	1.0
Debhile	Sp-3	8.6	1929	350	17	5.0	0.2	11	311	217	182	19	20	144	1.0
Debhile	Sp-4	8.4	1780	345	14	4.0	0.2	10	303	210	177	19	20	61	1.0
Kelo-al	Sp-5	7.6	2347	465	27	20	0.5	-	617	324	157	0.1	21	261	2.2
Bilen	Sp-6	8.0	937	180	17	12	7.4	-	414	76	49	2.0	3.3	96	0.2
Tendaho	TD-5	9.3	2335	480	79	4.0	0.1	50	11	715	89	3.1	1.1	465	-
Tendaho	TD-5	9.5	2785	565	93	4.3	0.2	52	-	856	106	1.8	1.3	556	-
Tendaho	TD-5	9.2	2538	490	79	4.4	0.2	43	26	748	92	2.7	1.2	471	-
Tendaho	TD-5	9.4	3000	585	92	4.7	0.1	59	-	861	105	1.8	1.3	546	-
Allalo.	AL-1	8.9	2778	545	40	21	0.1	20	20	730	247	0.9	0.9	289	2.2
Allalo.	AL-2	9.2	2570	530	39	19	0.1	24	-	735	205	0.9	0.7	289	2.5
Allalo.	AL-3	8.3	3050	575	38	22	0.2	-	57	794	247	1.3	0.8	273	2.9
Dobi	Do-1	7.6	12300	2240	61	363	1.8	-	29	3932	528	1.3	2.6	508	-
Merti	Bh-4	7.9	2766	345	36	39	17	-	630	223	149	14	3.5	93	0.4
Merti	Bh-7	7.9	1659	256	10	42	10	-	622	87	78	5.0	3.1	86	0.4
Metehara	Bh-1	7.7	2376	325	12	85	30	-	758	234	166	7.4	5.3	123	0.4
Metehara	Bh-2	8.0	2280	280	14	90	30	-	781	194	114	11	4.9	93	0.2
Debhiti	Bh-3	8.4	1956	380	26	9.0	3.8	11	802	168	85	2.7	5.4	81	0.8
Kurkura	Bh-5	7.8	681	93	8.3	41	12	-	35	35	22	3.6	1.4	111	0.2
Bulga	Rv-1	8.1	474	76	7.0	20	12	16	234	31	18	4.3	0.9	31	0.2
Awash	Rv-2	8.0	513	52	11	46	6.0	6.0	208	22	13	1.4	1.9	23	0.2
Kebena	Rv-3	7.7	240	15	3.0	24	7.0	-	132	9.0	5.5	2.1	0.4	34	0.2
Boloyta	DW-2	7.8	488	33	5	44	12	-	238	14	9.0	20	0.7	80	0.1
Arowadi	Dw-1	9.1	3806	1052	30	1.5	0.5	174	1337	411	338	164	14	53	1.5
Debhile	Lk-2	8.6	2082	395	18	50	0.6	16	491	222	164	8.2	22	159	1.5
Beseka	Lk-1	9.5	6140	1735	70	2.8	0.5	671	1817	592	542	1.2	35	135	3.8

Classification of water type

Three types of water are identified:

