Geothermal Development In Sabalan, Iran

MANUCHEHR FOTOUHI

ELECTRICITY POWER RESEARCH CENTER
MINISTRY OF ENERGY, IRAN

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Geothermal energy development projects in Iran began in 1975. Results indicate that Iran has substantial geothermal potential in the northern Provinces. With respect to higher priority, the region3 of Sabalan, Damavand, Maku-Khoy and Sareine are considered as promising prospects for electric Power generation.

The Sabalsn region contains of the three promising zones at Meshkinshahr, Boushli and Sareine, where according to geothermometric studies, the range of their average subsurface reservoir temperatures are 140-251°C. Pursuant to hydrogeological, geophysical end geochemical interpretations. the Meshkinshahr area has been selected for the first exploration drilling site.

Introduction

Interest in the geothermal energy originated in Iran since Mr. James R. McNitt, a United Nations geothermal expert visited Iran (December 1974). He reported that Iran has very promising prospects for geothermal energy development. Upon Mr. McNitt's recommendations in 1975, a contract between Ministry of Energy (MOE), ENEL (Ente Nazionale per L 'Energia Elettrica of Italy) and TB (Tehran Berkeley consulting Engineers of Iran) was signed for geothermal exploration in Northern part of Iran (Azarbaijan & Damavand regions).

Final reports of the regional investigations performed for those areas were delivered during 1980-1983. According to these reports and investigations of Electric Power Research Center (EPRC), priorities were given to the Sabalan, Damavand, Khoy-Maku and Sahand regions. Such findings were approved by Dr. Valgardur Stefansson (Interregional Adviser on Geothermal Energy, United Nations) on his visit to Iran of 1989.

since 1993, feasibility studies to justify exploration drilling and approximate the reservoir capacity in the Sabalan and Damavand regions were carried out by EPRC. As a result, respectively, the geothermal potential of the two regions are estimated to be 48×10^{18} and 5×10^{18} joule.

This article will cover exploration activities in the Sabalan region.

Geology of Sabalan

Sabalan is a Quaternary stratovolcanic mountain, that at the present time is at the solfatara stage. Surface geological surveys of the Sabalan area show that most of the area is covered by extrusive rocks.

The sabalan region has three geologically distinct provinces, they are as follows: Northern, southern and Sabalan volcanic provinces.

Rock types of the Northern volcanic province consists of the following sequence: Andesite ash flows, andesite porphyry and quartz latite unit.

These volcanic areas have been intruded by a Monzonite, believed to be equivalent to the southern quartz Monzonite that is dated from 22.5 to 23.0 m. Y. The Youngest volcanic unit appears to be an andesite ash flow.

The southern Volcanic province is bounded on the north by the main road between the cities of Sarab and Ardebil, and extends southeast toward the study area boundary. Rock types of this province are as following in an young to old sequence:

Alluvium, terrace conglomerates, volcanoclastic sediments, olivine basalt porphyry flows, hornblende andesite porphyry flows and pre- volcanic sediments. The pre-volcanic sediments are the oldest rock units in the Sabalan zone.

The Sabalan province shows characteristics of an earlier strombolian type eruptions, therefore in some localities there is evidence of weak to violent eruption of moderately fluid lava, generally of an andesitic to basaltic composition and thicker blocky flows. Rock types of this area are as following in an young to old sequence:

Alluvium, quaternary terrace conglomerate, volcanoclastic sediments, quartz latite flows, Post caldera andesite, basalt flows, latite porphyry flows, andsite flows, quartz monzonite intrusions, lalite porphyry flows, mafic andesite flows. and pre- volcanic sediments

Regional stratigraphy of the Sabalan is related to the sedimentary substratum (Fig. 1&2) that is taken from the bibliographical data regarding the surrounding areas and north of Iran in general.

