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GROUNDWATER CHEMISTRY IN THE VICINITY OF THE OULED FARÈS AREA, NORTHERN MARGIN OF THE CHELIFF VALLEY (N ALGERIA)

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Abstract: Detailed geological and hydrogeological mapping has been carried out in the northern, marginal part of the Cheliff Valley (area of about 50 km^2). Three groundwater systems have been identified. All the three circulation systems are dominated by either brackish or saline waters (TDS 2-14 g/dm^3). In general increased TDS content is accompanied by changes in chemical composition from the SO_4 - Ca type through several multi-ion types to the Cl - Na one. Saturation index (SI) has been calculated for 23 samples in respect to various minerals. Waters from both the subsurface and shallow-circulation systems are close to equilibrium with both gypsum and calcium carbonates (aragonite and calcite) but tend to be supersaturated in respect to dolomite. Chemical composition of each groundwater system is critically influenced by mineralogy of rocks. It seems that an equilibration is quickly achieved between water and $CaSO_4$, and followed by a slow, gradual enrichment in other ions, caused by leaching of small amounts of NaCl and $MgSO_4$ from the gypsum beds.

Key words: groundwater chemistry, gypsum, water-rock interaction, Algeria.

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INTRODUCTION

The Ouled Farès area is situated within southern part of the Dahra Mts which delimit from the north the Cheliff Valley/Depression. Both morphological units are, simultaneously, the important tectonic ones. The Cheliff Valley is a deep graben formed over the subduction zone of the Tell Atlas which has been thrusted under the Dahra Mts – one of the orogenic zones of the Northwestern Africa (Biju-Duval & Montadert, 1977).

The Dahra Mts have been distinguished by Panteleev & Goloubev (1978) as one of hydrogeological subregions of the Mediterranean Coast. In their short report these authors conclude that hydrogeology of the Dahra Mts is poorly known. Therefore, any field study and hydrogeological data seem to be worth reporting.

The studied area covers about 50 km^2 and is morphologically diversified. In common opinion of local population an insufficient water quality is the main factor which precludes development of local agriculture as water in springs is mostly bitter. It is reflected in local geographical names – one of the largest valleys (Fig. 1) is called "el Morra" which means "bitter" in Algerian Arabic.

The studies on hydrogeology and quality of groundwater have been based on the geological mapping of the Ouled Farès area, basic hydrogeological observations and single sampling of waters for chemical analyses. Analytical work has been carried out by Mrs A. Adamczyk in the Institute of Hydrogeology and Engineering Geology, University of Mining and Metallurgy in Kraków (Poland).

GENERAL GEOLOGY

The Ouled Farès area is a part of the northern margin of the Cheliff Graben filled with Tertiary and Quaternary sediments, over 3000 meters thick (Ousmer *et al.*, 1983). The oldest rocks reported from outcrops (Fig. 1) are dark clays with thin intercalations of limestones and dolomites, all belonging to the Upper Tortonian (Messinian, according to Meghraoui, 1982). These are unconformably covered by Sarmatian sandstones and gypsums (Sahelian, according to Dalloni, 1955). In the western part of the studied area gypsum deposits are locally underlain by thin-layered calcareous marls.

Regression of Lower Pliocene sea from the Ouled Farès area is documented by alternating marine and continental sediments, mostly clays and poorly cemented sandstones with rare, thin limestone interlayers. Upper Pliocene sequence includes red, continental deposits – chiefly poorly cemented sandstones with conglomerate intercalations. Locally, in the upper part of Upper Pliocene series thin layers of caliche occur – a sediment widespread in northern Algeria (Horta, 1979).

Both Uppermost Pliocene and Lower Quaternary sequences overlaying sediments of different age. In valleys these are light-coloured gravels and sands whereas on valley slopes and plains weathering crusts are developed. A small sheet of Pliocene-Quaternary gravels (fragments of old river terrace) has been found to cover gypsum beds which built up the highest hill in the studied area (500 meters a.s.l., Fig. 1). Upper Quaternary alluvial deposits – brownish-red, sandy silts with intercalations of sands and gravels fill a wide morphological depression (100 - 150 meters a.s.l.) which partly belongs to the south-western edge of the studied area. Recent alluvial gravels, sands and silts fill Wadi Quahrane and a small morphological depression south of Sidi Abdallah village (Figs 1, 2).

In the Cheliff area the E-W and SE-NW structural trends predominate (El-Foul, 1984). In Ouled Farès region typical are SW-NE directions which

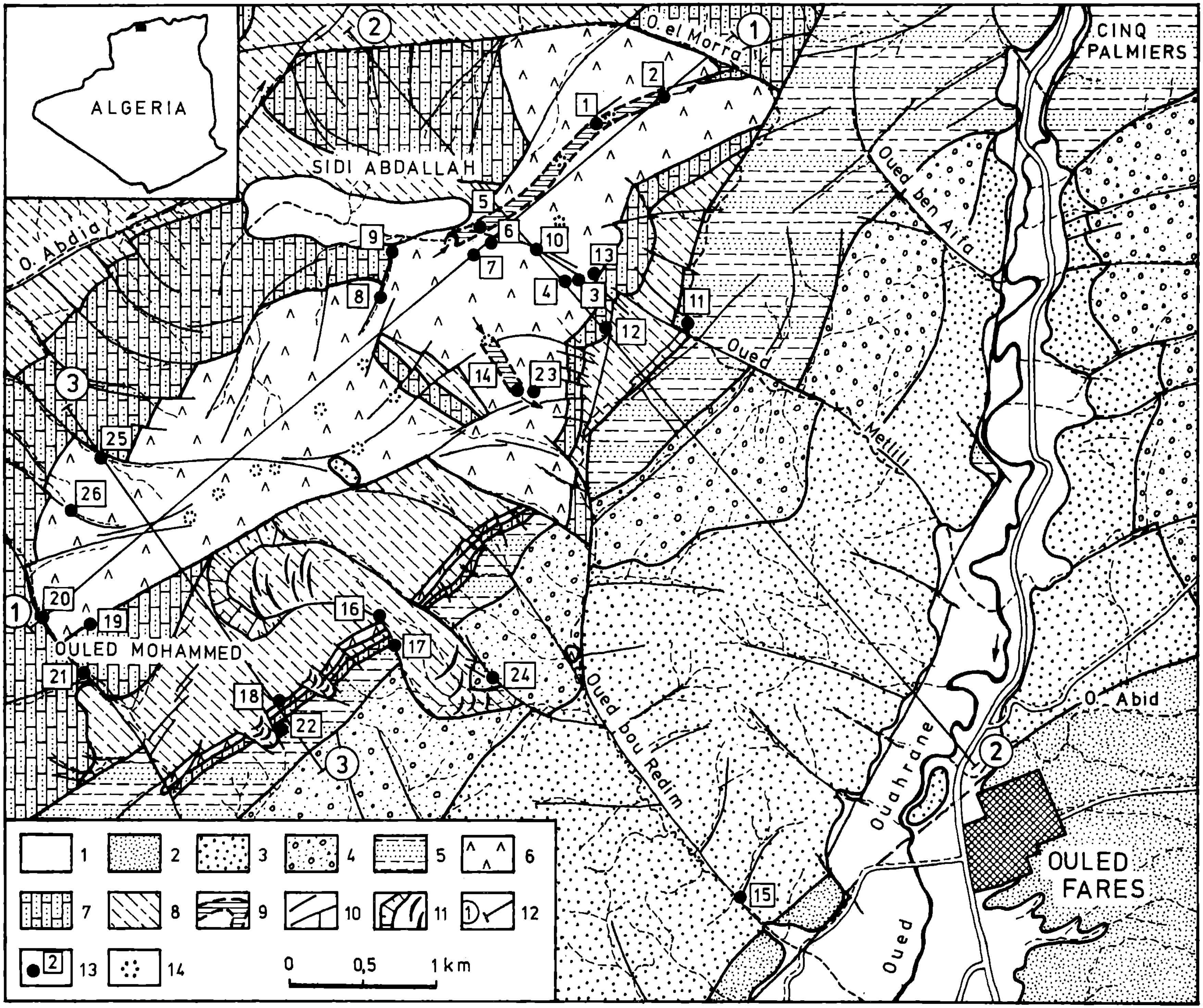

Fig. 1 Geological map of the Ouled Farès area. *1* – recent alluvia, *2* – older Quaternary alluvia, *3* – the oldest Quaternary and Uppermost Pliocene alluvia and other continental sediments, *4* – Upper Pliocene, continental clastic sediments, *5* – Lower Pliocene, continental-marine shallow clastic sediments, *6* – Upper Miocene, Sarmatian (Sahelian), gypsums, *7* – Upper Miocene, Sarmatian (Sahelian), sandstones, *8* – Upper Miocene, Tortonian, clays, *9* – generalized plan of cave galleries, *10* – linear discontinuities, *11* – landslides, *12* – cross-sections, *13* – sampling sites, *14* – sinkholes