- Na / SO_4-Cl
- $NaHCO_3$
- Ca-Mg / HCO_3

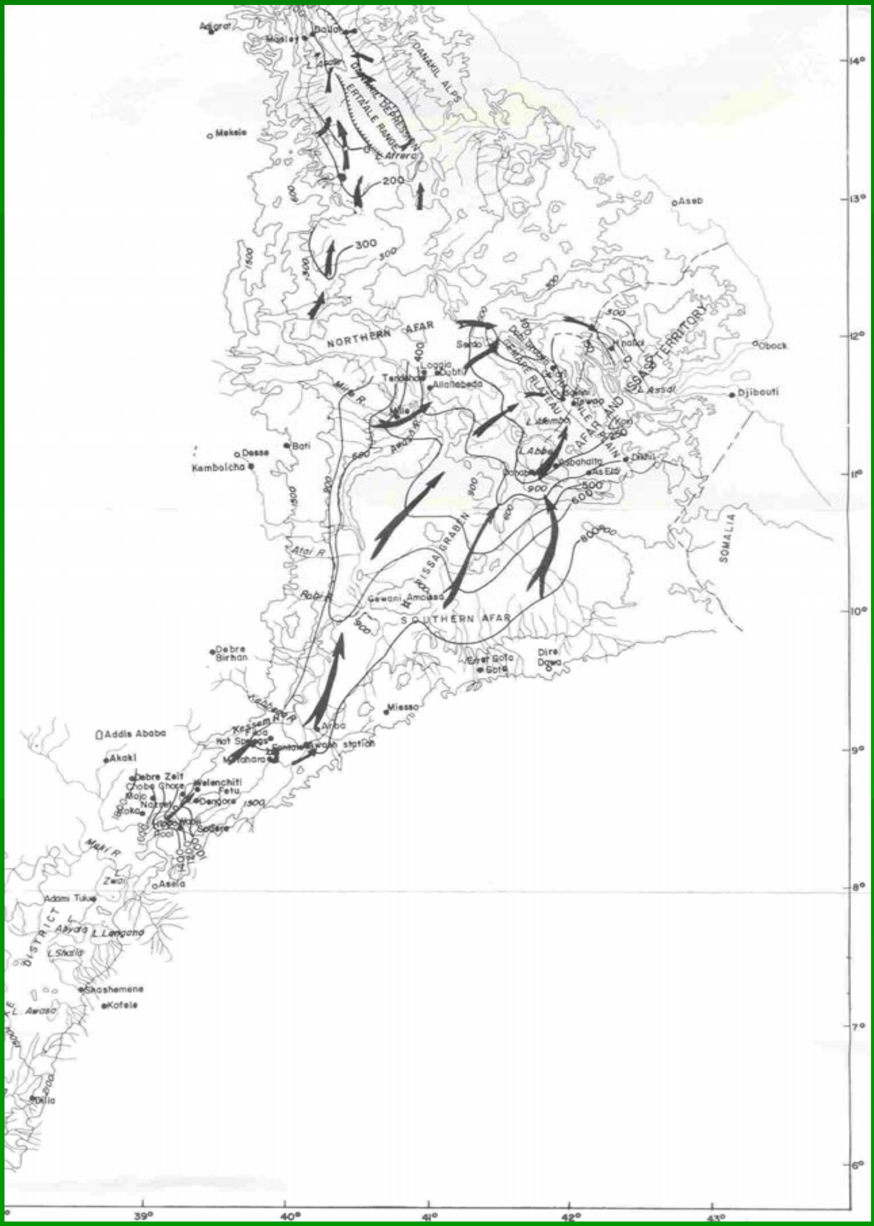


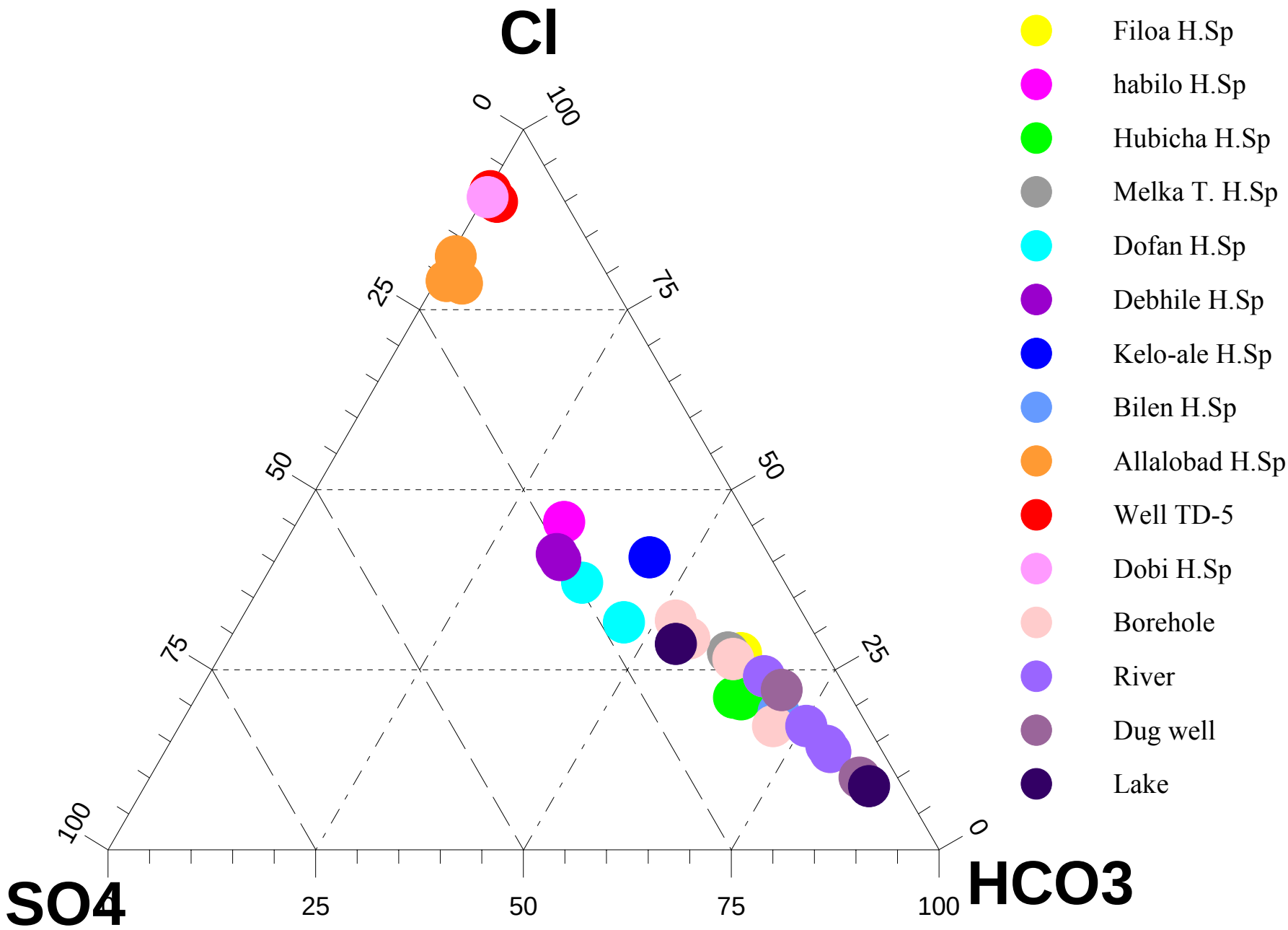
Langelier-Ludwig plot for waters from D-F and Tendaho

Main directions of ground-water flow, Awash basin and Danakil