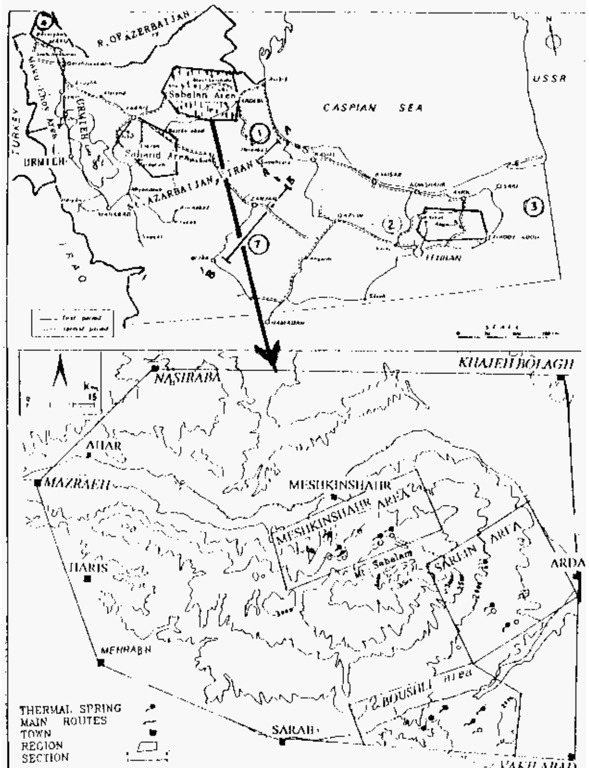


FIG 1- LOCATION OF GEOTHERMAL AREAS, GEOLOGICAL SECTION AND THERMAL SPRINGS IN SABALAN REGION

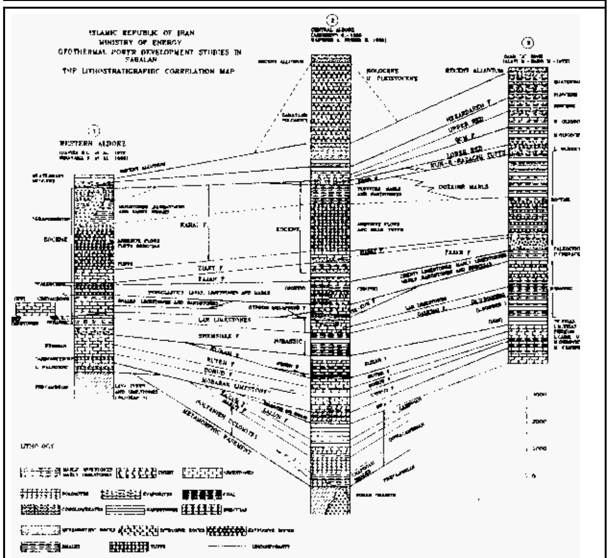


FIG 2 THE LITHOSTRATIGRAPHIC CORRELATION MAP

Tectonics

Since *the Sabalan is covered by* ***volcanic*** *debris and extrusives, there are* ***no*** *outcrops of the sedimentary substratum. Therefore it is impossible to identify its teconic and structural lineaments. Structural information is derived from the neighboring regions.*

Azarbaijan is situated ***on*** *the* ***eastern*** *part of the Turkish continental plateau. which lies on an intracontinental orogenic zone between the Eurasiatic and Arabian* ***plates.***

As an effect of the principal Alpine diastrophism. the Alborz end Zagros chains have converged in the **structural** *unit of the continental plateau.*

The Sabalsn region is situated on the eastern part of the plateau, that is near the margin of the Caspian sea.