reflect strikes of frame dislocations of the Cheliff Graben.

Two principal tectonic units can be distinguished within Ouled Farès area (Figs 1, 2):

- Quaternary-Pliocene system of folds and faults,
- Miocene system of folds and faults.

One of the most important tectonic structures in the investigated area is the Ouled Farès Fault along which the Wadi Quahrane is developed north of Ouled Farès village (Figs 1, 2). This transcurrent dislocation is still active and shows average annual horizontal displacement of about 0.12 mm (El-Foul, 1984). The accompanying echelon fault system, NW-SE in strike controls the development of local valleys (e.g., Wadi bou Redim, Wadi Metlili, Wadi ben Aïfa).

The main, SW-NE tectonic trend is accompained by parallel fold systems of the Quaternary-Pliocene structural stage. Several units have been distinguished: Wadi Ouahrane flexure, Wadi bou Redim syncline (which contains Upper Pliocene and Quaternary sediments in the core), Cinq Palmiers anticline and flexure (Figs 1, 2).

Structural pattern of the Miocene fold and fault systems is complicated. Rigid but fragile gypsum beds and sandstones rest unconformably upon strongly folded, plastic Upper Tortonian clays. During the development of compressional faults, Tortonian clays were emplaced within tectonic blocks, then folded and displaced along the fault planes whereas the overlying sandstones and gypsum beds were fractured and separated into fragments (blocks, plates) of various size and spatial orientation. In the vicinity of Ouled Mohammed (south-western part of the studied area) a tabular body composed of sandstones and gypsum has been disrupted. The resulting fragments which have survived in its southern part were separated into blocks and emplaced into the Tortonian clay beds (Figs 1, 2,).

CONDITIONS OF GROUNDWATER CIRCULATION

The studied area is a part of the Dahran Mts which have been distinguished as one of hydrogeological regions of the Mediterranean Coast by Panteleev & Goloubev (1978). Climate of the Cheliff Valley is continental. Average annual precipitation falls into the range of 300-400 mm (Rosfelder, 1955, Tab 1). Summers are hot and dry, with high number of days of a temperature close to or exceeding 40°C. Winters are chilly and humid.

In the Ouled Farès area three hydrogeological units can be distinguished, varying in character of groundwater circulation (Fig. 1):

- Wadi Ouahrane unit (including Ouled Farès depression),
- Cinq Palmiers unit (composed of Quaternary and Pliocene sediments),
- Ouled Mohammed - Sidi Abdallach unit (composed of Miocene sediments),

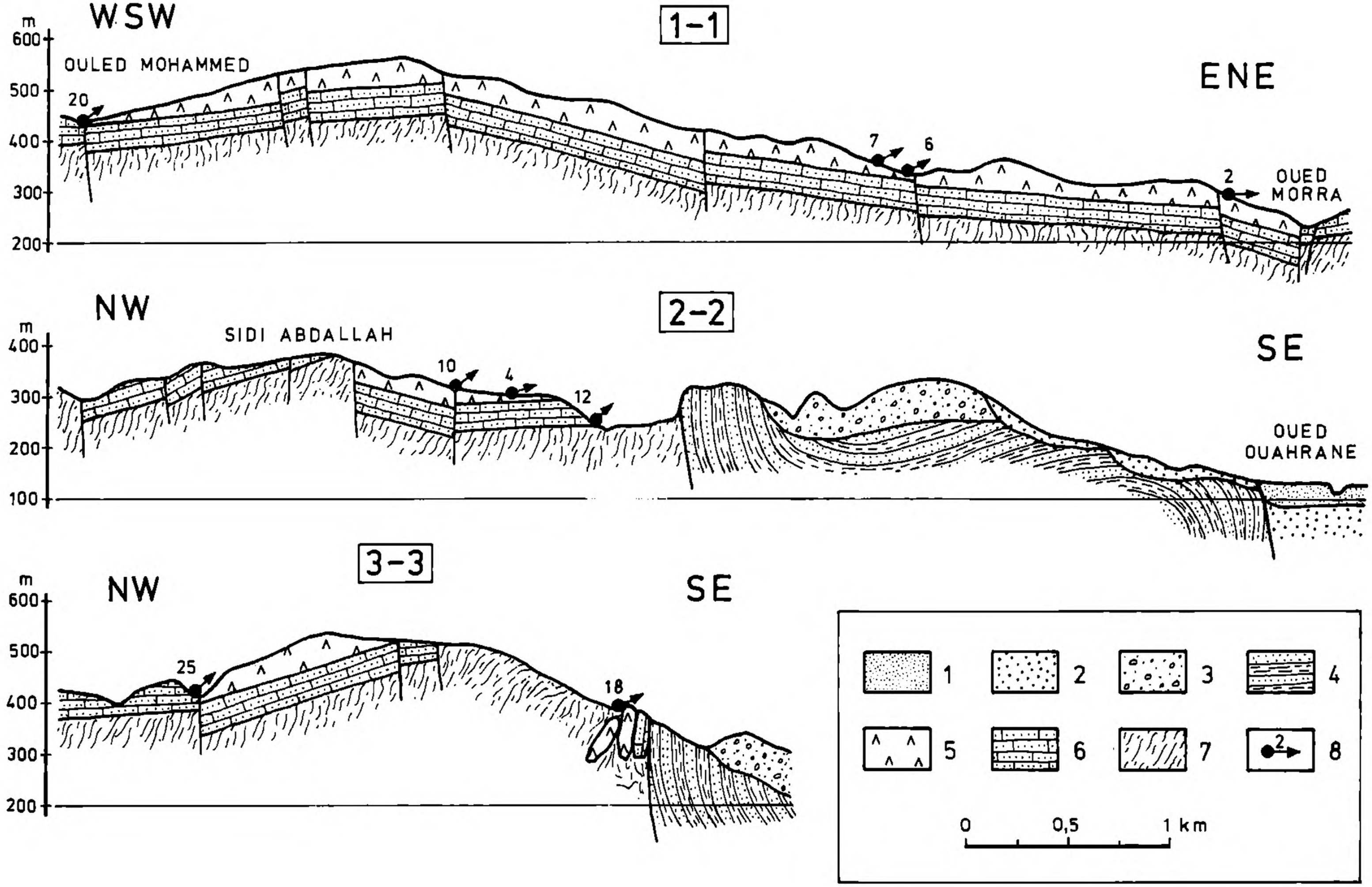

Fig. 2 Geological cross-sections. *1* – recent alluvias, *2* – Quaternary - Pliocene alluvia and other continental sediments, *3* – Upper Pliocene, continental sediments, *4* – Lower Pliocene, continental-marine shallow clastic sediments, *5* – Upper Miocene, Sarmatian, gypsums, *6* – Upper Miocene, Sarmatian, sandstones, *7* – Upper Miocene, Tortonian, clays, *8* – springs

Both Wadi Ouahrane and Ouled Farès depression are filled with Quaternary, mostly recent or fossil alluvial sediments. Water-bearing strata are sands and gravels, partly also sandy silts, i.e. aquifers of porous character. The Cinq Palmiers unit consists of folded Quaternary and Pliocene beds. The Pliocene water-bearing sediments are sands and poorely cemented sandstones intercalated by clay layers. It is, therefore, a vertically inhomogenous water aquifer of porous character. The Quaternary suite includes mainly residual deposits of the weathering crusts accompanied by minor fossil alluvia. The Cinq Palmiers unit is in hydraulic contact with the adjacent Wadi Quahrane one (Figs 1, 2).