- Waters flow from the Lakes District via Southern Afar to the Danakil Depression.

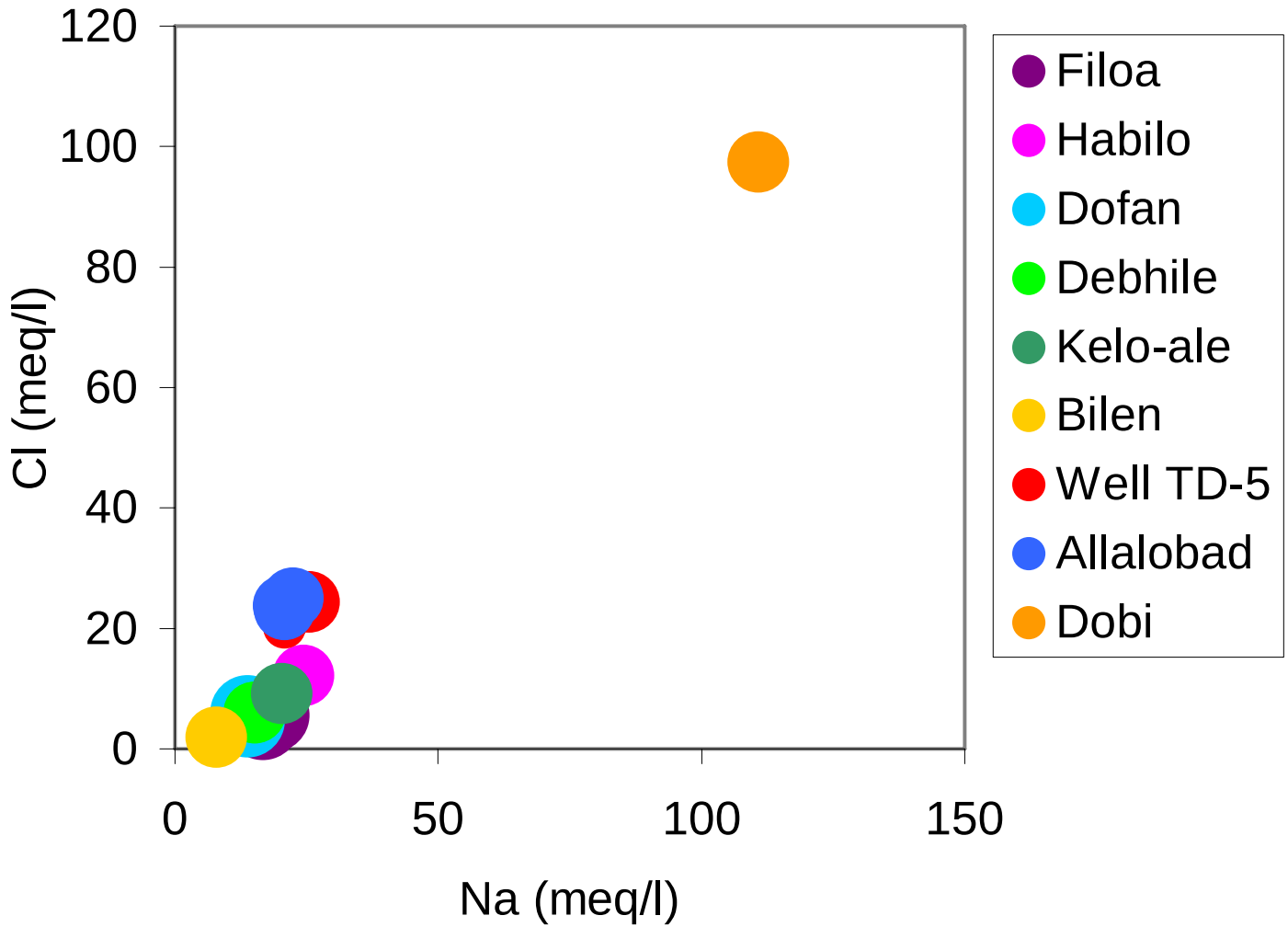
- In the mean time these waters undergo chemical evolution starting as $NaHCO_3$ in Lakes District evolve to $NaSO_4$ in Southern Afar and finally to mature NaCl water in the Danakil Depression.