Thermal springs

There are ***more*** *than 17 thermal springs in the Sabalan region. These springs* ***are*** *scattered from* **the** *northwest flank to* **the** *southeast of Sabalan and distributed in groups; Meshkinshahr, Boushli and* ***Sareine*** *(Fig.1)*

The average temperatures of the thermal springs **are** *about 40°C . The hottest springs are Situated in the Meshkinshahr group (85°C) and the Boushli group (77°C).*

The maximum flow rate in the Meshkinshahr group is 9000 l/min and in the ***Sareine*** *group* ***abut*** *4000 l/min,* ***there*** *is* **no** *record on Boushli group.*

Practically all springs display considerably a higher flow rate in May than **in** *Agust.*

Hydrology & Hydrogeology

AS ***a result*** *of local uplifting of the* **sediments** *in sabalan* ***area*** *and due to volcanic forces or fast cooling of the* ***extrusive*** *rocks. the* ***area*** *is highly fractured. According to the fracture studies, it* ***appears*** *that the* **major** *element influencing hydrology of spring's* ***reservoir*** *is the sabalan* **Caldera.** *Due to the collapse and its associated features (ring fractured, etc), it is found that there is an* ***excellent*** *collecting* ***area*** *for* ***water*** *runoff. In fact the caldera* ***area*** *is responsible for directing the ground waters along the fractures into the subsurface* ***reservoirs***

Reservoir Rocks and ***Caprocks***

With regard to stratigraphic ***sequence.*** *permeability and porosity characteristics, the reservoir rocks of sabalan. from old to .young. are* ***as*** *follows:(Fig. 31*

The Cambrian rocks, mainly **composed** *of limestones. dolomites and sandstones display a good permeability and porosity (e.g. Soltanieh F.* ***Barut*** *F. Zaigum F. & Lallun F.). The permo-Triassic succession made up of quartzite alternated with limestone and dolomite. also displays* ***a*** *good permeability when fractured (e.g. Dorud F., Ruteh F. & Elika F.).*

The Shemshak formation (Jurassic) with composed thickness of about 1000m Shale, siltstones and sandstones can be considered ***as*** *impermeable caprocks. for the above mentioned Cambrian -Permian succession.*

The ***calcareous*** *rocks of* ***Lar,*** *Tiz -Kuh and Orbitolina limestones (Mid.* **Jurassic - Lower** *Cretaceous/, approximalety 400-500 m thick, display* ***good*** *permeable reservoir* ***rocks,*** *that is* ***overlaine*** *by Karaj formation(Eocene-Oligocene) as a* ***caprock.*** *This formation is mainly made up of volcanic rocks (Lavas and to a* ***lesser*** *degree, tuffs), but layers of limestones* ***and*** *gypsum* ***are*** *present locally. The overall permeability of this formation is medium,* ***even*** *if locally it* ***can*** *be high in correspondence with lithoid and slightly altered lava* ***or*** *low in layers of ceneritic tuffs. There are* ***also*** **layers** *with low permeability that* ***can*** *be considered caprock,*

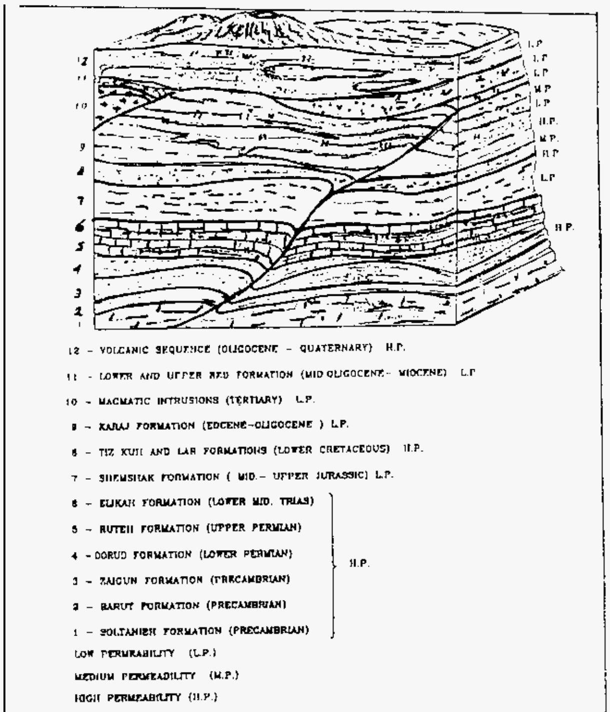


FIG 3 BLOCK DIAGRAM SHOWING THE STRATIGRAPHIC SEQUENCE AND THE SCHEMATIZED

***The** Deep Geological structure*

*Gravimetric surveys **were** carried out in the Sabalan region in order to construct the deep geological structures of the area.*