The Ouled Mohammed - Sidi Abdallach unit includes Sarmatian gypsum deposits and sandstones unconformably resting upon the thick Tortonian clays. Gypsum beds host a system of karst fissures and cavities as well as two caves illustrated in Fig. 1 and Pl. I. Porous sandstones which underlie gypsum series are also fissured. Therefore, Sarmatian (Sahelian) sediments belong to the mixed, karstic-fissured (gypsum) and porous-fissured (sandstones) aquifer type. Gypsum and sandstone layers built up the highest hills in the studied area (Fig. 2). Consequently there is a natural trend to a gravitational migration of waters into the valleys. The underlying Tortonian clays facilitate the surficial discharge of groundwater from gypsum beds and sandstones. In fact, the Ouled Mohammed - Sidi Abdallach unit is abundant in springs in comparison with adjacent areas (Fig. 1). Its water-bearing beds are in lateral contacts with those of the Cinq Palmiers one, through short segments of dislocations. South of Sidi Abdallach, a small morphological depression is filled with Quaternary alluvia and deluvia. However, insignificant thicknesses of these sediments diminish their role as groundwater reservoirs.

Three systems of groundwater circulation can be distinguished: subsurficial, shallow and deep. Rapid subsurficial circulation proceeds through large karst cavities and caves cut in gypsum beds, close to the surface as well as through suffosion channels developed within Quaternary slope sediments. The length of subsurficial circulation channels varies from some tens of meters (suffosional channels) to several kilometers (caves and cavities in gypsum). An example is an underground stream flowing through a 500-meters-long gypsum cave. Water flows only during rain season and No. 14 spring which drains this cave (see Figs 1, 3), disappearing several to dozen days after rainfall. Ponor (Pl. I) is located some tens of meters upslope from the cave entrance, in a sinkhole which forms a local surficial catchment area. The shallow circulation systems include pore spaces within clastic rocks as well as fissures and karst cavities (Pl. I) at greater depths (see e.g., No. 3 and 4, Figs 1, 3; Pl. I). Combined systems have also been recognized. So e.g. No. 9 spring comes up from the Sarmatian (Sahelian) sandstones giving rise to a small, 600-meters-long stream. The stream runs into locally collapsed gypsum cave and, after about 2-kilometers-long subsurface flow, appears at the cave entrance as No. 2 spring (Figs 1, 3).

Deep circulation system is related to unrecognized Miocene/Pliocene base-

Table 1

Precipitations in the Chlef area

Month → Year	PRECIPITATIONS (mm)												Total (mm/yr)
	J	F	M	A	M	J	J	A	S	O	N	D	
1965	53.0	57.5	33.3	b.d.	b.d.	6.6	0	0	8.5	60.0	89.0	55.6	b.d.
1966	33.0	20.8	14.7	43.5	59.9	0.8	1.8	0	17.5	253.9	61.6	8.3	515.3
1967	27.0	47.5	10.1	111.0	5.9	11.7	0	0	0.2	36.7	87.7	110.7	448.5
1968	13.9	49.8	36.9	38.0	69.7	10.3	4.0	0.6	8.3	0	32.7	103.2	367.4
1969	69.0	20.9	71.7	38.4	59.3	71.8	15.7	0.4	4.2	94.9	119.8	b.d.	b.d
1970	95.5	4.2	34.7	22.4	19.7	2.6	0.4	0	0	14.2	3.0	64.3	261.0
1971	113.4	6.0	38.7	54.8	2.9	0	0	0	0	0	b.d.	b.d.	b.d.
1973	b.d.	b.d.	b.d.	37.5	0	14.8	0	0.8	29.7	8.8	10.3	82.0	b.d.
1974	5.5	105.5	56.3	138.2	0.1	8.6	0	1.2	5.4	86.0	36.9	7.2	450.9
1975	11.8	44.7	115.5	75.0	41.5	9.9	0	13.3	14.6	1.8	82.6	53.4	464.1
1976	41.5	131.0	10.3	28.5	46.7	18.2	30.6	2.3	47.3	121.4	34.2	58.8	570.8
1977	48.6	12.3	9.5	18.8	80.4	21.0	2.5	0	1.0	20.5	60.6	43.2	318.4
1978	70.0	18.6	33.0	76.9	30.0	0	0	0	0	132.0	37.8	38.9	437.2
1979	54.0	141.3	75.0	33.2	16.9	14.3	0	0	41.0	67.2	32.8	38.7	514.4
1980	48.0	16.2	54.5	29.8	29.0	1.3	0	0.3	6.3	b.d.	20.9	128.6	b.d.
1981	31.5	56.0	31.0	71.7	7.9	0.8	0	0.6	1.5	10.0	0	45.3	256.3
1982	44.8	76.8	21.6	20.5	30.5	0	0	1.1	11.2	56.6	172.3	78.0	513.3
1983	0	79.0	31.3	6.5	0	0	7.5	26.3	0	2.3	62.2	47.1	262.2
Average	44.8	52.2	39.9	49.7	29.4	10.7	3.5	2.6	10.9	56.8	55.6	60.2	413.8

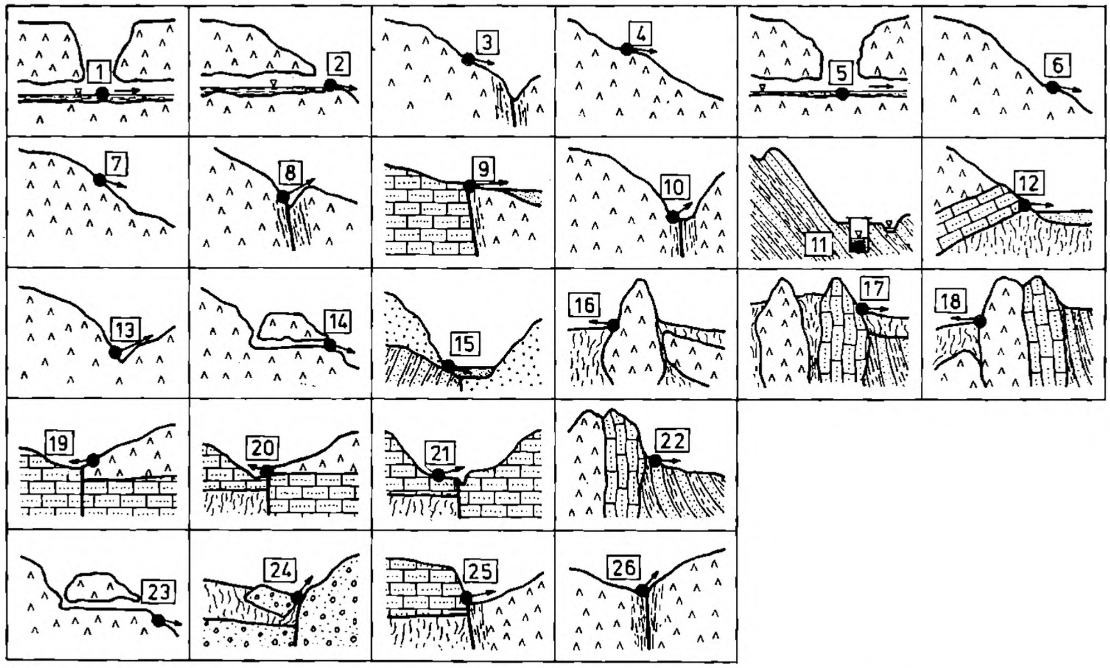

Fig. 3 Morphologic-geological sketches of sampling sites; explanations as in Fig. 2

ment. Its recharge areas are probably distant and located north of the studied area, in the higher parts of the Dahra Mts. Some of ascending springs which accompany fault zones belong presumably to this system (e.g., No. 10 spring, Figs 1, 3, Pl. II: 2). Typical features of such springs are: small but stable discharge and detectable salty taste. Moreover, hydrogen sulphide was found to release from No. 10 spring.