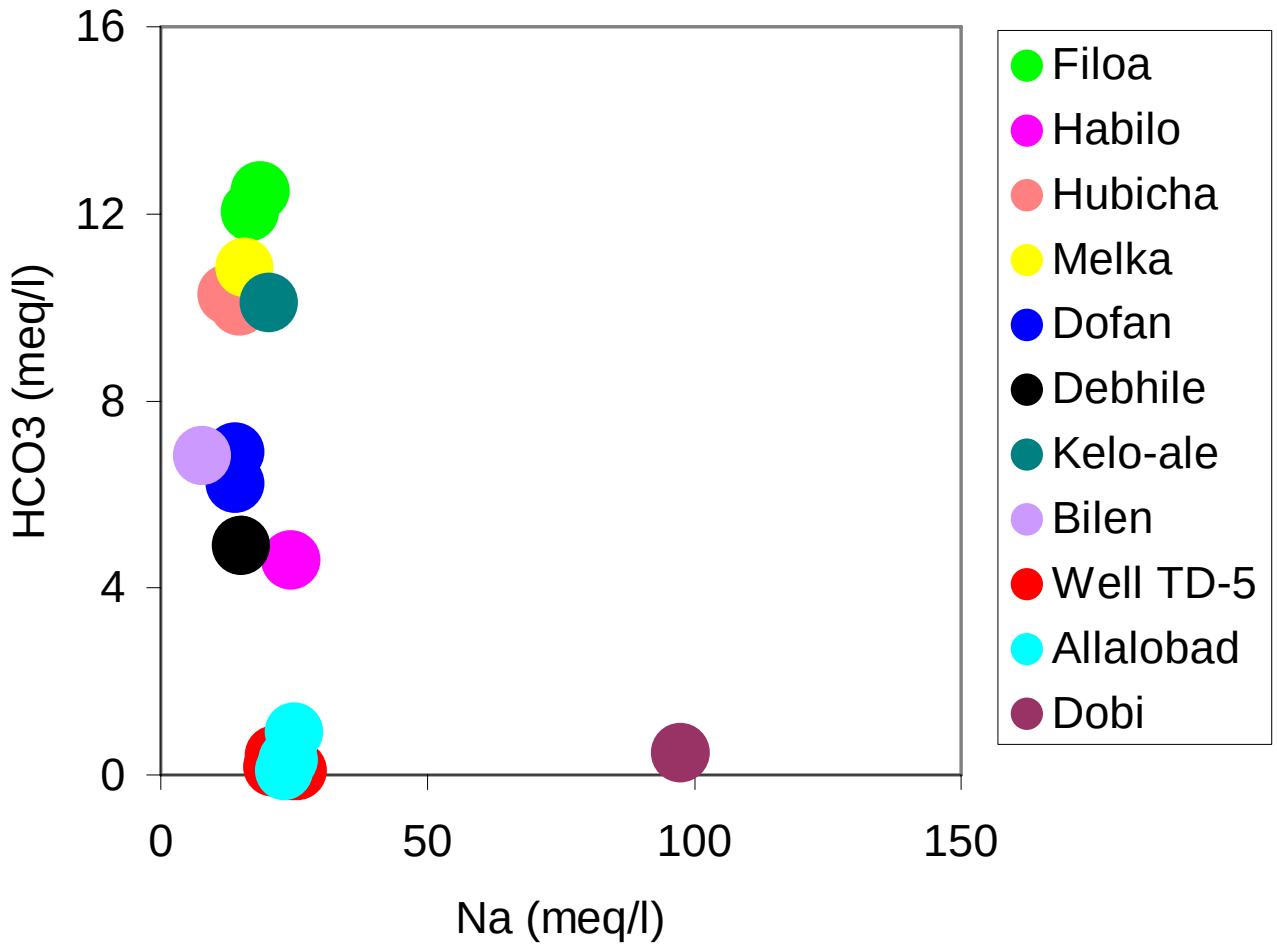


Cl-SO4-HCO3 plot for waters from Dofan-Fentale and Tendaho geothermal fields

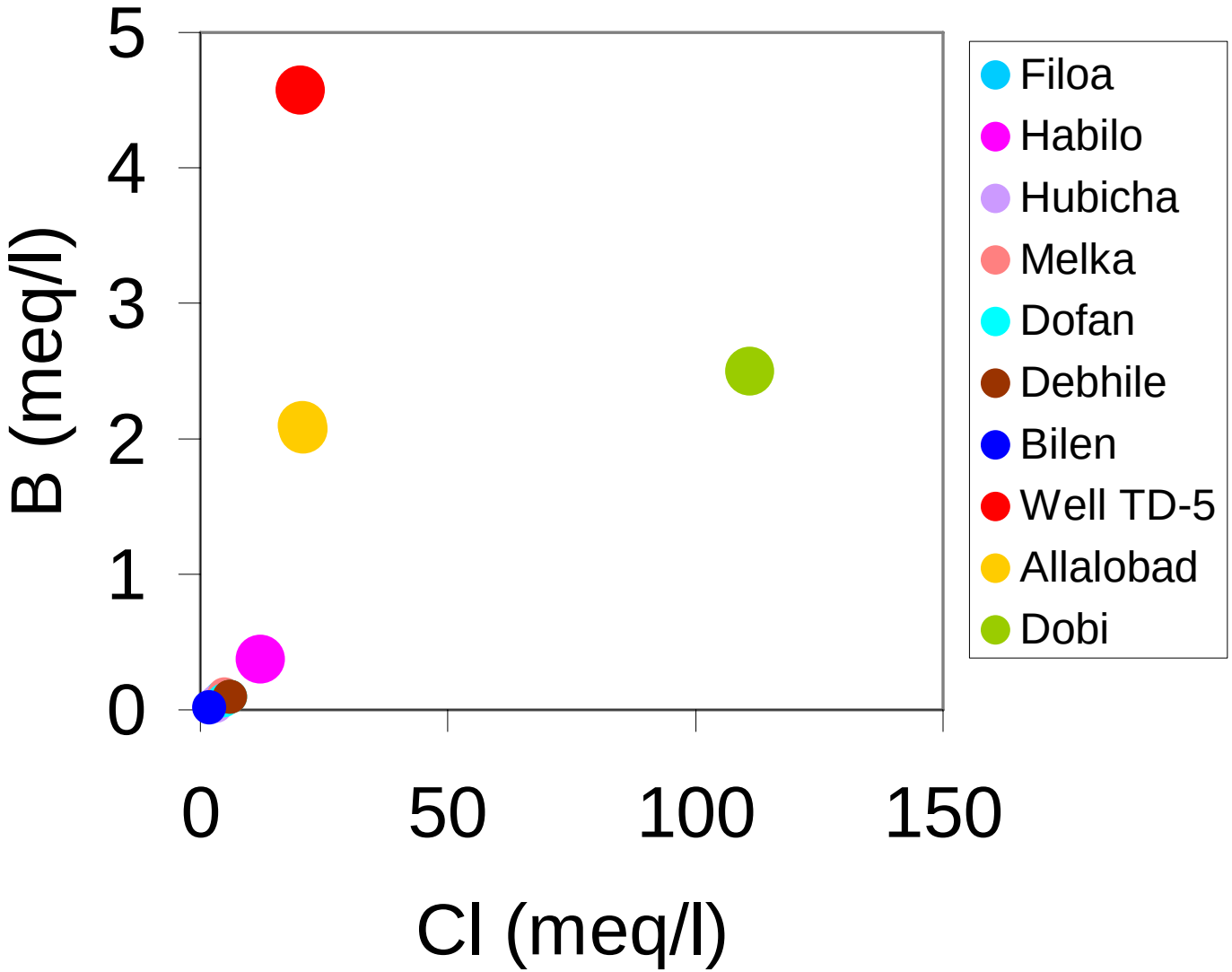
Chemistry of the sampled features



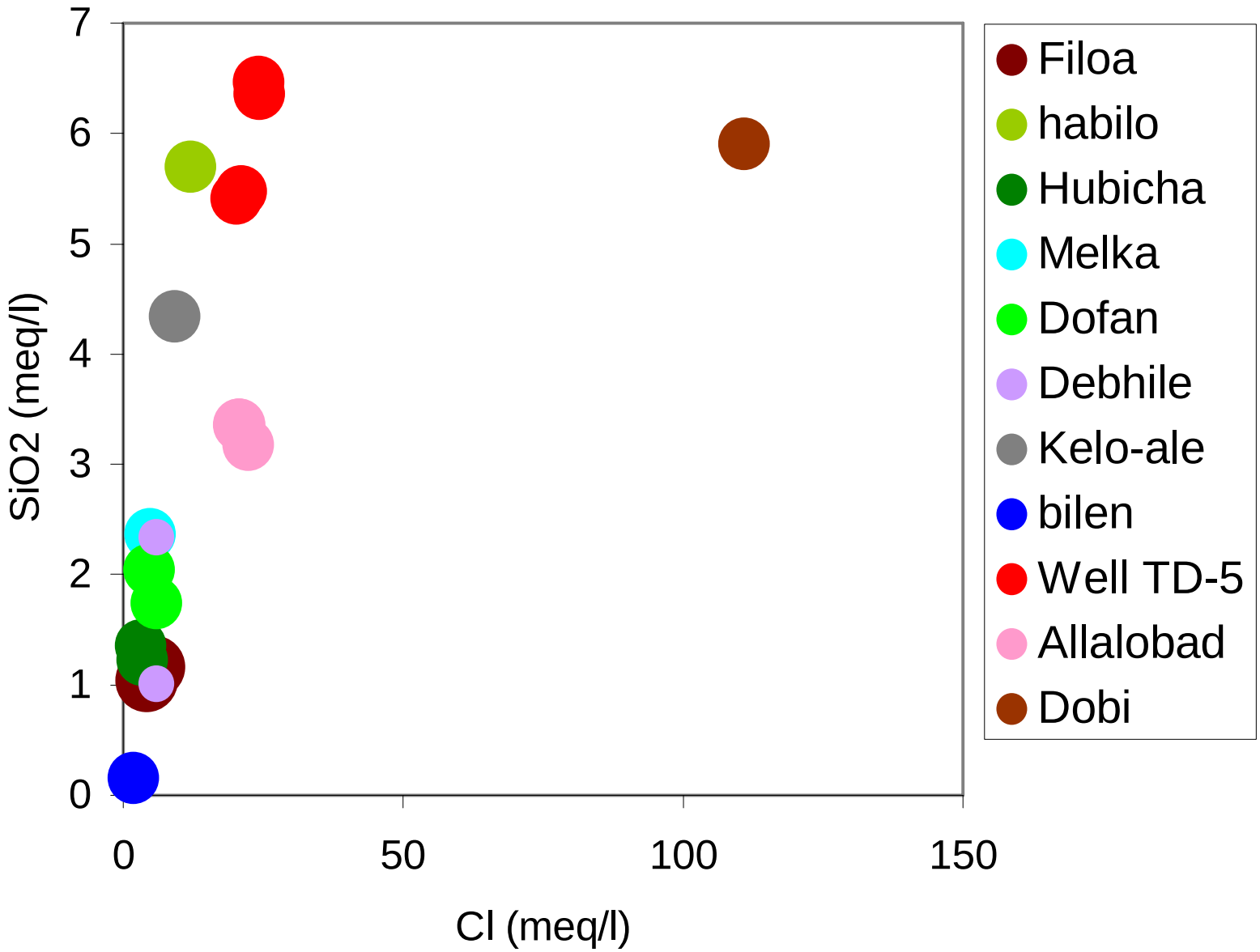
Na^+ versus Cl^- plot for waters from Dofan-Fentale and Tendaho geothermal fields



