GEOLOGY, ENVIRONMENTAL CHANGE IN WATER RESOURCES, ZAGROS-IRAN

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ABSTRACT

The water quality of many karst formations in southern Zagros macrotectonical unit is related to natural geological and hydrogeological conditions and ground water mismanagement. Evaporatic sediments including: gypsum, anhydrite, salt, marl, and marly limestone are existed in some formations such as: Kazhdomi, Pabdeh-Gurpi, Gachsaran, Mishan and Agha Jari formations. This situation makes the covering layers of the karst formations changing the water quality by rainfall and runoff infiltration. The most important factors that strikingly differ the water quality are the distribution of innumerable salt domes (180 diapirs between 6-200 km^2) and the out gassing of oil reservoir and geothermal effects in the karst terranes of southern Zagros range.

The typical karst features in Iran are mostly developed in massive limestone and dolomitic limestone of Asmari formation (Oligo-Miocene) and Sarvak formation (upper Cretaceous) in southern Zagros range.

The area under study is located in semi-arid climate, and has been selected by providing 60 l/s water for Dalan natural gas refinery. Hydrogeological characteristics of semi-arid karst area and topics discussed in this paper are as follows:

1) Environmental change of water quality is related to geology, climate, karst formations, hydrogeological conditions and ground water mismanagement. The most important problem in semi-arid karst under study are the mineralization of aquifers resulted from over pumping during dry and vegetation periods of a year, the existing salt plug in catchment area and evaporation zones in alluvial aquifers.

2) The water quality in depth of aquifers has been changed. The value of electrical conductivity in karst aquifer is about 620-4000 mμ /cm and in alluvial aquifer is about 680-33000 mμ /cm which changes respectively from recharge to discharge areas or from upward to downward of ground water flow.

3) The rate of discharge in one of Sarvak karst (Khormayek area) is about

101 l/s with maximum drawdown 5.29m in pumping well and 0.59m in two piezometer wells 22 m away. In one of the Asmari karst is about 94 l/s with drawdown 0.30m in pumping well and for two piezometer wells adjacent the well being about 0.17 meters (22 meters away).

4) For protecting and controlling water resources quality, it is recommended to exploit water in selected boreholes with low capacity (30 l/s) and water quality should be strictly controlled in tapping. The water management in area under study (Khormayek & Farashband) should be under severe control. Every developing of aquifers before artificial recharge is not allowed.

INTRODUCTION

In order to provide technical services for Dalan natural gas refinery on water supply (drinking and industrial purposes), and making choice between alluvial and karst aquifer for tapping in semi-arid area, some investigations were carried out, such as:

a) Geology, tectonic and karst geomorphology;

b) Geophysical studies utilizing the geoelectric method (110 soundage with AB=2000 m);

c) Exploratory boreholes in different karst formation (5 point drillings with total 690 m) and 4 points as exploratory and productive wells adjacent the boreholes (400 m), 23 exploratory boreholes totalling 1800 m in alluvial aquifers;

d) Hydrology and climatological studies;

e) Pumping tests in alluvial and karst boreholes have been done with different capacity to control change of quality.

f) Geochemical investigation based on 300 samples of water points (borehole, springs, shallow wells, deep wells on different depth of aquifers).

1 GEOLOGY

The oldest geological formation in area under study is Khormayek salt plug of pre-Cambrian with surface dimension of 12 km in lenth, 1.7 km in width and 180 m in height. It dominates in NW of southern part of Bahar anticline and along the lateral fault.

Fig.1 indicates schematical presentation of tectonical activities in some part of southern Zagros and area under study. Khormayek salt plug has been formed by Bahar thrust fault and two normal faults in southern part of the area. Lithology includes marl, gypsum, salt, dolomite and black shale. This salt plug in Khormayek alluvial aquifer changes the water quality remarkably.

The value of electrical conductivity in one of piezometric borehole (400 meters away from salt plug) is about 27000 mμ /cm. The above value in alluvial drainage of Khormayek and Farashband area is about 9600 mμ /cm.

The analysis of brine waters from various salt plugs in southern Zagros indicates that the range of Cl^- is about 189-197 g/l and Na^+ is about 119-124 g/l and $Ca^{++}+Mg^{++}$ is about 0.41-2.3 g/l. Where the salt plugs penetrates into karst formation, the water quality is highly mineralized.