*In the **NE** sector of the **area** (Fig.4) the strong positive anomaly corresponds to the mountainous chain which lies parallel to the Caspian **sea.***

*Regional effects decrease in the SW direction, and the center of this anomaly most likely lies outside the surveyed **area** in correspondence with the mountainous massif of Sahand.*

The negative anomaly is caused by an extended depression filled with lighter volcanic formations.

Details of the high gravity valves are as follows:(Fig.4)

- *The rectangle-shaped structure present to NE of the Sabaln volcanic **cone,** due to higher density **mass** ic nature.*
- *The system of structure that winds south of **volcanic** massif presents smaller anomalies to the preceding ones.*

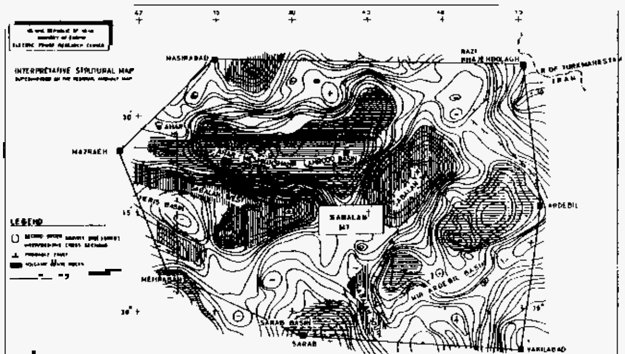


Fig GRAVITY SURVEY OF SABALAN REGION

Sabalan lies at the point of intersection of views, and represents the youngest volcanic eruption.

*The main negative anomalies are: that of Ahar, Meshkinshahr & Lahrood basin on the northern past of Sabalan massif; the anomaly of the Nir-Ardebil basin (Sareine basin) that is situated on the eastern side of Sabalan mountain and the anomaly of the **Sarab** basin (Bushli area) that is located on southern part of the **Sabalsn**. These three basins are the main structures of geothermal reservoirs in the Sabalan region.*

*There **are** two possible interpretation to explain these relative negative anomalies:*

- *The anomalies are caused by **real** tectonic depression(grabens) filled with recent and partially incoherent sediments, i.e. **lower-** density sediments.*
- *The anomalies **are** developed by the presence of lower density subsurface volcanic rocks. That is to say, rocks **are** constituted from tuff and other pyroclastics. The negative anomaly is thus caused only by **a** lateral horizontal variation of the lithological facies. In support of this second hypothesis there is the ascertained presence of **some** volcanic effusive formations inside the "basin" as **well as** in the central part of the volcanic mass.*

*The final interpretation of the two possibilities is that the basins **are** of a tectonic nature (grabens) and filled in part with lighter tuffaceous volcanic formtion.*

Geochemical Exploration:

*Geochemical studies of the Sabalan region recorded 65 types of spring waters, 14 gases, 30 hydrothermal alteration **areas** and deposits, and 335 run off waters.*

*The samples collected from four **zones** (Fig.1) are as follows: Sareine: 1001, 1002 , 1003. 1004, 1007, **1008**, 1009, 1010 and 1011. Boushli: 1005, **1006**. 1045, 1045A, 1046, 1048, 1051, 1052, 1102 and 1103. Meshkinshahr: **1012, 1013, 1014, 1015, 1016, 1017, 1018, 1019,** 1020, 1021, 1022, 1023 and 1075. Ahar: **1070.***

*The analyses of samples was carried out in two different laboratories by Tehran Berkeley consulting Engineers (T.B) and ENEL (Italy). The results of the both analyses are **well** matched.*