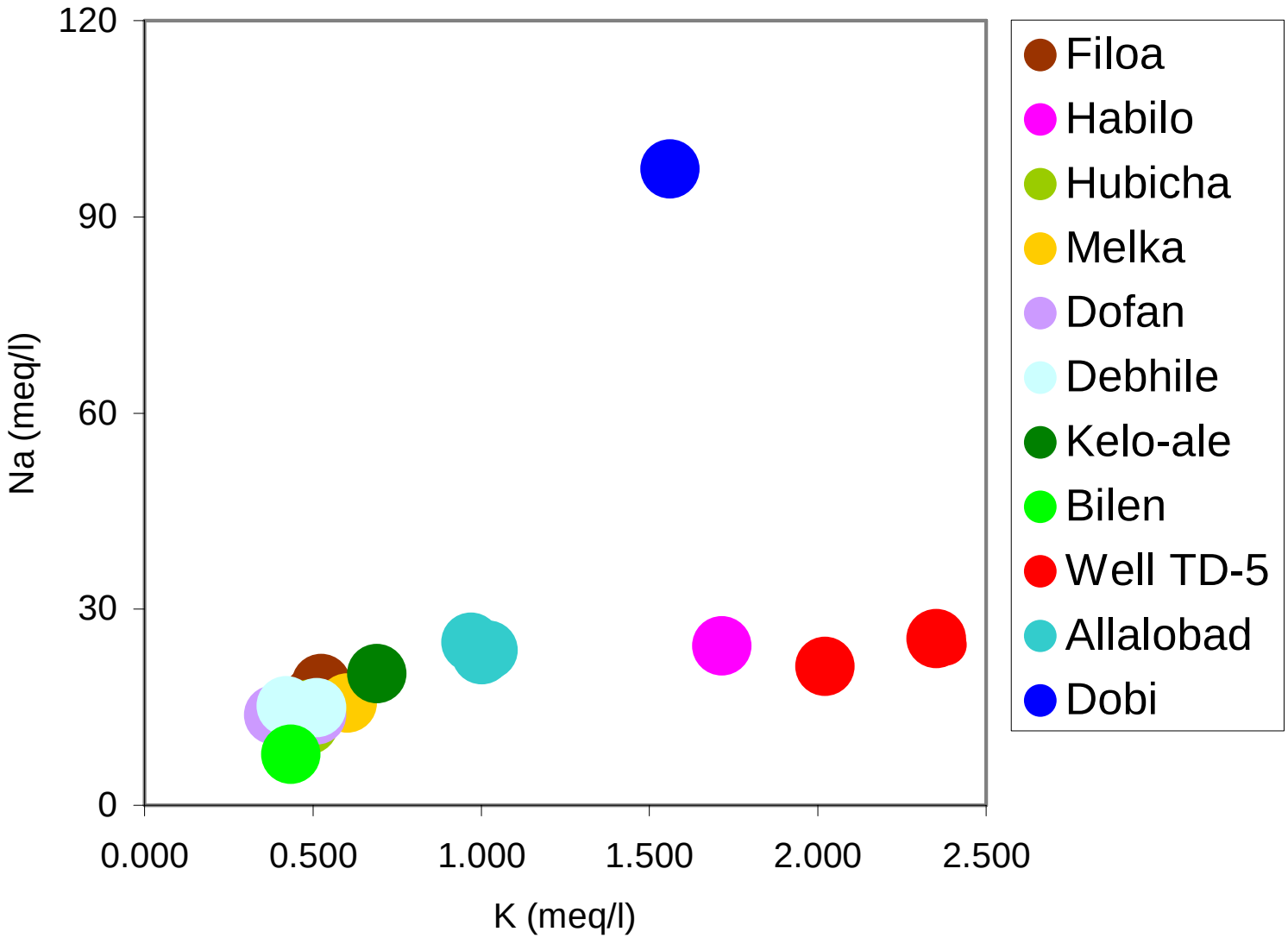
Na^+ versus HCO_3 plot for waters from Dofan-Fentale and Tendaho geothermal field



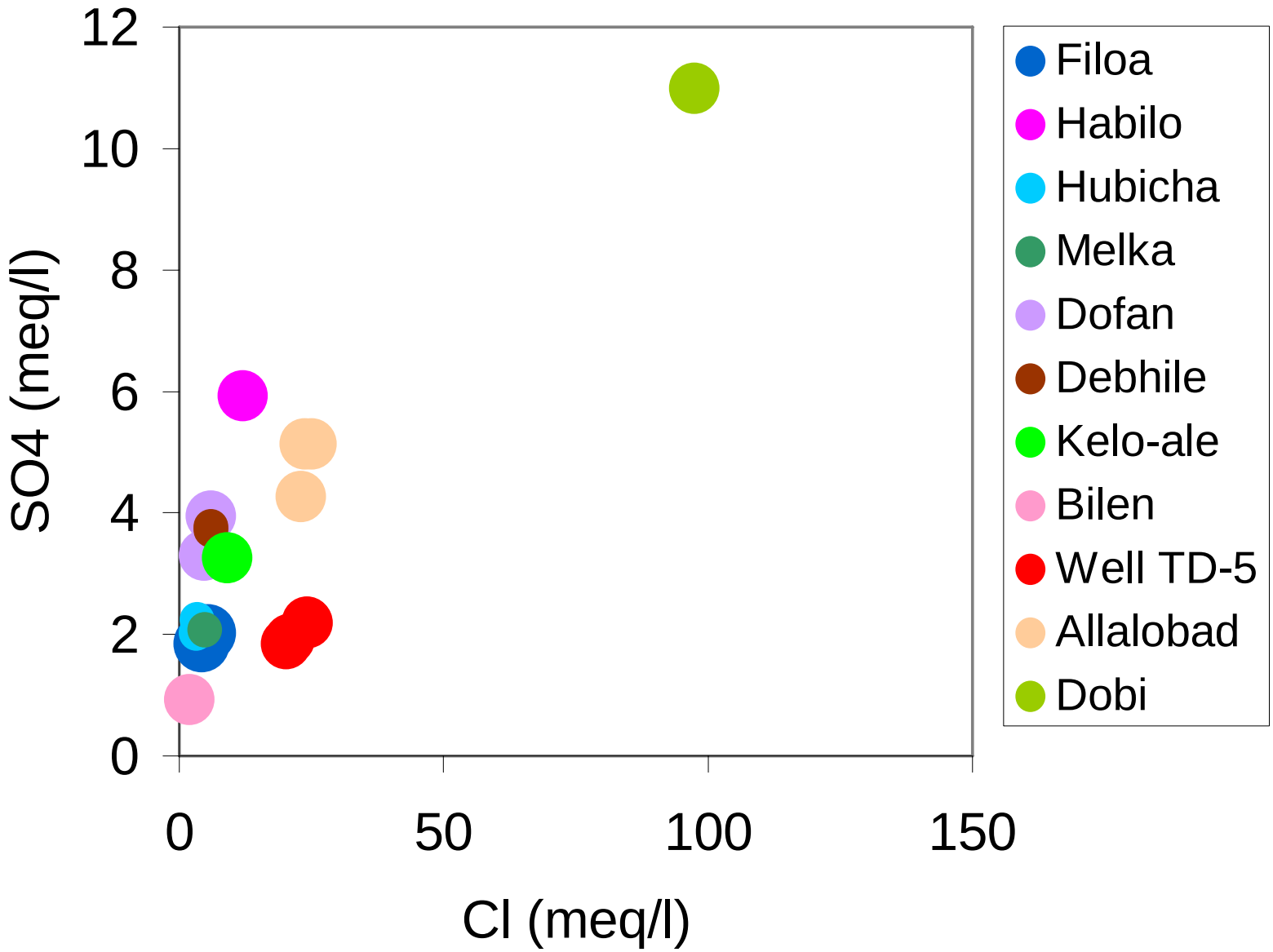
Cl^- versus B plot for waters from Dofan-Fentale and Tendaho geothermal fields



Cl^- versus SiO_2 plot for waters from Dofan-Fentale and Tendaho geothermal fields



K^+ versus Na^+ plot for waters from Dofan-Fentale and Tendaho geothermal fields



Cl^{-} versus SO_4^{-2} plot for waters from Dofan-Fentale and Tendaho geothermal fields

Results from the chemistry of the Sampled features

- Most of the hot springs in the Dofan-Fentale geothermal area are characterized by near neutral Na/SO_4-Cl. However some of hot springs, boreholes, rivers, lakes and dug wells belong to slightly alkaline $NaHCO_3$ and $Ca\text{-}Mg/HCO_3$ water type.