Ouled Farès area is seismically active and earthquakes influence the conditions of deep circulation system. Strong earthquake which affected Chlef area on September 10th, 1980 caused, among other effects the vanishing of numerous springs (including the karst ones) and the appearance of new ones in previously dry areas (Issaadi *et al.*, 1981).

GENERAL CHARACTERISTICS OF CHEMICAL COMPOSITION OF GROUNDWATER

In order to characterize groundwater from Ouled Farès area 26 samples were collected, 23 of which originated from springs, two from sinkholes truncating the above mentioned 2-kilometers-long gypsum cave (Fig. 1) and one from the Wadi Metlili water well (Fig. 3). Discharges have been measured for both the springs and the underground cave flow and, for all the samples, conductivity and pH have been measured in the laboratory (Tab. 2). All the

Table 2

Chemical composition of water

No of sample	Date of sampling	Debit (dm^3/s)	pH	Conductivity in 250°C γ_{25} ($\frac{\mu S}{cm}$)	Total hardness TO ($mval/dm^3$)	Concentration of ions (mg/dm^3)						Total dissolved solids TDS (mg/dm^3)
						Ca^{2+}	Na^{2+}	$(Na+K)^+$	HCO_3^-	SO_4^{-2}	Cl^-	
1	27.02.1986	9.5	7.67	3200	41.16	628.5	119.2	97.0	167.7	1640.0	300.0	2952.4
2	27.02.1986	10.0	7.68	3400	40.18	627.6	107.4	243.7	122.0	1949.2	289.7	3339.6
3	27.02.1986	1.5	7.86	2600	32.34	598.9	29.9	22.3	134.2	1304.2	139.7	2229.2
4	27.02.1986	3.0	7.86	2600	30.38	608.8	0.1	77.9	112.2	1334.9	146.4	2280.3
5	28.02.1986	4.5	8.08	3400	35.28	648.0	35.8	47.8	128.1	1285.6	299.9	2445.2
6	28.02.1986	0.02	8.45	3900	35.28	608.8	59.7	80.9	122.0	1193.4	423.3	2488.1
7	28.02.1986	0.05	8.06	4200	29.40	549.8	23.8	434.2	122.0	1594.3	463.4	3187.5
8	28.02.1986	1.2	7.62	2500	28.42	628.4	35.7	203.5	167.1	1800.0	103.1	2937.8
9	28.02.1986	2.3	7.49	2700	31.40	608.8	12.4	225.6	122.0	1059.4	607.7	2635.9
10	28.02.1986	0.07	7.45	21000	17.64	67.7	173.4	5028.2	750.3	428.5	7625.3	14073.3
11	06.03.1986	-	7.34	600	n.o.	n.o.	n.o.	n.o	n.o.	65.0	n.o.	n.o.
12	06.03.1986	0.25	7.81	3500	36.26	510.6	131.0	702.8	128.1	2714.1	289.9	4476.5
13	06.03.1986	0.05	7.48	2700	35.28	481.1	137.0	64.1	134.2	1527.8	143.3	2487.5
14	06.03.1986	0.8	7.75	2600	34.30	530.2	95.4	332.3	103.7	2098.6	118.0	3278.2
15	06.03.1986	0.03	7.51	6200	29.40	196.3	239.5	901.6	231.8	580.6	1872.2	4024.0
16	07.03.1986	0.08	7.29	3400	34.30	137.4	333.7	993.6	158.6	3216.4	280.1	5119.8
17	07.03.1986	0.2	7.99	4300	41.20	569.5	155.5	471.5	115.9	1857.0	748.9	3918.3
18	07.03.1986	1.1	8.21	10500	73.50	510.6	584.0	1645.4	209.8	3939.8	2110.5	9000.1
19	20.03.1986	0.03	8.14	11000	70.56	451.6	584.0	1787.5	237.9	3566.6	2485.0	9112.6
20	20.03.1986	0.4	7.59	2400	18.62	490.9	71.3	7.1	103.7	1133.8	189.7	1996.5
21	20.03.1986	0.025	8.04	5900	32.34	373.1	166.9	880.2	173.2	1640.4	1191.4	4425.2
22	20.03.1986	0.02	7.36	3950	42.14	687.3	95.4	357.1	170.8	1926.1	523.0	3759.7
23	27.03.1986	0.4	7.79	2700	37.24	608.8	83.5	136.3	97.6	1778.9	159.9	2865.0
24	04.04.1986	0.1	7.79	12500	80.36	667.7	572.1	1321.3	201.3	1893.9	3370.8	8027.1
25	07.04.1986	0.09	6.91	6400	69.60	530.2	524.7	39.5	353.8	2003.5	843.2	4294.9
26	07.04.1986	0.6	7.52	2500	25.20	628.4	71.1	36.3	128.1	1625.3	99.9	2589.1

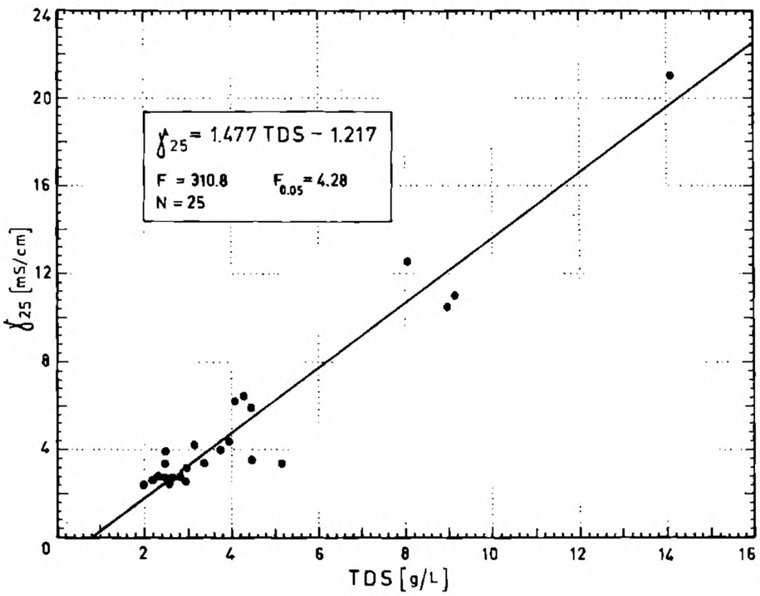

Fig. 4 Conductivity at 25°C (γ_{25}) versus TDS

samples have been analysed for Ca^{+2}, Mg^{+2}, (Na^{+}+ K^{+}), HCO_3^-, SO_4^{-2} and Cl^- ions except that from the Wadi Metlili well for which only sulphate ion has been determined. The results of chemical analyses are listed in Table 2. The discharges of springs were insignificant, usually below 1 dm^3/s. Only few of them showed higher values (from several to 10 dm^3/s) (Tab. 2).