For example, one of the exploratory borehole which has been drilled at depth 70 m, out of area under study (Gavebast anticline near Bandar Abbas port and Persian Gulf), the value of electrical conductivity is about 40000 mμ /cm. The theory of Diapirizm is out of the aim of this paper but as it is an important factor influencing the salinity of water resources (groundwater & surface water) in Zagros, the general information could be introduced as follow:

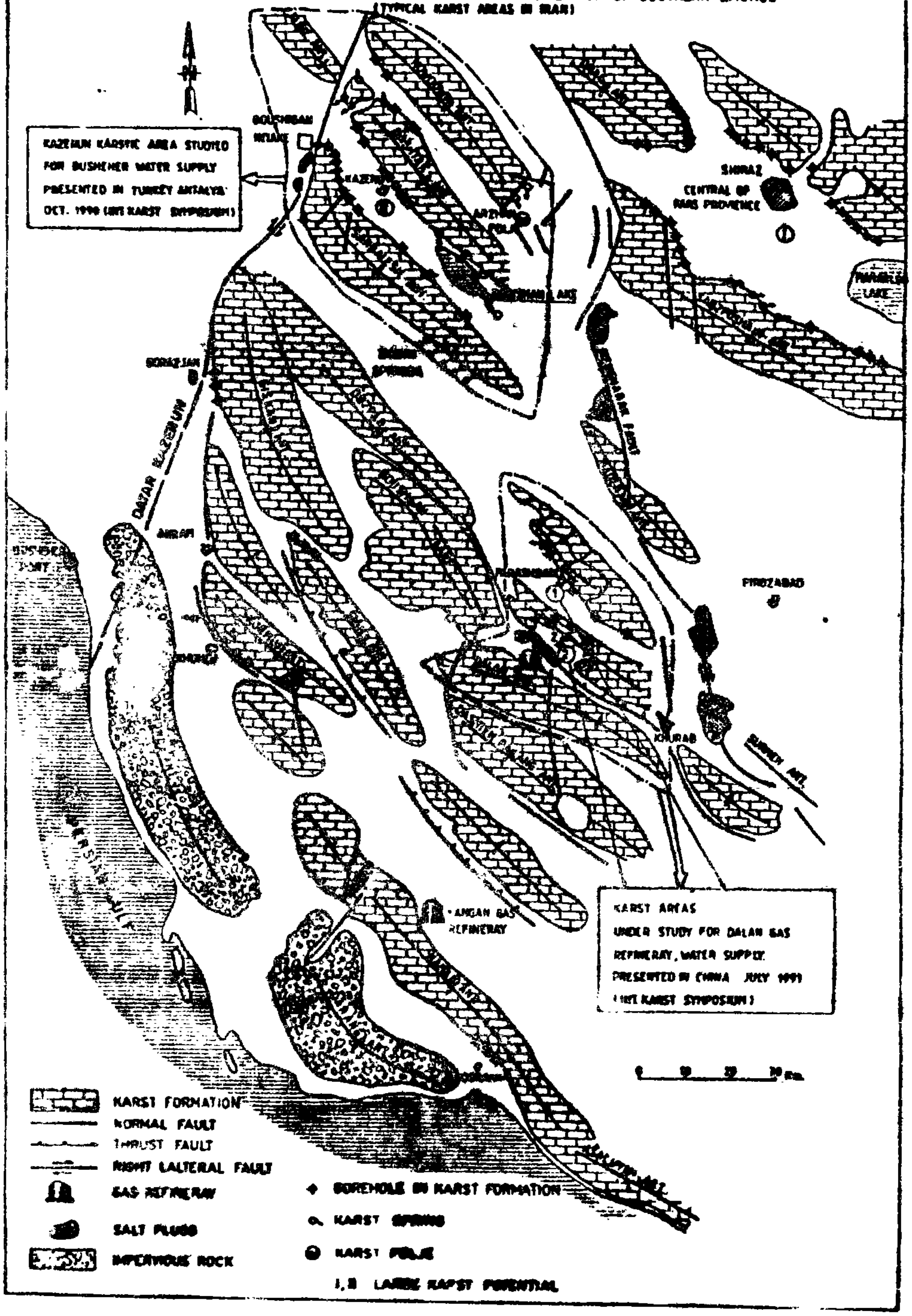
The salt plugs which pierced cover rocks of up 10,000 m in thickness, are distributed along the main Zagros thrust and its parallel thrust lines as well as along regional basement strike-slip faults.