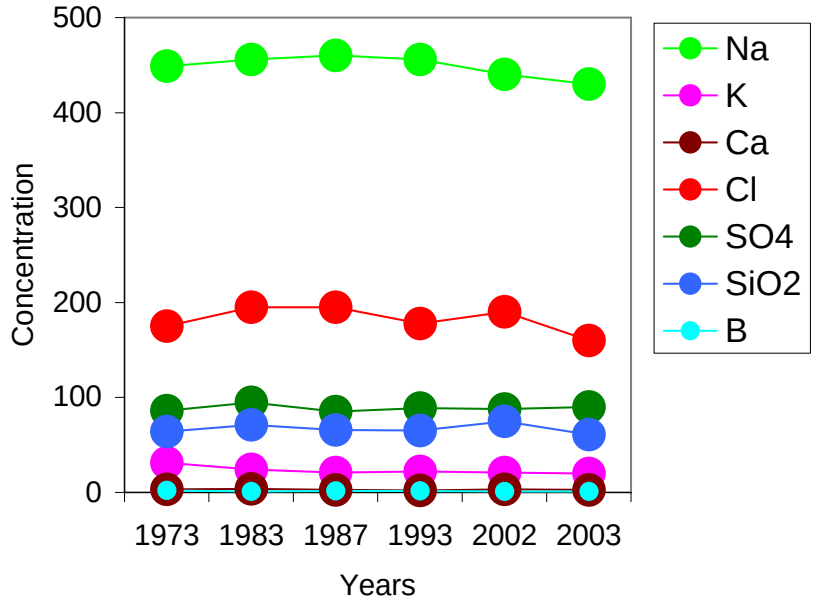
- The water discharge of well TD-5 and the hot springs are alkaline mature geothermal NaCl type. Well TD-5 water is more alkaline than the hot spring waters.

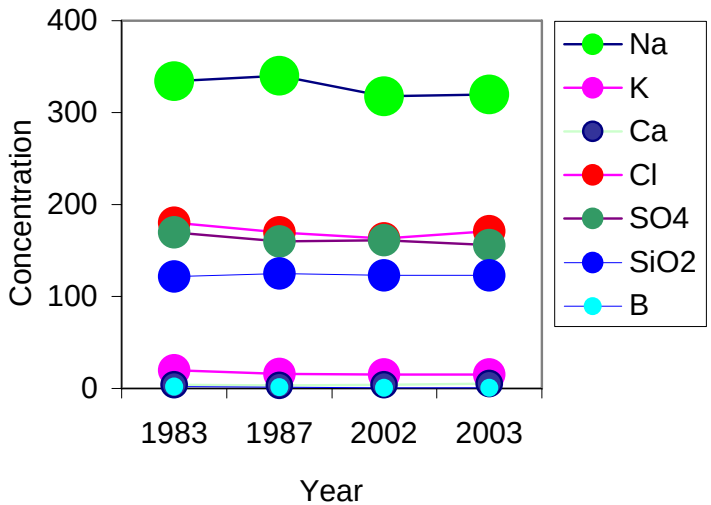
- The hot springs in the Tendaho area are chemically more concentrated than the Dofan-Fentale hot springs.

Chemical variation assessment through time

- The chemical concentrations of (cations and anions including silica and boron) have shown no significant change for the last 30 years.

- the small ups and downs that are seen in the plot might be due to sampling as well as analytical error.





Deep temperature determination

Determination of the deep temperature is an important factor in the assessment of geothermal potential for electricity generation.

Calculated deep temperatures of water samples from Dofan-Fentale and Tendaho geothermal fields

Feature Name	Code	SiO_2-A	SiO_2-B	Chalcedony	Na-K(1)	Na-K(2)	Na-K-Ca	K-Mg
Filoa	Sp-1	113	112	83	165	184	130	105
Filoa	Sp-2	118	117	90	161	180	112	113
Melka	Sp-3	158	150	134	183	201	97	96
Habilo	Sp-4	220	200	206	233	247	107	170
Hubicha	Sp-5	121	119	93	185	202	67	76
Hubicha	Sp-6	126	123	98	172	190	151	180
Dofan	Sp-1	149	143	124	160	178	118	97
Dofan	Sp-2	140	135	114	180	197	123	93
Debhile	Sp-3	159	151	134	162	181	124	136
Debhile	Sp-4	111	111	82	150	169	130	129
Kelo-al	Sp-5	199	183	181	174	192	92	136
Bilen	Sp-6	135	131	108	212	228	84	84
TD-5	W	265	236	261	249	275	282	209
TD-5	S	262	233	258	249	275	251	200
TD-5	W	273	241	271	246	274	247	193
TD-5	S	261	232	255	242	271	282	216
Allalo.	AL-1	206	190	190	157	209	285	179
Allalo.	AL-2	206	190	190	157	209	284	178
Allalo.	AL-3	202	186	185	147	201	251	164
Dobi	Do-1	254	227	247	80	146	187	142

SiO_2-(A) TºC =	$1309/(5.19-\log(SiO_2)-273.15$	Quartz, no S. loss (C.C)
SiO_2-(B) TºC =	$1522/(5.75-\log(SiO_2)-273.15$	Quartz, Max S. loss (A.C)
Chalcedony TºC =	$1032/(4.69-\log(SiO_2)-273.15$	0-250 ºC
Na-K-(1) TºC =	$1217/(1.483+\log(Na/K)-273.15$	Truesdell 1976
Na-K-(2) TºC =	$1390/(1.75+\log(Na/K)-273.15$	Giggenbach et al. 1983
Na-K-Ca TºC =	$1647/(\log(Na/K)+\beta*(\log(?Ca/Na+2.06)+2.47)-273.15$	Fournier and Truesdell 1973
K-Mg TºC =	$2330/(7.35-\log(K^2/Mg)-273.15$	Fournier in preparation