The conductivity of the samples measured at 25°C vary from 600 (No. 11 spring) to 21000 μScm^{-1} (No. 10 spring). Specifically, 22 samples (84%) showed conductivity below 6400 μScm^{-1} and the remaining four gave the results over 10500 μScm^{-1}. The conductivity of water is closely related to the content of total dissolved solids (TDS) (Fig. 4). The TDS (measured as sum of ions) change from 2.0 to 14.1 g/dm^3. The pH for most of the analysed samples falls into the range 6.9 - 8.4, i.e., most of the waters studied are weekly alkaline.

The waters have been classified according to the system after Altowski-Szwiec, modified by Kleczkowski (1979). Only the ions which showed concentrations over 20% mval/dm^3 were considered. Although samples were collected mostly from waters coming from or flowing through gypsum beds (16 samples), only 5 of them showed SO_4-Ca composition (Tab. 3, Fig. 5). Commonly, these two ions were accompanied by Mg^{+2} or Na^{+} or both. In some samples, showing the TDS below 5 g/dm^3, increased contents of Cl^- were detected. Concentrations of this ion were found to increase with the increasing TDS and above 14 g/dm^3 the water type was changing into the Cl-Na one (sample No. 10, Tab. 3, Pl. II. 2). It should be emphasized that both the TDS and chemical composition of groundwater from gypsum beds of Ouled Farès area are different from those coming from gypsum beds in Sorbas

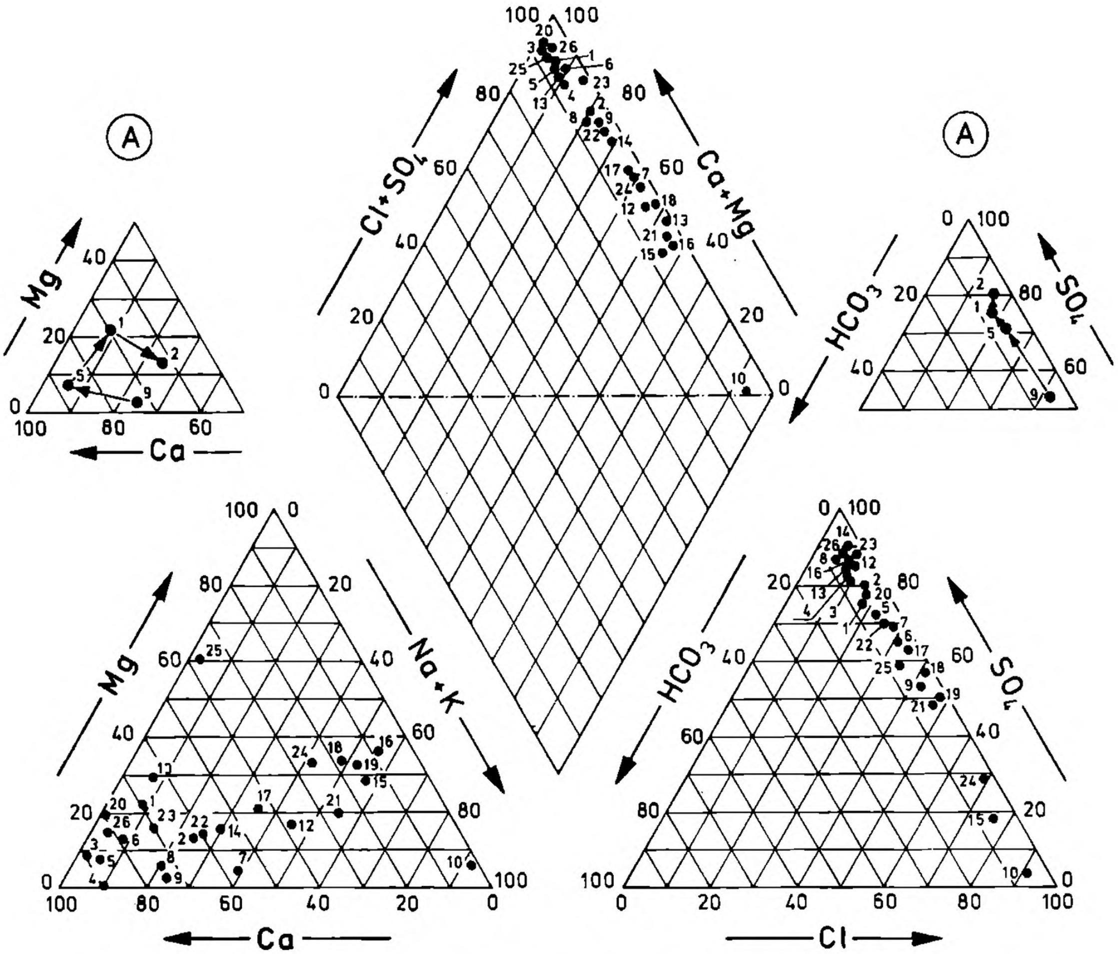

Fig. 5 Triangular diagram for groundwaters from Ouled Farès area. A – fragments of diagrams illustrating trends in ionic proportions along the cave flow, south from Sidi Abdallach (Fig. 1). Numbers of points correspond to sample numbers

(Almeria, Spain) – an area climatically identical with the Ouled Farès (Pulido-Bosch, 1982, 1986). Waters from Spain represent mostly the SO_4-Ca type, although this author found also increased concentrations of Mg^{+2}, Na^+ and Cl^- and related their presence to the inflow of brines from rocks adjacent to gypsum beds.

FACTORS CONTROLLING CHEMICAL COMPOSITION OF GROUNDWATER

ANALYSIS OF HYDROCHEMICAL DATA

In order to analyse conditions which affected the chemistry of Ouled Farès groundwater, changes in concentrations of main ions and in water hardness

Table 3

Hydrochemical indices and water types from the Ouled Farès area

No of sample	Total dissolved solids TDS (mg/dm^3)	SAR = $\frac{\text{mmol Na}}{\text{mmol (Ca + Mg)}}$	$\frac{\text{mmol Na}}{\text{mmol Cl}}$	$\frac{\text{½ mmol SO}_4}{\text{mmol Cl}} \times 100$	$\frac{\text{mmol Cl}}{\text{mmol HCO}_3}$	$\frac{\text{mmol (SO}_4 + \text{HCO}_3)}{\text{mmol Cl}}$	Type of water
1	2952.4	0.930	0.499	403.9	3.076	4.364	SO_4 – Ca – Mg
2	3339.6	2.365	1.297	497.1	4.085	5.215	SO_4 –Ca – Na
3	2229.2	0.241	0.246	689.6	1.791	7.454	SO_4 – Ca
4	2280.3	0.870	0.821	673.4	2.245	7.179	SO_4 – Ca
5	2445.2	0.495	0.246	316.8	4.029	3.416	SO_4 – Cl – Ca
6	2488.1	0.838	0.296	209.2	5.950	2.261	SO_4 – Cl – Ca
7	3187.5	4.924	1.445	254.1	6.535	2.694	SO_4 – Cl – Ca – Na
8	2937.8	2.348	3.041	1288.7	1.062	13.828	SO_4 – Ca – Na
9	2635.9	2.476	0.572	128.8	8.570	1.404	SO_4 – Cl – Ca – Na
10	14073.3	73.613	1.017	4.15	17.483	0.0987	Cl – Na
12	4476.5	7.177	3.736	691.2	3.895	7.169	SO_4 – Na – Ca
13	2487.5	0.664	0.691	787.9	1.836	8.423	SO_4 – Ca – Mg
14	3278.2	3.489	4.339	1312.9	1.956	13.640	SO_4 – Ca – Na
15	4024.0	10.224	0.742	22.9	13.895	0.301	Cl – Na – Mg
16	5119.8	10.432	5.468	848.1	3.038	8.810	SO_4 – Na – Mg
17	3918.3	4.517	0.971	183.1	11.116	1.921	SO_4 – Cl – Ca – Na – Mg
18	9000.1	11.801	1.202	137.9	17.302	1.437	SO_4 – Cl – Na – Mg
19	9112.6	13.085	1.109	106.0	17.969	1.116	SO_4 – Cl – Na – Mg
20	1996.5	0.102	0.058	441.5	3.147	4.733	SO_4 – Ca
21	4425.2	9.517	1.139	101.7	11.831	1.101	SO_4 – Cl – Na – Ca
22	3759.7	3.383	1.053	272.0	5.268	2.910	SO_4 – Cl – Ca – Na
23	2865.0	1.374	1.315	821.7	2.819	8.572	SO_4 – Ca
24	8027.1	9.063	0.604	41.5	28.806	0.450	Cl – SO_4 – Na – Mg – Ca
25	4294.9	0.292	0.072	175.5	4.100	1.999	SO_4 – Cl – Mg – Ca
26	2589.1	0.442	0.560	1200.7	1.343	12.752	SO_4 – Ca