Movements along these basement faults and accompanying shear zones disintegrated pieces of the neighbouring basement rock and cover rock. Then fragments were secondarily transported by rotational ascent of the Hormuz salt to the present and former land surface.

Most of the diapirs in southern Iran are of pre-Cambrian. It comprises dominately salt and gypsum, and subordinate dolomite, black limestone & shale, red sandstone banded by quartz & hematite as well as mafic and siliceous igneous rocks.

Temperature is critical for the occurrence of salt plugs or diapirs. This can be achieved when the saline material is buried to a sufficient depth of 7000 m. If the salt is heated above 205℃ it becomes soft and plastic, flows indefinetely, and is plastic during the entire process of intrusion. At a depth of more than 7000 m, the mobile salt behaves hydrodynamically as it is the case in the southern part of the Zagros and Persian Gulf sector.

Fig.1 SCHEMATICAL PRESENTATION OF TECTONICAL ACTIVITIES IN SOME PART OF SOUTHERN ZAGROS (TYPICAL KARST AREAS IN IRAN)



1.1 Tectonic in Zagros

Regional anticlines in Zagros folded belt are intensively fractured by normal faults, crest and flank grabens, step faults as well as by circular collapse structures "cauldrons". The diapires in SE Zagros are regularly distributed.

The SE Zagros includes the largest salt extrusions of the Middle East.

1.2 Karst formation & impervious rock

After salt plugs, geological formations from lower to upper include: Kazhdomi, bituminous shale, argillaceous limestone of middle and upper Cretaceous. Illam (Argiilaceous & marly limestone) and Sarvak. Karst formation in most southern Zagros and area under study is developed on these argillaceous and chalky limestone, massive and rudist limestone, soft and fragile limestone. Karstifications was happened due to Zagros macrotectonical processes in late Cretaceous. All the karst formation especially in humid and sometimes in semi-arid climate bring about high porosity and transmissivity so that productive wells. Pabdeh Gurpi, purple shale, marly & argillaceous limestone (Paleocene-Oligocene), impervious layers covering Illum & Sarvak. Asmari Jahrum: marly and thin bedded limestone, massive limestone, (karst formation, in mostly southern Zagros) dolomitic and crystaline limestone with good karstification and productive aquifer (Oligo-Miocene). Gachsaran, Mishan and Agha Jari with lithology as marl, gypsum, marly limestone, micro-conglomerate of lower Miocene-Pliocene makes the impervious layers covering Asmari Jahrum karst formation. Most of the oil fields in Zagros have been discovered in Asmari formation. In depth below 3000-4000 m there are oil reservoir and where it is widespread in surface it becomes ground water aquifer. Because of macrotectonical, orogenic and epirogenic movements in Zagros system, about 5000 m of sediments have been uplifted. For this case karst processes have completely been done in some carbonate rocks as Asmari-Jahrum and Sarvak formations.

2 CLIMATOLOGY

Semi-arid climate governed in the area under study extending 51° 45′ to 52° 30′ longitude and 28° 35′ to 29° 05′ North latitude.

The average daily temperature is about 22/3 ℃ and the maximum & minimum temperature are 48℃ (July) and 3℃ (March) respectively. The maximum and minimum annual precipitation are about 550 mm (1983-1984) and 101 mm (1971-1972) and the annual average 330 mm. 17% of precipitation related to summer time and 83% related to winter time. The annual average of pan evaporation is 2910 mm and 1726 mm for evapotranspiration. The obtained equation of linear relationship between rainfall and topographic height are as follows:

$$P=192.9+0.164H \qquad r=0.95$$

where H=height in m; P=precipitation in mm; and r=coefficient of relationship

and the maximum & minimum of relative humidity are about 83% and 24% respectively (ave. 53%).