*The results of the chemical analyses (table1-3) were used for geothermometer calculations with computer code WATCH (Andersson et **el.** 1982). For such calculations, the quartz temperature was selected **as a** reference temperature (The subsurface temperature).*

*When computer **codes are** used to simulate **unknown** conditions, certain assumptions **are** made about the **processes** taking place. With the WATCH method of*

Table1: Chemical composition in mg/l of the samples from Meshkinshahr

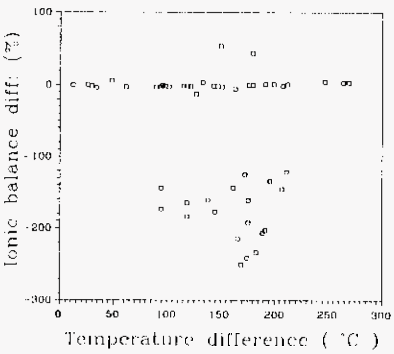
Sample No.	^0C	l/sec	$pH/^0C$	SiO_2	B	Na	K	Ca	Hg	CO_2	SO_4	H_2S	Cl	F	TDS
1012	38.5	0.7	2.7/25	60.0	0.53	182.0	32.1	28.1	10.30	760.0	528.0	85.0	88.8	0.6	936.0
1013	6.5	0.2	5.5/25	81.0	0.03	20.9	3.9	32.1	6.20	46.0	139.0		1.8	0.3	317.0
1014	49.5	0.7	6.7/25	109.0	0.16	221.0	16.8	74.2	49.80	845.0	274.0		4.6		1132.0
1015	11.0	0.1	5.7/25	88.0	0.05	29.9	3.9	68.1	46.20	1232.0	134.0		1.5	0.3	612.0
1016	37	0.1	6.0/24	154	3.35	322	43.0	80.2	19.5	376.0	283.0		426.0	1.0	1464.0
1017	83.5	16.7	6.8/22	128	7.78	690	105.6	124.2	21.90	163	432.0		958	1.4	2610.0
1018	44.5	0.5	5.7/22	26	0.80	80.5	30.1	92.2	24.30	366	480		1.8	1.0	878.0
1019	14.5	0.2	6.8/22	60	0.10	13.1	5.5	28.1	5.22	78	33.1		6.0	1.0	258
1020	11.5	0.1	7.5/22	37	0.12	11.9	3.0	42.1	8.38	125.0	4.8		5.0	0.3	253
1021	16.5	0.3	7.6/22	58	0.08	19.1	4.3	22	5.83	72	12.		12.1	0.1	201
1022	22	6.7	7.6/22	71	0.07	15.	4.7	4.7	14	3.04	77		9.6	0.2	174

Table 2 Chemical composition in mg/l of the samples from Boushli

Sample No.	^0C	l/sec	$pH/^0C$	SiO_2	B	Na	K	Ca	Hg	CO_2	SO_4	H_2S	Cl	F	TDS
1005	77	0.1	7.3/22	76	24.8	2208	266	54.1	31.6	1269	130		2911	2.8	6316
1045	40.5	0.1	6.7/22	92	29.16	2001	258	130	24.3	1165	274		2804	1.8	6446
1046	41.5	0.1	6.7/22	150	20.52	2093	176	190	42.5	1620	1056		2094	1.9	7006.
1047	12	0.1	7.2/22	60	0.80	17.0	3.0	28.0	4.13	107.0	13.4	7.3	8.8		245.0
1048	52.5	0.2	7.0/22	87	20.57	1587	219	180	25.5	1190	235		1988	1.5	4729
1051	22.0	0.2	6.6/22	86	23.76	1817	219	220	52.20	1710	161.0		2201	1.1	5605.0
1052	40.5	0.2	6.5/22	77.0	28.08	2093	270	220	59.5	1860	1056		2485	0.5	6474
1102	11.0	0.1	6.5/22	40	0.39	98.9	3.2	86.2	26.7	284	245.0		22	0.4	768