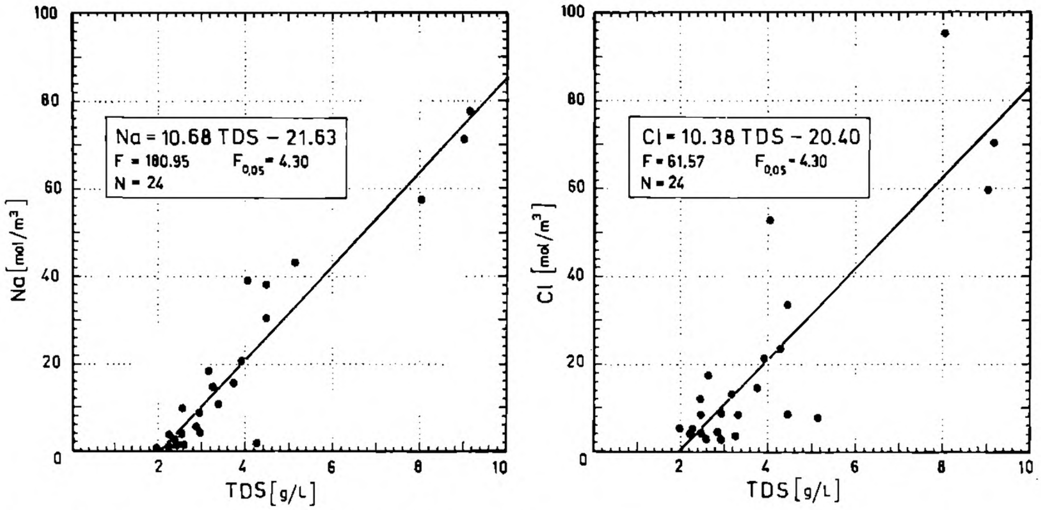

Fig. 6 Concentration of Na$^+$ and Cl$^-$ versus TDS

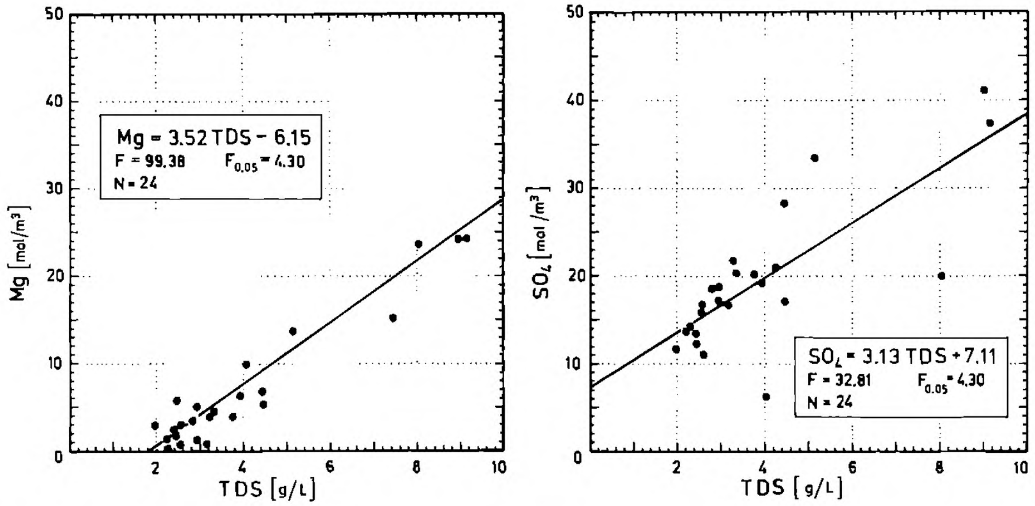

Fig. 7 Concentrations of Mg^{+2} and SO$_4^{-2}$ versus TDS

were plotted against increasing TDS (Figs 6 - 9). Moreover, equilibria have been calculated between waters and typical rock-forming minerals from the reservoir rocks. Calculations have been made for the samples representing subsurficial and shallow circulation systems. The sample from No. 10 spring (i.e., belonging to deep system) has been excluded.

The equilibria were calculated using the WATEQ programme (Plummer *et al.*, 1976) modified for IBM PC (Bull *et al.*, 1987). Saturation index (SI) has been applied as a measure of equilibrium, according to the formula:

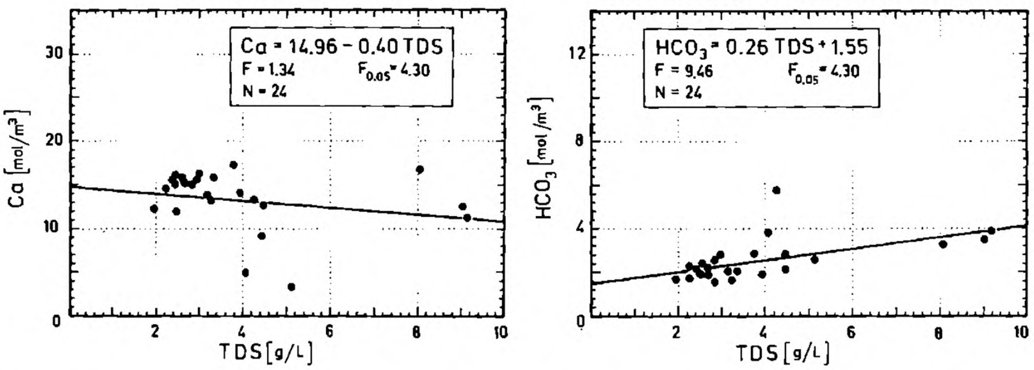

Fig. 8 Concentrations of Ca^{+2} and HCO_3^- versus TDS

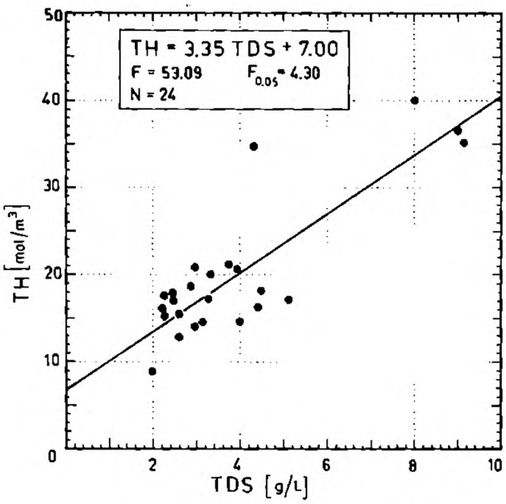

Fig. 9 Total hardness TH versus TDS

$$SI = \log \frac{IAP}{KT}$$

where:

IAP – Ion Activity Product for ions forming minerals poorly soluble in given water solution, calculated according to the law of mass action for the given reaction,

KT - equilibrium constant for a given reaction.