3 HYDROLOGY

The inlet volume of all surface water derived from mountainous part is about 57 m.c.m./year. The volume of outlet is about 73 m.c.m/year for surface catchment area 820 km^2.

4 INVESTIGATIONS

a) Approximately 110 geoelectrical soundings with distance of electrodes for current sender about AB=2000 m has been done in the border of karst terraces. According to results of 5 boreholes drilled, finally an area has been selected for 4 boreholes as exploratory and extraction for water supply. Table 1 indicates the obtained data. The range of specific resistivity in saturated karst is 120-600 ohm.m, the depth of karstification 40-300m

b) Some data about quality of water during pumping test and important factors influencing the salinity, and amplitude of annual water table fluctuation have been indicated in Tab.1. Fig.2 & 3 presented the results of drillings and geoelectrical soundings.

c) Hydrochemical data based on 300 samples of water.

Fig.2 indicates that mostly karst water type are chlorine and sulfate. Because of groundwater mismanagement in Farashband alluvial aquifer during the past 10 years (developing from 9 to 45 m.c.m/year) most of the alluvial water change to chlorine, sulfate type. In Khormayek alluvial aquifer groundwater developing from 1 to 9 m.c.m/year has all changed to SO_4-Ca, Cl-Na water type. Most water type in karst formation of Khormayek area as extraction zone for project under study are SO_4-Ca.

d) Groundwater planning has been done. In order to control the quality, the extraction from selected boreholes should be done with low discharge in separate points.

e) Pumping tests in selected karst boreholes in two stage has been done.

One stage with 6" inches pumping test at constant discharge in 1990 and second stage with 8" inches in 1991. The results of pumping test has been indicated in Tab.1.

The results of second stage of pumping tests in two productive boreholes are as follows:

The maximum drawdown in Sarvak karst aquifer (Tab.1 EXT.BH_3) at the rate of 101 l/s during 72 hours in pumping well is about 5.29 m and in two piezometric boreholes with distances 22-24 m upward and downward of pumping well respectively is about 0.19 and 0.59 m.

The maximum drawdown in Asmari karst aquifer (Table 1 EXT.BH_4) at the rate of 94 l/l during 72 hours in pumping well is about 0.30 m and in two piezometric boreholes (upward & downward) with distances described above is about 0.13 and 0.17 m respectively.

The values of transmissivity estimated by deep well pumping test in exploratory & productive borehole of karst formations in area under study, on the basis of Jacob & Theis method is about 17900-29800 m^2/day. The values of effective porosity were under estimated. The reasons of this problem may be related to short distance between pumping well and piezometric borehole (22-24 m), small capacity and rate of discharge, low drawdown (less than 0.6 m in piezometers).

f) All the dynamic reserves in Farashband karst area (Sarvak karst formation) has been evacuated by over pumping in alluvial aquifer, till 1983. The dynamic reserves in Khormayek karst area (AS & SV. karst formations) discharged or fed alluvial aquifer. No karst spring has been dominated around the alluvial plains.

Tab 1 Comparison of Investigated data on Piezometric, exploratory & extraction boreholes in semi-arid karst, zagros IRAN