Note: **β** = 4/3 for T<100ºc, 1/3 for T>100ºC

W = Weir box water sample

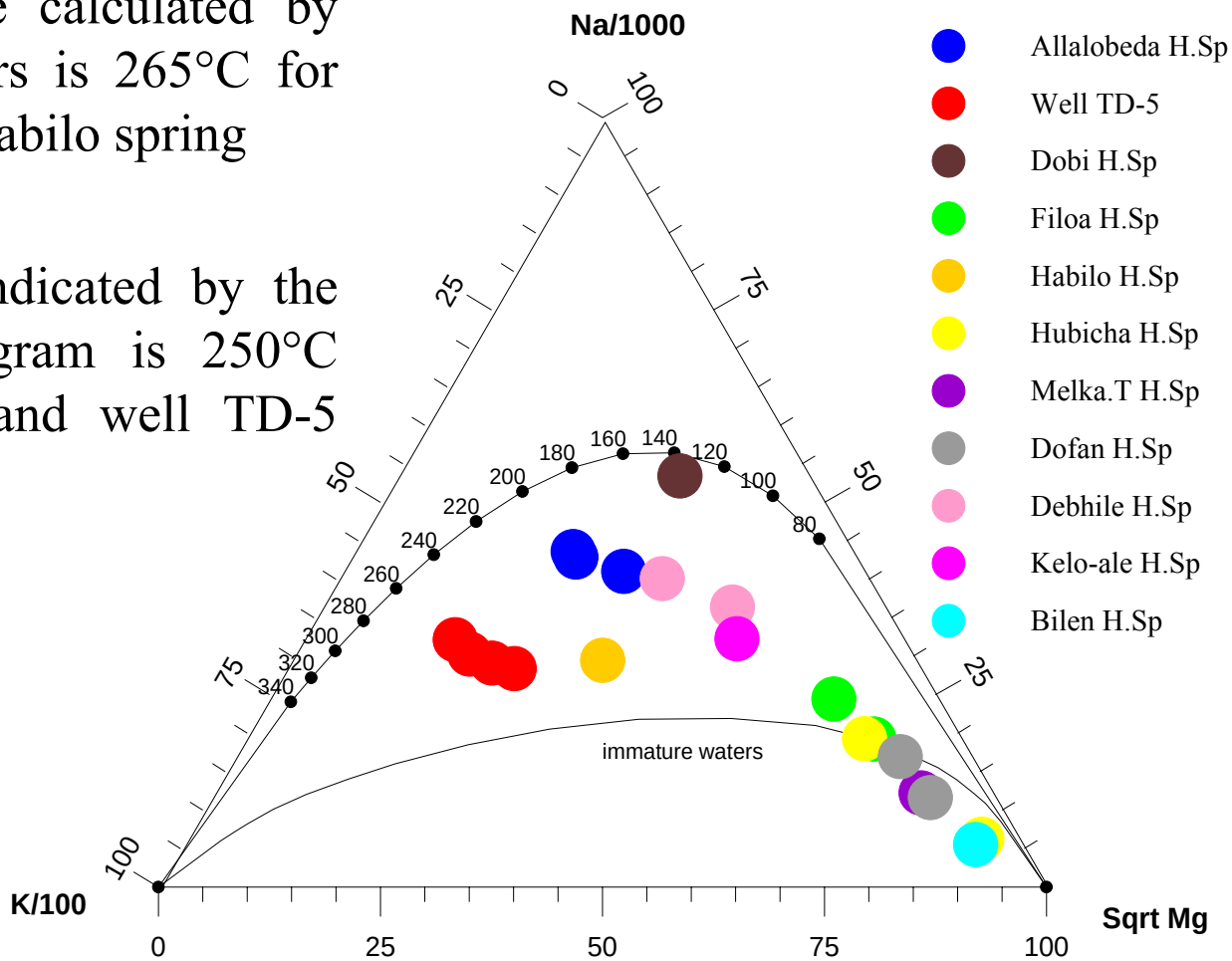
S = Separated water sample

(C.C) = Conductive cooling

(A.C) = Adiabatic cooling

Calculated deep temperatures

- The average temperature calculated by chemical geothermometers is 265°C for well TD-5 and 247° for Habilo spring
- The deep temperature indicated by the Giggenbach ternary diagram is 250°C and 270°C for Habilo and well TD-5 respectively



Na-K-Mg plot for waters from Dofan-Fentale and Tendaho

Reservoir temperatures calculated using different gas geothermometers

Well No.	Sampling Date	CO_2	H_2S	H_2S-CO_2	CO_2/H_2	H_2S/ H_2	H_2	CO_2 /N_2
TD-5	15/03/05	260	279	256	235	204	239	302
	7/04/05	267	281	259	247	215	245	290

CO_2 geothermometer $T° C = -44.1 + 269.25\ Q_C - 76.88\ Q^2_C + 9.52\ Q^3_C$

H_2S Geothermometer $T° C = 246.7 + 44.81\ Q_S$

$Q_S = \text{Log } CO_2$, $Q_S = \text{Log } H_2S$

H_2S-CO_2 Geothermometer $T° C = 194.3+56.44Q_{SC}+1.5Q^2_{SC}$

$Q_{SC} = \text{Log } H_2S + 1/6\text{Log } CO_2$

CO_2/H_2 Geothermometer $T° C = 341.7 – 27.58Q_{CH}$

$Q_{CH} = \text{Log } CO_2 – \text{Log } H_2$

H_2S/ H_2 Geothermometer $T° C = 304.1 – 39.48Q_{SH}$

$Q_{SH} = \text{Log } H_2S – \text{Log } H_2$

H_2 Geothermometer $T° C = 212.2 + 36.59Q_H$

$Q_H = \text{Log } H_2$

CO_2 /N_2 Geothermometer $T° C = 135.9 = 63.14\ Q_{CN} + 6.241Q^2_{CN}-1.813Q^3_{CN}$

$Q_{CN} = \text{Log } CO_2 – \text{Log } N_2$

N.B: - All the gas geothermometers are in Log mmoles per Kg of steam.

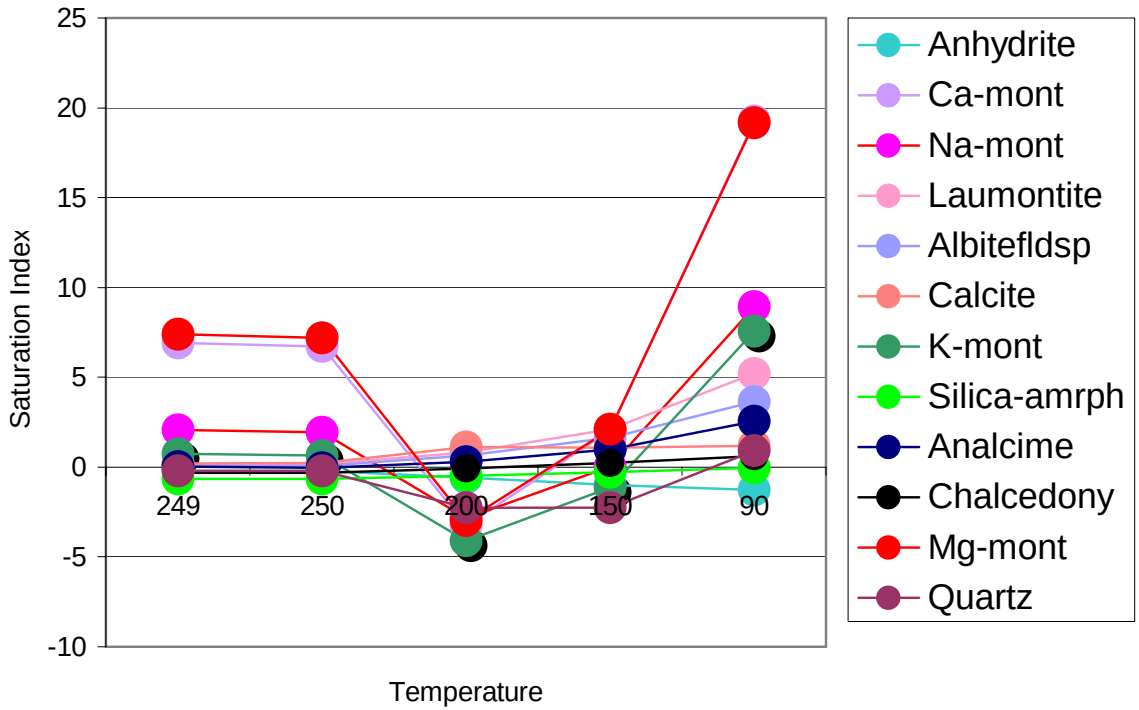
Steam Fraction

- The steam fraction of well TD-5, as calculated using the temperature of chemical geothermometer is 30 %.