According to Deutsch *et al.*, (1982), water solution is in equilibrium with a specific mineral if the SI values fall into the range 0±5% logKT. For SI > 5% logKT solution is supersaturated and for SI < -5% logKT – it is undersatu-

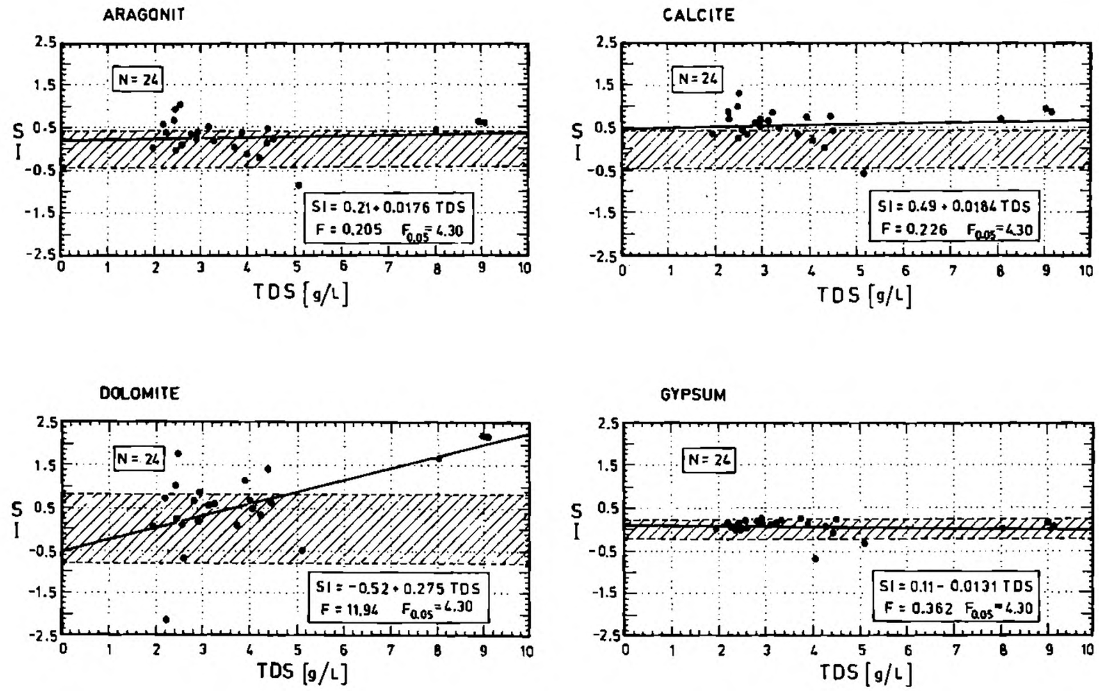

Fig. 10 Saturation index SI of selected minerals versus TDS

rated in relation to a given mineral (Fig. 10).

Statistics of the relationships between concentrations of main ions and increasing mineralization (TDS) have been estimated by means of the F test (see Davis, 1973) (Figs 6 - 8). Correlations have been taken into account if the F values calculated for trend lines exceeded F critical values (at $\alpha = 0.05$).

INTERPRETATION

The analysis of chemical data revealed characteristic changes in chemical composition of waters plotted against increasing TDS. The concentrations of Cl^-, SO_4^{-2}, Na^+ and Mg^{+2} were found to increase (Figs 6, 7). Statistically insignificant drop in Ca^{+2} content and minor decrease in HCO_3^- one (Fig. 8) was observed.

Increase of Cl^- and Na^+ concentrations begins at the TDS about 2 g/dm^3 (Fig. 6) proceeds in equivalent proportions:

$$\frac{\mathrm{molNa^+}}{\mathrm{molCl^-}} = \frac{10.68}{10.38} = 1.03$$

Similar equivalent dependance is valid for SO_4^{-2}, and Mg^{+2} (Fig. 7):

$$\frac{\mathrm{molMg}^{+2}}{\mathrm{molSO}_4^{-2}} = \frac{3.52}{3.13} = 1.12$$

Simultaneously, water solutions are in equilibrium with gypsum and tend to be supersaturated in relation to dolomite and calcite (Fig. 10). The most probable explanation of these relationships seems to be the leaching of gypsum rocks. Waters circulating within the gypsum aquifers usually show diversified ionic composition, similar to the studied springs (Posochov, 1985; Freeze & Cherry, 1979; Macioszczyk, 1987). Gypsum beds usually contain small inclusions of sodium and magnesium chlorides and sulphates which are more soluble than $CaSO_4$. Even after short leaching, circulating waters become saturated in relation to gypsum and reach mineralization (TDS) about 2 g/dm^3 and Ca-SO_4 composition. Longer filtration patches cause gradual increase in concentrations of sodium and magnesium chlorides and sulphates leached from the inclusions which rises their percentage in ionic composition, shifting it into the multi-ion type.

Concentrations of ions derived from minerals showing higher solubility higher than gypsum may result also from evaporation in subsurface zone. It seems, however, that this process is of rather limited importance and may occur in small aquifers of limited discharge and stagnant waters (static resources) hosted within isolated blocks of gypsum rocks. Water balance of such aquifers seems to facilitate the concentration of TDS.

Mineralized saline waters ascending from deeper parts of Tertiary suites do not contribute significantly to the composition of waters as a source of additional amounts of Cl^-, SO_4^{-2}, Na^+ and Mg^{+2} ions. Such a component, if exists, cannot originate from typical connate waters which show molNa/molCl < 1 and molNa/molMg > 4. Ionic proportions observed in the studied springs (molNa/molCl > 1 and molNa/molMg = 1.5) cannot result from direct mixing of Ca-SO_4-type, shallow-circulation waters with the sedimentary connate ones. Similarly, the cation exchange processes preferably shift the ionic proportions in an opposite direction. Finally, dedolomitization:

$$CaSO_{4(aq)} + CaMg(CO_3)_{2(rock)} \Rightarrow 2CaCO_{3(rock)} + MgSO_{4(aq)}$$

is rather a doubtful source of Mg sulphate since the studied waters tend to be supersaturated in relation to dolomite (Fig. 10).

We may conclude that chemical composition of waters from both the subsurface and shallow circulation systems is controlled mostly by leaching of minerals contained in gypsum beds. Seasonal, intense evaporation from the subsurface zone may contribute partly to the evolution of chemical composition of the TDS. Connate saline water originating from marine sediments seems to play but local role.

CONCLUSIONS

Chemical composition of groundwater from the Ouled Farès area has been studied in 26 samples originating from springs (23), shallow, cave flows (2) and one water well. The waters in question originated from gypsum beds and from underlying Upper Miocene (Sarmatian) sandstones.

Three systems of underground circulation were distinguished:

1. subsurficial, in gypsum karst cavities,
2. shallow, including pore spaces in sandstones and systems of fissures as well as of deeper karst cavities,
3. deep, connected with unrecognized basement.

All the systems are dominated by salty and saline (2 - 14 g/dm^3) waters. The increasing TDS contents are accompanied by transition of water types from SO_4-Ca through multi-ionic to Cl-Na ones.

Detailed studies of both subsurficial and shallow systems revealed that waters are close to equilibrium with both calcium sulphate and carbonate and tend to be supersaturated in relation to dolomite. The increase of TDS in the range 2 - 10 g/dm^3 is caused by the growth of NaCl (molNa/molCl = 1.03) and $MgSO_4$ (molMg/molSO_4 = 1.1) contents.

In the present authors opinion, chemical composition of groundwater in the studied area is influenced mainly by mineral composition of reservoir rocks which allows fast saturation in relation to gypsum and slow enrichment in other ions leached from NaCl and $MgSO_4$ included within gypsum beds.