No	No of well		Depth (m)	ElV. (m)	S.W.T (m)	Date of Drilling	Variation of Quality in Depth: Depth (m)	Variation of Quality in Depth: E.C mμ/cm	Pumping Test Data: Q 1/sec	Drawdown (m): Pumping well	Drawdown (m): PZ	Drawdown (m): PZ	time (Hour)	Date of pumping	E.C m/μ/cm	karst Formation	Specific Resistivity in Saturated zone ohm. m)	Annual W.T Fluct. (m)	Base of karst. (m)	Important Factors influencing the salinity
1	PZ. BH.	kh	150	850	32	9.1989	80 100 140	1480 1720 2000	—	—	—	—	—	—	—	AS-Ja	190-260	1.17	575	Evaporites(Gs) in area, Marly & argillaceous Limestone in karst.
2	PZ. BH.	kh	90	810	29	9.1990	30 34	2280 2300	—	—	—	—	—	—	—	SV	200	0.86	770	Lithology in Formation marl, argillaceous Lst.
3	EXP. BH.	kh	150	820	36	1.1990	40 70 85	1100 1100 950	37	0.06	—	—	72	2/1990	1194	SV	120-300	1.13	500	Marl & Marlly limestone as intercalation in karst Formation
4	EXP BH.	kh	80	820	37	11.1990			101	5.29	0.19	0.59	72	1/1991	1078	SV	120-300	1.13	500	〃 〃 〃
5	EXP BH.	kh	150	840	54	12.1990	60 90 120 140	610 850 900 1100	31	0.02	—	—	72	1/1991	1611	AS-Ja	—	1.0	600	Marl & Argillaceous Limestone, Limonite in karst Formation
6	EX. BH.	kh	120	840	53	1.1991	—	—	94	0.30	0.13	0.17	72	2/1991	1454	AS-Ja	—	1.00	560	〃 〃 〃
7	PZ BH.	kh	150	840	73	8.1990	80	650	—	—	—	—	—	—	—	ILL-SV	200-600	1.00	580	〃 〃 〃
8	EXP BH.	F	148	905	94	2.1977	—	509	measured as piezometer					2/1991	1900	ILL-SV	200	4.53	680	Marl, marlly Limestone
9	EXP BH.	F	136	680	50	5.1977	—	773	16	installed for drinking Purpose				5/1991	650	ILL-SV	420-800	—	520	〃 〃 〃
10	EXP BH.	F	138	820	38	8.1972	—	750	25	〃	〃	〃	〃	5/1991	792	ILL-SV	250-350	—	550	Shale, Pyrite, Argille
11	EXT. BH.	F	90	818	40	5.1979	—	1440	16	〃	〃	〃	〃	10/1991	1454	ILL-SV	250-350	—	470	Marl & Marlly Limestone
12	EXT BH.	F	100	815	45	5.1990	—	750	16	〃	〃	〃	〃	10/1991	828	ILL-SV	250	—	530	〃 〃 〃
13	EXT BH.	F	130	810	48	6.1990	60	3500	60	unsuitable for drinking				8/1990	4045	ILL-SV	300	—	560	Geothermal gases. Shale, Pyrite, Argille.
14	PZ BH.	F	55	800	10.4	8.1972	30	2800	—	—	—	—	—	—	3400	ILL-SV	150	—	500	〃 〃 〃

Notes
PZ BH. = Piezometric borehole
EXP. EXT. = EXPloratory & Extraction
Kh = khormayek
F = Farashbank

ELV. = Elevation
E.C = Electrical conductivity
Q = Discharge (Liter per second)
W.T. fluct. = water Table fluctuation

Base of kastification from sea level
As-Ja = Asmari-Jahrum formation (Oligo-miocene)
ILL-SV = Ilan Sarvak formation (upper cretaceous)
SV = Sarvak formation (upper Cretaceous)