Table 3: Chemical composition in mg/l of the samples from Sareine

Sample No.	^0C	l/sec	$pH/^0C$	SiO_2	B	Na	K	Ca	Hg	CO_2	SO_4	H_2S	Cl	F	TDS
1001	17	0.1	5.9/22	106	0.04	25.3	6.7	54.1	13.40	903	34.6		4.3	0.1	390
1002	11	0.3	6.3/22	84	0.08	12.4	2.0	46.1	12	361	12		3.9	0.4	288
1003	15.5	0.1	5.6/22	78	0.04	13.1	2.5	42.1	9.8	139	48		5.0	0.4	277
1004	46.5	1.3	6.0/22	105	1.94	190.9	36	72.1	18.2	932	96		209.4	0.3	936
1007	23	0.1	5.5/22	107	0.45	62.1	16.8	44.1	12	190	96		29.1	0.7	446
1008	12.5	0.6	7.1/22	54	0.10	19.1	1.4	80.2	11.2	198	38.9		3.0	0.8	361
1009	35.5	1.0	4.6/22	84		23	6.3	172	8.6	485	485	0.2	2.0	0.5	876
1010	16.5	0	6.5/22	56		15.4	2.5	92.2	9.6	95	230		1.0	0.6	510
1011	11.5	0.2	6.5/22	35	0.09	16.1	1.9	86.2	14.6	204	12		8.2	1.1	321



i r 5 Relation between the differences in Nak and quartz temperature and the differences in ionic balance for surface and deep water

calculation, the assumption is that there is no mixing takingplace. If however. there is mixing takingplace between the thermal water and ground **water,** the **result of** the calculation will be in error. This is true in the **case of** samples taken from Sabalan region. First. the large variation in flow rate of the springs indicates that ground water **influences** the springs flow rate. Secondly, the calculated NaK temperature is based on the ratio between the concentration **of** Na and K,& SiO_2 in the water. so mixing will have at **less** influence on the NaK temperature than that of SiO_2. The third **reason** is that whereas the ionic balance of the samples is in all cases **good,** the ionic balance of the calculated deep Water composition is frequently not in balance.

The table **4**. shows the difference between SiO_2 temperature and NaK temperature for the samples from Sabalan together with the ionic balance for the surface

Table 4 : Silica, NaK temperatures and ionic balance for surface and deep water at Sabalan

Sample	T QZ ^0C	T NaK ^0C	Surface water Balance	Deep water Balance
1012	105	252	-10.81	41.97
1013	118	269	1.26	-159.96
1014	113	171	-8.98	-8.20
1015	112	224	5.59	-198.08
1016	150	226	0.15	-191.54
1017	141	245	5.05	7.54
1018	70	341	-6.48	-3.22
1019	105	.355	14.66	15.99
1020	84	303	15.29	15.86
1021	104	291	15.95	16.54
1022	114	321	14.13	14.66
1005	116	220	-2.92	-2.84
1045	124	227	-1.82	-1.49
1046	149	177	0.93	3.78
1047	105	183	-16 47	-15.32
1048	122	235	2.42	2.81
1051	121	219	1.99	2.68
1052	116	224	-3 90	3.05
1102	87	100	14.11	15.76
1001	131	300	-19.57	-199.05
1002	120	252	-1.69	-7.54
1003	117	272	77 24	-184.91
1004	131	263	.86	-196.95
1007	132	308	63.14	-185.11
1008	100	170	18.16	22.11
1009	120	307	3.30	-142.42
1010	102	253	.27	0.81
1011	81	220	64.67	67.34

samples and the calculated ionic balance **for** the deep water. Figure **5** shows **a** relation between NaK and quartz balance between surface and deep water. The samples fell mostly into two Categories, those with relatively good agreement between the ionic **balance** and those with relatively poor ionic balance at surface end those calculated for the deep waters.