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Streszczenie

CHEMIZM WÓD PODZIEMNYCH W OKOLICY OULED FARÈS W PÓŁNOCNYM OBRZEŻENIU KOTLINY CHELIFFU (PÓŁNOCNA ALGIERIA)

Jacek Motyka & Stanislaw Witczak

Rejon Ouled Farès znajduje się na południowym krańcu masywu gór Dahra, ograniczającego od północy Kotlinę Cheliffu. Zarówno góry Dahra jak i Kotlina Cheliffu są ważnymi jednostkami morfologicznymi i tektonicznymi śródziemnomorskiej strefy Afryki Północnej. Badany obszar ma powierzchnię ponad 50 km^2 (Fig.1) i charakteryzuje się skomplikowaną budową geologiczną. Jest on częścią północnego obrzeżenia zapadliska Cheliffu, wypełnionego osadami trzeciorzędowymi i czwartorzędowymi o miąższości ponad 3000 m. (Ousmer *et al.*, 1983).

W rejonie Ouled Farès dominują kierunki strukturalne SW-NE, towarzyszące głównym dyslokacjom, ograniczającym rów zapadliskowy Cheliffu. W badanym obszarze można wyróżnić dwie główne jednostki tektoniczne, którymi są zespoły fałdów i uskoków obejmujących osady czwartorzędowe i plioceńskie oraz fałdów i uskoków obejmujących osady mioceńskie (Fig. 1, 2). Tektonika zespołu fałdów i uskoków obejmujących utwory miocenu jest bardzo skomplikowana. Sztywne i kruche gipsy i piaskowce sarmatu leżą niezgodnie na silnie sfałdowanych, plastycznych iłach tortonu. Pod wpływem działania sił górotwórczych iły tortońskie ściskane w obrębie bloków tektonicznych, ograniczonych dyslokacjami kompresyjnymi uległy sfałdowaniu lub przesunięciu wzdłuż dyslokacji podczas gdy leżące na nich niezgodnie piaskowce i gipsy popękały dzieląc się na różnej wielkości płyty i bloki, ułożone pod rozmaitymi kątami (Fig. 3, Pl. I: 1).

Wyróżniono trzy systemy przepływu wód podziemnych (Fig. 3): 1) przypowierzchniowy w kanałach krasowych w gipsach miocenskich; 2) płytki, obejmujący przestrzeń porową w piaskowcach oraz systemy szczelin i głębiej rozwinięty system kanałów krasowych w gipsach; 3) głęboki, związany z nierozpoznanym podłożem. Badania składu chemicznego wykonano dla próbek wody pobranych jednorazowo z występujących na tym obszarze źródeł i strumieni podziemnych (25 próbek) oraz ze studni wykonanej w dolinie uedu (1 próbka).

Mineralizacja ogólna tych wód (TDS), określona jako suma jonów (Tab. 2) wynosiła od około 2 do 14.1 g/dm^3. Wielkość pH badanych próbek zmieniała się w granicach od około 6.9 do 8.4. Do określenia typu chemicznego wody stosowano klasyfikacje Altowskiego-Szwieca w modyfikacji Kleczkowskiego (1979). Mimo że próbki wody pobrano w przewadze z wód podziemnych wypływających z gipsów lub przepływających przez te skały (16 próbek), to tylko 5 z nich było typu SO_4-Ca (Tab. 3, Fig. 5). W pozostałych próbkach dosyć często, oprócz tych dwóch jonów stwierdzono podwyższoną zawartość jonu Mg lub Na względnie obu tych jonów razem.

W miarę rosnącej mineralizacji (TDS) następuje przyrost zawartości jonów Cl^-, SO^{-2}, Na^+ i Mg^{+2} (Fig. 6,7). Obserwuje się natomiast nieistotny statystycznie spadek zawartości jonu Ca^{+2} i mało istotny statystycznie wzrost HCO_3^-, czyli praktyczna stałość stężeń tych jonów w wodzie.

Stwierdzono, że wody przypowierzchniowe i płytkiego systemu przepływu znajdują się w stanie bliskim równowagi z gipsem i węglanami wapnia (aragonitem i kalcytem) oraz wykazują tendencje do przesycenia dolomitem (Fig. 10). Na skład chemiczny badanych wód decydujący wpływ ma skład mineralny skał, pozwalający na szybkie nasycenie wód względem gipsu i powolne wzbogacenie w inne jony przez ługowanie niewielkich wtrąceń chlorków sodu i siarczanów magnezu o czym świadczy fakt, że wzrost mineralizacji (TDS) w przedziale 2 do 10 g/dm^3 następuje dzięki przyrostowi zawartości NaCl i $MgSO_4$. Świadczy o tym stosunek nachylenia prostych (Fig. 6) Na = f(TDS) i Cl = f(TDS): (molNa/molCl = 10.68/10.38 = ok. 1) oraz prostych (Fig. 7) Mg = f(TDS) i SO_4 = f(TDS): (molMg/molSO_4 = ok. 1.1)

EXPLANATIONS OF PLATES

Plate I

1 — Sinkhole with ponor - upper part of a system of karst cavities and fissures terminated with a cavern and intermittent stream (spring No. 14). Cave entrance visible in the middle of the photo (dark spot) has the height of 1.5 m

2 — Spring No. 3

Plate II

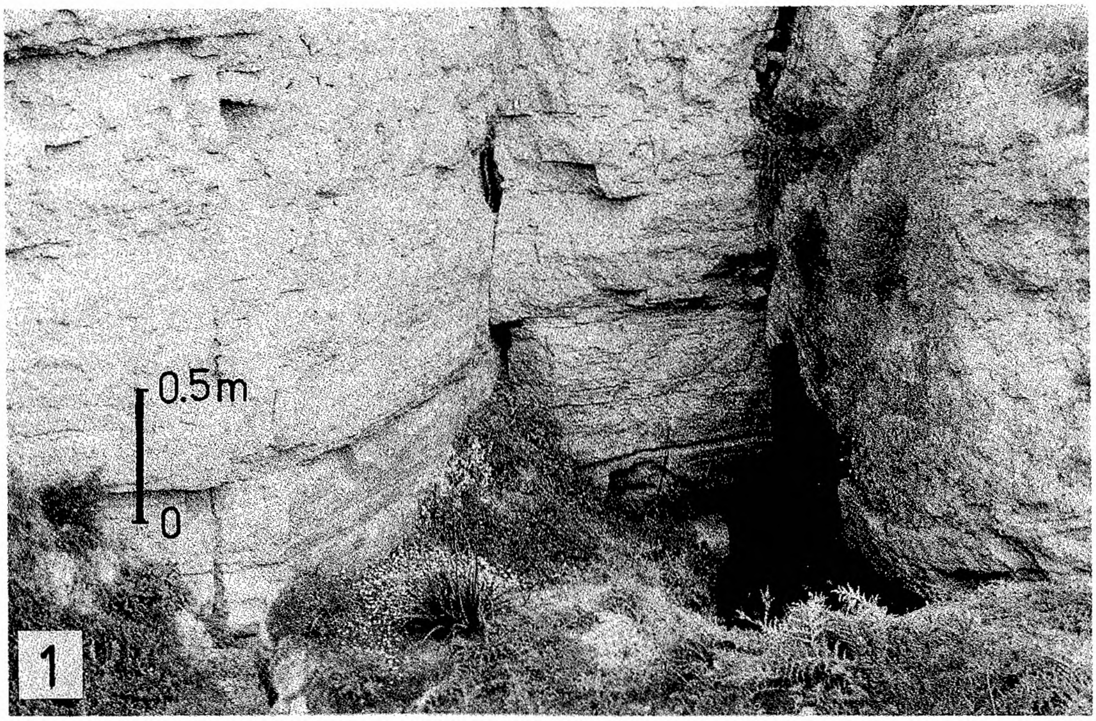
1 — The cave developed in fissure, fragment of entrance

2 — Spring No. 10 supplying mineralized, H_2S-rich water

1

2

1



2