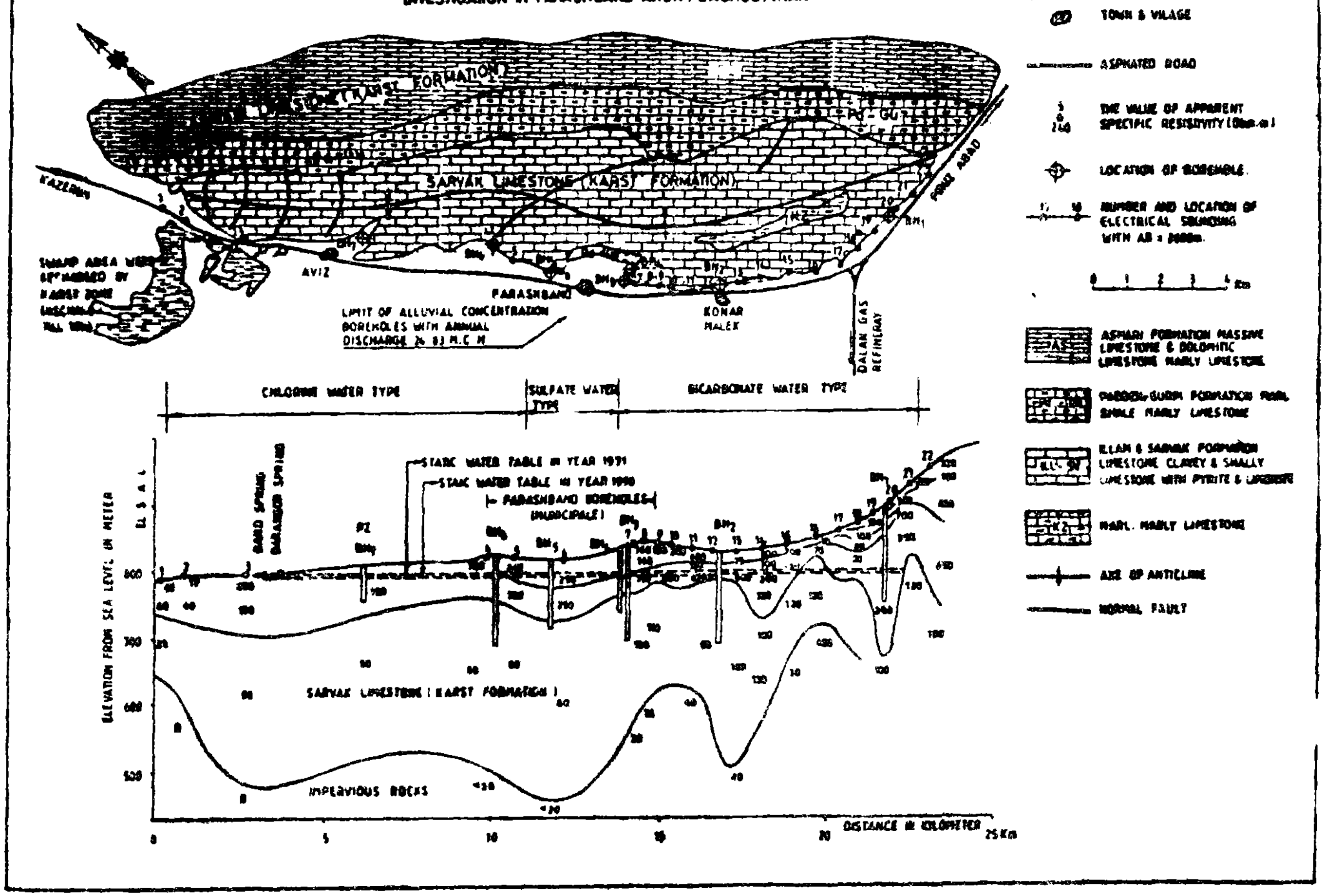
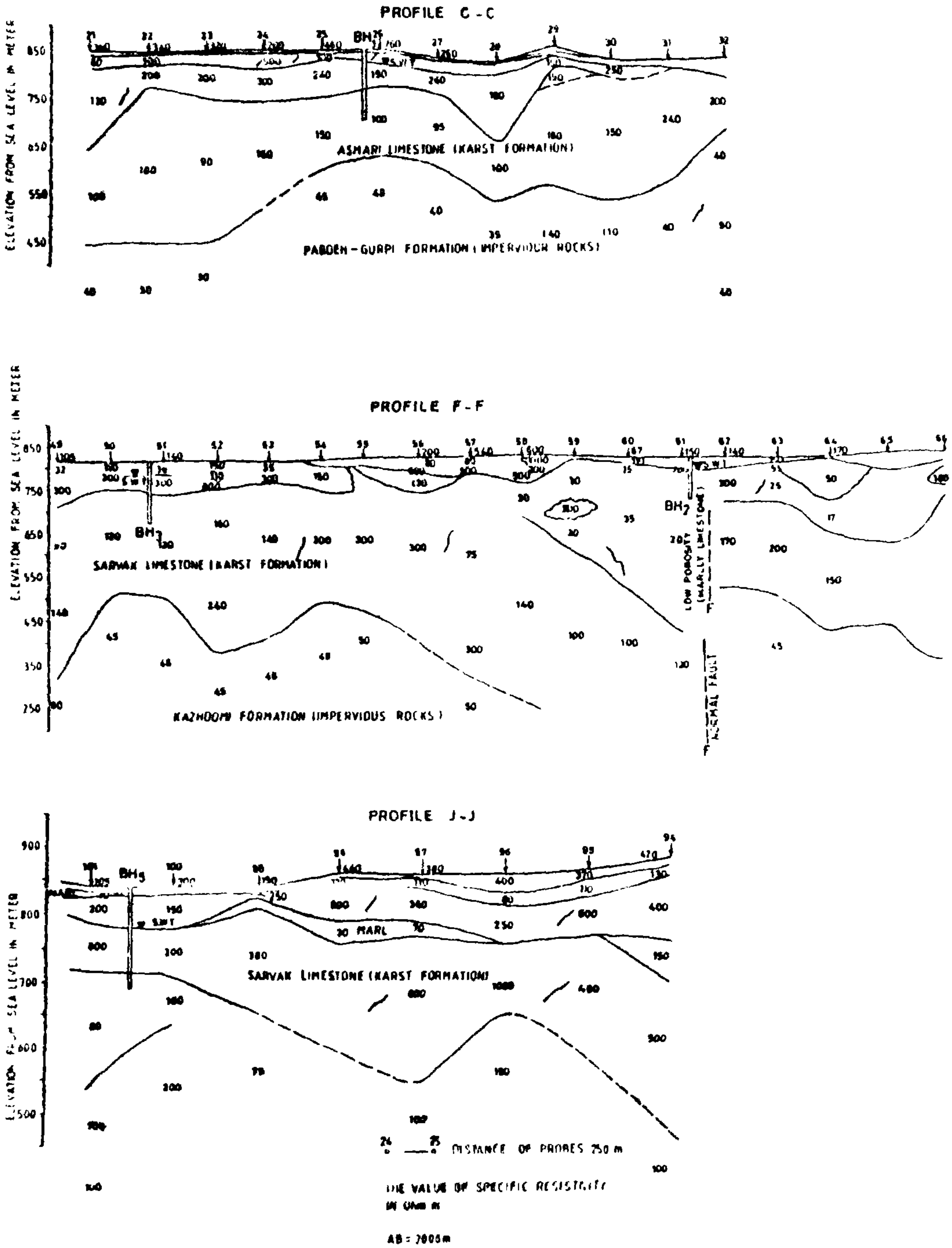