The mixing of thermal water with ground **water** influences the calculated geothermometers as mentioned

Table 5 : Geothermometers for samples from Meshkinshahr

Samples No.	L/S	Spring	CH	QZ	QZ ADIAB.	AMORPH	Crist. α	Crist. β	NAK	NAKCA 4/3	NAKCA 1/3	CO_2 4/3	CORR. 1/3
1012					110	0	50	13	261	44	79	71	77
1013					123	7	75	27	269	-5	81	-	--
1014		50	114	142	137	21	91	43	169	21	60	39	25
1015			102	130	127	11	80	31	224	-26	46	-	--
1016		37	135	163	154	40	113	63	226	46	80	82	87
1017	17	84	124	151	145	30	101	52	243	87	110	112	123
1018		45	45	74	78	0	24	0	384	22	9s	78	85
1019	0	15	82	110	110	0	60	13	407	4	113		
1020	0	12	59	88	91	0	38	0	313	-9	YY		
1021	0	17	80	109	108	0	55	11	296	14	112		
1022	U	24	92	120	118	2	69	22	342	27	130		

Table 6: Geothermometers for samples from Boushli

Samples No.	L/S	Spring	CH	QZ	QZ ADIAB.	AMORPH	Crist. α	Crist. β	NAK	NAKCA 4/3	NAKCA 1/3	CO_2 4/3	CORR. 1/3
1005	0	77	94	122	120	4	72	24	215	153	112	138	107
1045	0	41	104	13J	125	13	82	34	222	113	97	161	147
1046	0	42	134	161	153	39	111	61	178	87	78	107	103
1047	0	12	82	110	110	0	60	13	261	-4	88		
1048	0	53	101	130	126	10	75	31	230	101	99	151	150
1051	0	22	101	129	126	10	78	30	215	88	85	106	105
1052	0	41	95	133	131	4	72	25	222	95	87	107	103
1102	0	11	63	92	94	0	42	0	103	-15	34		

Table 7 : Geothermometers for samples from Sareine

Samples No.	L/S	Spring	CH	QZ	QZ ADIAB.	AMORPH	Crist. α	Crist. β	NAK	NAKCA 4/3	NAKCA 1/3	CO_2 4/3	CORR. 1/3
1001	0	17	112	140	135	20	90	41	320	-23	70		
1002	0	11	99	128	125	8	77	29	246	-30	57		
1003	0	16	95	124	121	5	73	25	272	-23	68		
1004	1	47	112	140	135	19	89	41	270	33	79	80	86
1007	0	23	113	141	136	20	90	43	325	22	93	80	78
1008	1	13	77	105	106	0	55	S	185	-31	51		
1009	1	36	99	128	125	S	77	29	326	-26	55		
1010	0	17	79	107	107	0	57	10	250	-26	69		
1011	0	12	57	86	89	0	36	0	213	-32	55		

above. Table 5-7 shows several geothermometer readings for the samples from Meshkinshahr, Boushli and Sareine.

It is assumed that the discrepancy between the calculated NaK and quartz temperature are due to mixing of the thermal waters with ground water. If that is the case, the calculated quartz temperatures become too low, and in fact all temperatures in tables 1-2 are lower than the NaK temperatures. It is of interest to know whether the three thermal areas in Sabalan are independent geothermal systems or if the thermal independent fluid originates from a comn source. Most of chemical components in thermal waters are temperature dependant. However. this is not the case for Cl and B. For a given geothermal system the B/Cl ratio is therefore constant (Fig 6). This indicates that the three areas of Meshkinshahr, Boushli and Sareine can have a comn source of thermal water. If the thermal water at Meshkinshahr. Boushli and sareine have comn source, it is expected that this system located at high elevation would be more influenced by boiling effects of springs located at lower elevation, and the springs at low elevations are