- The steam fraction result calculated by the engineers is 32 %.

Fluid mineral equilibria

- All geothermal fluids contain dissolved solids that are in equilibrium with the rock reservoir at high temperature and pressure.
- As the fluid is brought to the surface, it is cooled conductively and therefore the the tendency of scaling to take place is high.
- Therefore in order to assess the possible occurrence of scaling in the future geothermal wells, the saturation index of certain minerals was plotted versus temperature using the chemistry of Habilo spring, as a result:



Temperature versus Saturation Index plot for Habilo spring

Results from gas Study

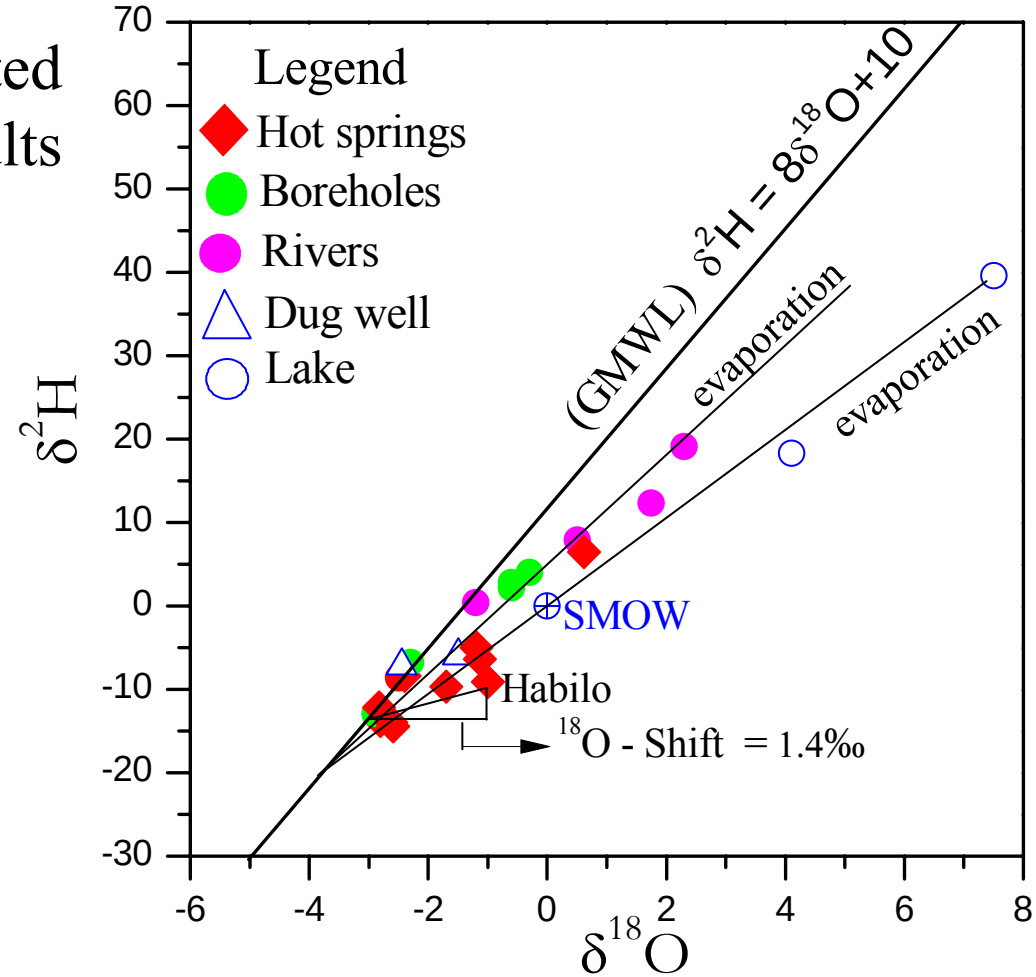
- CO_2 and H_2S are the most abundant gases in the steam phase of well TD-5 and constitute over 99 %. CO_2 alone exceeds 93% in the steam phase.
- The weight % of gas in the "steam flow" of well TD-5 is **0.049%** which is really very low as compared to the weight percent of gas in LA-3 (Aluto-Langano geothermal field) which is **6.86%**.
- The temperature given by the gas geothermometer is in good agreement with the temperature calculated using chemical geothermometer.

Gas concentrations of well TD-5 (Concentrations in mMoles/100moles of H_2O

Sampling Date	Well head Pressure	Sampling point Pressure	Sampling Pressure	CO_2	H_2S	H_2	N_2	CH_4
15/3/05	7.6 bar	7.5 bar	6.30 bar	205	9.48	0.03	0.70	0.12
7/4/05	10.3 bar	10.0 bar	9.5 bar	164	10.3	0.06	0.88	0.40

Results from isotopic study (Dofan-Fentale)

- $\delta^{18}O$ versus $\delta^{2}H$ was plotted and the following results were observed
- 1) evaporation effect
- 2) meteoric water
- 3) "^{18}O-shift"



$\delta^{2}H$ versus $\delta^{18}O$ plot for waters from Dofan-Fantale area

SUMMARY OF RESULTS

- The hot springs in the Dofan-Fentale area are characterized by near neutral Na/SO_4-Cl and slightly alkaline Na-HCO_3 waters.
- The geothermal well TD-5 and the hot springs in the Tendaho area are alkaline mature geothermal Na-Cl type.
- Evaluation of change of concentrations of elements through time has demonstrated the state of stable condition of the thermal system in the Dofan-Fentale geothermal field for the last 30 years.
- The deep temperatures calculated using chemical geothermometrs have indicated 247°C for Habilo and 265°C for well TD-5.
- The saturation index versus temperature plot has suggested that scaling in the future exploration wells will not take place inside the well but inevitable at the surface at 100°C at atmospheric pressure.
- Habilo spring has shown ‘’^{18}O-shift” of 1.4‰ which might indicate higher circulation period and longer residence time.
- The weight percent of gas in the steam flow of well TD-5 is 0.049%.


Thank you