Fig:2 SCHEMATICAL PRESENTATION OF KARST TERRANE, BOREHOLES, & GEOELECTRICAL INVESTIGATION IN FARASHBAND AREA, ZAGROS, IRAN

Fig 3 RESULTS OF INVESTIGATION GEOELECTRICAL SOUNDINGS AND BOREHOLES ALONG THE KARST TERRANES IN FARSHBAND (KHORMAYEK) AREA, ZAGROS - IRAN



The important factors influencing the salinity are the rate of circulation and the area of contact between the water and the rocks as well as the quantity of salts available for dissolution with the carbonate fabric.

Massive limestone in Zagros of Iran contain mostly large fissures and channels and there are few narrow fissures. Water circulation is rapid and the area of contact with the water is small in relation to the volume of water circulating. This kind of karst formation are relatively pure and contain few soluble salts.

The predominant constituents are HCO_3^- and Ca^{++}, and there are relatively small amount of SO_4^{2-}, Cl^- or Na^+. The Mg^{++} content depends on the amount of Mg in the carbonate rocks.

Water resources are mostly in compact or massive limestone as Asmari (middle) and Sarvak (middle) formations in Zagros ranges with humid climate (with bicarbonate water type, electrical conductivity ranging about 300-500 mμ /cm). When the factors influencing the salinity by upper part of saturated massive limestone (Asmari aquifer) as marly limestone, marl, gypsum (upper Asmari, Gachsaran, Mishan & Agha Jari formations) and for Sarvak aquifer are surrounded by Pabdeh Gurpian IIlam formations in upper and lower part aquifer, the water quality has been changed by straight recharge of precipitation and runoff or passing the water through the above sediment till reached to the aquifer. In this case chemical analysis data indicate that the ranging of electrical conductivity is about 700-2000 mμ /cm when the limestone are porous or contain fine fissures. The water circulates slowly and the contact area between the water and the rocks is greater. Chlorides and sulfates can more readily be dissolved, especially from marly limestones, under certain conditions it may happen that the amount of sulfate & chlorine is more than the bicarbonate. Water from dolomitic limestone and dolomites has the same characteristics as water from limestone, but differs in it in ratio of magnesium to chlorine.