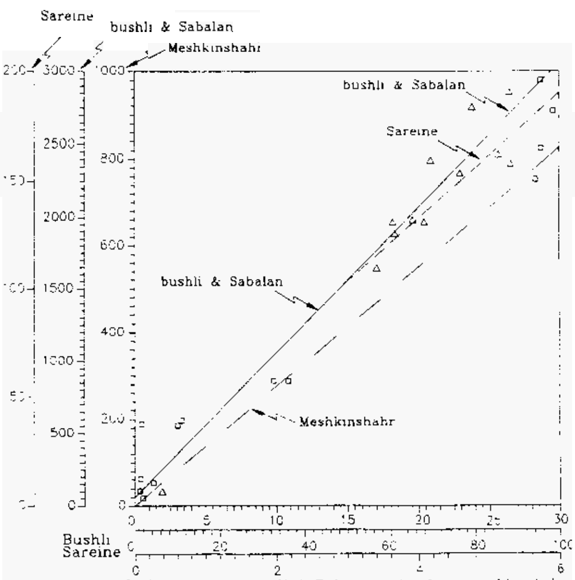


FIG.6 -Relation between Cl & B for samples from meshkinshahr, Bushli , Sareine & Sabalan (all) the best linear fit corresponds to the B/Cl Ratio 27.5, 29.7,31 & 30.5

*expected to have higher concentration in CI. Figure 7 shows the relation between CI and elevation of springs in the Sabalan **area.***

*At present, it **seems most** appropriate to **assume** that there is only one up flow zone in the Sabalan **area,** and such flow zone is **closer** to Meshkinshahr than the other thermal **areas.***

*The main conclusions of the chemist from the samples taken in the Sabalan **area** are as follows:*

- *Thermal **water** is mixed with groundwater. The different degree of mixing and **local** ground water conditions offsets the results of **usual** chemical calculation of subsurface condition as geothermometers.*
- *The B/Cl ratio in thermal water from Sabalan indicates that the thermal **waters** in Meshkinshahr, Boushli and Sareine **can** have a comn source.*
- *The **low pH value** for sample 1012 in the Meshkinshahr **area** is due to mixing of H_2S gas with groundwater.*
- *The thermal **waters** in the Sabalan region originated from **a** high temperature geothermal source. Temperatures in excess of 150 $^{\theta}C$ are expected to found in deep **wells.***
- *The up flow zone of Sabalan geothermal system is expected to be found at relatively high elevation and the Meshkinshahr area is considered to **be** the most promising **area** for exploration drilling.*

*The average value for the **Quartz** and NaK geothermometers **are** 130$^{\theta}$C and 251$^{\theta}$C respectively.*

Conclusions:

*Surface geothermal explorations (geological, geophysical and geochemical) have **been** carried **out** in the Sabalan region, Results of the feasibility studies performed for three **zones** of high geothermal potential **(48x10^{18} Joules)** in the **Sabalan** region indicate the following order of priority: Meshkinshahr. Boushli and Sareine. According to geothermometric evaluations, the average temperature of deep reservoirs **are 130$^{\theta}$C (Qz)** and **251$^{\theta}$C (NaK).** Therefore the Sabalan region has the highest geothermal potential in Northern Iran. This region is recommended for the first exploration drilling and electrical generation from geothermal **energy** in Iran.*

*Thus it is concluded that the next step in geothermal development in **Iran** will be exploration drilling in the Meshkinshahr **zone.***

*In order **to** eliminate risk in exploration drilling, it is highly recommended to carry **out** magnetotelluric **survey** in the Sabalan **area.** **However** the present geothermal data from Sabalan **area** is sufficient to justify exploration drilling.*

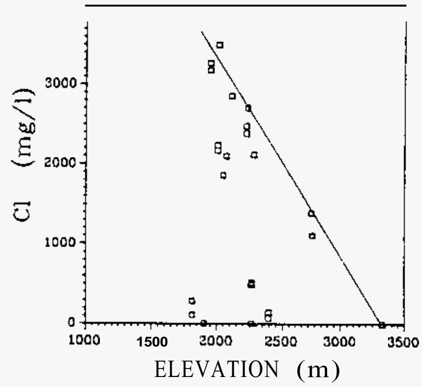


Fig 7 - Relation between Cl and elevation if springs in the Sabalan area

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