5.1 Evaporite & Salt Plug

Gypsum and anhydrite, or sulfate and salt-bearing rocks may have ground water passing through them. Because of the great solubility of these minerals, the ground water may contain large quantities of $CaSO_4$ and NaCl, even to the point of saturation.

The value of EC is 33000 mμ /cm in central parts of Farashband alluvial aquifer (evaporite zones) and the EC in Khormayek alluvial aquifer (influenced by salt plug) is about 27000 mμ /cm. The general water type in alluvial aquifers as $CaSO_4$, NaCl indicates the rapid change of quality in ground water. It is an important problem which shows that water balance should be under severe control. The EC range for karst aquifer (620-4000 mμ /cm) indicates that water quality in the area is very senstive for changing.

5.2 Argillaceous limestone in karst formations

Asmari and Sarvak formations in area under study have argillaceous limestone. Water in clay and shales may be more or less salty depending on the degree of leaching. Clay also absorbs some ions. Water in contact with argillaceous rocks, or in aquifers containing clay, may become charged with salts.

5.3 Changes in chemical composition

Dissolved salts in ground water may become concentrated by solution processes as the water circulates, or by evaporation where the water table is at shallow depth. Farashband evaporite zones (alluvial aquifer) in certral parts of plain with 23000 mg/l TDS and Khormayek alluvial aquifer influenced by salt plug with 19000 mg/l TDS are the typical cases for change of quality in aquifers under study.

5.4 Influence of Hydrogeological conditions

Further changes occur while the ground water is in transit the rocks, although these changes are far less intense. As the water commonly travels a long way and takes a long time to move through the system, there may be a considerable secondary concentration of constituents, particularly when the aquifer has not previously been strongly leached. Especially in confined ground water, circulating slowly through the rocks where there is little leaching. There may be general increase in the total amount of dissolved salts, with consequent changes in the chemical composition: HCO_3^- remains constant,SO4 and CL increase while the rSO_4^{2-}/rCl^- ratio remains the same. Once the total concentration of salts reaches a certain value.the rSO_4^{2-}/rCl^- ratio will diminish,with an accompanying increase in the rMg^{2+}/rCa^{2+} ratio.

Finally, the sequence becomes $rCl^- > rSO_4^{2-} > rHCO_3^-$ and $rNa^+ > rMg^{2+} > rCa^{2+}$ with the possibility, at the highest concentration, of the $(rCa^{2+}+rMg^{2+})/(rSO_4^{2-}+rHCO_3^-)$ ratio being greater than unit. This change can be followed by establishing isocones (lines of equal concentration of total salts), isochlors, and lines of equal value of rSO_4^{2-}/rCl^-, rMg^{2+}/rCa^{2+} etc. Only the isochlors can be used to evaluate the circulation of the water, since this is the only constituent which does not react appreciably with the rocks, that is in the strata above and may, for example, show a $HCO_3^--SO_4^{2-}$ sequence beneath a SO_4-Cl sequence. Karst water quality in area under study (Khormayek-20 km from south Farashband. Fig.1) in natural position, especially in winter time after heavy precipitation without any water withdrawl changes from bicarbonate to sulfate and chloride type as the depth increases.

After pumping of each borehole or all system (alluvial & karst aquifer), water type changes quickly to sulfate and chloride. The contents of TDS or EC will be increased rapidly. Tab.1 indicates the variation of quality in depth in ground water in karst area under study

6 CONCLUSION

1) Karst water developing in semi-arid climate should be under control in quality & quantity because these karst areas have low annual precipitation and so low recharge or dynamic reserves.

2) Karst water quality changes by natural conditions of geology, hydrogeological conditions, evaporatic sediments, salt plugs & ground water mismanagement.

3) Typical karst features as solutional cave, natural arch (Asmari, Sarvak massive limestone), few large & narrow fissures have been observed in semi-arid climate which are related to tectonic and paleogeography in the past.

4) Geoelectrical studies is very useful for locating borehole in karst formations & determining the base of karstification, the thickness of saturated zone and change of karst water quality.

5) Because of regional tectonic activities and karst processes, the capacity of boreholes in semi-arid climate can be the same as in humid climate (Tab.1).