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HYDROGEOLOGICAL INVESTIGATIONS ON THE AREA SOURROUNDING SANTA CESAREA TERME SPRINGS (SOUTHERN APULIA) (**)

SUMMARY

S. Cesarea Terme represent the sole example of sulphurous hot springs existing in the Salento Peninsula which, as a whole, constitutes a well defined hydrogeological unit having singular characteristics within the region.

Though, in the run of decades, the springs have been matter of study by various authors the geological and hydrogeological outlines of the area sourrounding S. Cesarea T., up till now, are known only in a general way.

This is precisely why this work wants to make up for such a lack by facing up the geolithological, tectonic and hydrogeological study of the area in question.

The first results of the just undertaken work, have shown that this area is particularly complex both as for its tectonics and its hydrogeology.

1. INDRODUCTION

Santa Cesarea Terme springs are the only example of sulphurous hot springs existing in the Salento Peninsula that, as a whole, makes up a well defined hydrogeological unit having singular characteristics within the region.

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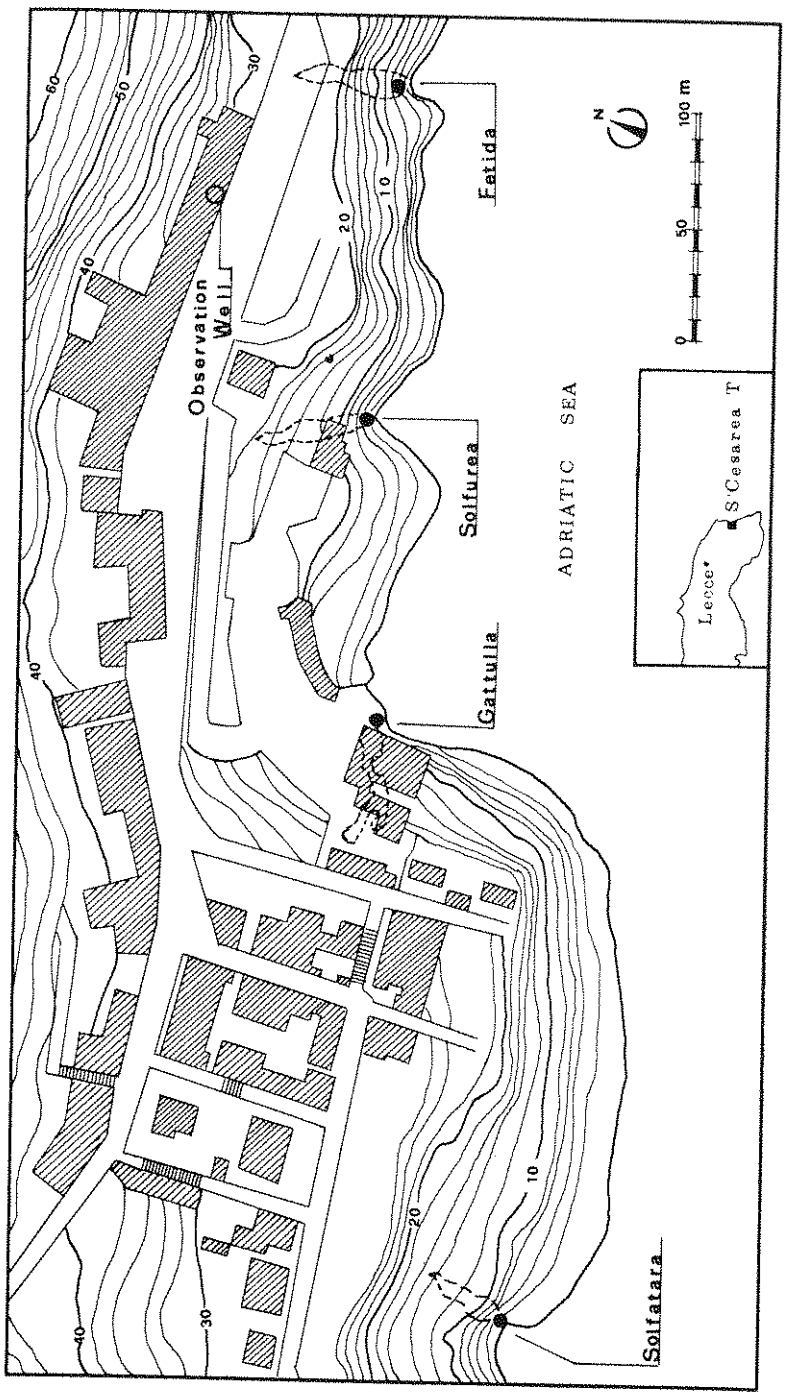

Fig. 1 - S. Cesarea Terme Planimetry.

Even though, over the last decades, springs have been matter of study by various scholars, the geological and hydrogeological features of the area surrounding Santa Cesarea Terme are, up till now, the reason of further investigations [1, 3, 4, 5, 7, 13, 14].

Given the peculiarity and the importance of such springs within the hydrogeological and economical field of Salento Peninsula, this investigation has been thought of being important in order to obtain a detailed picture of the hydrogeology in this zone.

Santa Cesarea Terme spring complex is constituend by four grottos (Solfatara, Gattulla, Solfurea, Fetida) located in a coastal tract overlooking the village about 800 mt long (Fig. 1).

Since previous studies have all maintained the assertion that the waters of the four grottos originate from a sole source, during the first phase of the study, investigations have been carried out only on the grotto Gattulla having the advantage of being accessible from the land.

The sulphurous springs have accounted for the starting point in the field work; then they have gradually stretched in lenght in order to confine the zone concerned with the sulphurization phenomenon, hence, determining its genesis.

Moreover an observation well located behind the grottos has been used for determining the chemical and physical characteristics of sulphurous water (Fig. 1).

2. GEOLOGY

In the studied area there are outcrop marine formations dating five different «ages» from the upper Cretaceus to the Quaternary (Fig. 2).

The Cretaceous is represented by compact white limestones locally associated with dolomitic limestones, calcarenites and marly limestones; at times veins and glauconite-sands pockets are found.

Within such a formation S-E Vitagliano a bank of whitegreenish kaolinitic clay associated with terra rossa has been found; this testifies a phase of local emergence during the carbonate sedimentation.

The stratification, generally not very evident, locally shows along the coast a dip accentuated towards the sea, while towards the inland shows a trend weakly inclined towards N-E (area behind Santa Cesarea Terme village).

Paleogene soils, known as «Castro's limestones» [9], prevailingly outcrop along the coastal strip and in the immediate inland resting trasgessively on more ancient limestones.

This contact is pointed out by the presence of calcareous coarse breccia mixed up with terra rossa. Lithologically in this formation one distinguishes two types: one ascribable to the Eocene and other to the Oligocene [6, 10].

Generally to the Eocene belong whitish-coloured bioclastic limestones sometimes porcelaneous containing veins, clay layers and inclusions and glauconite sands. Sometimes there are reef limestones as North Porto Miggiano.

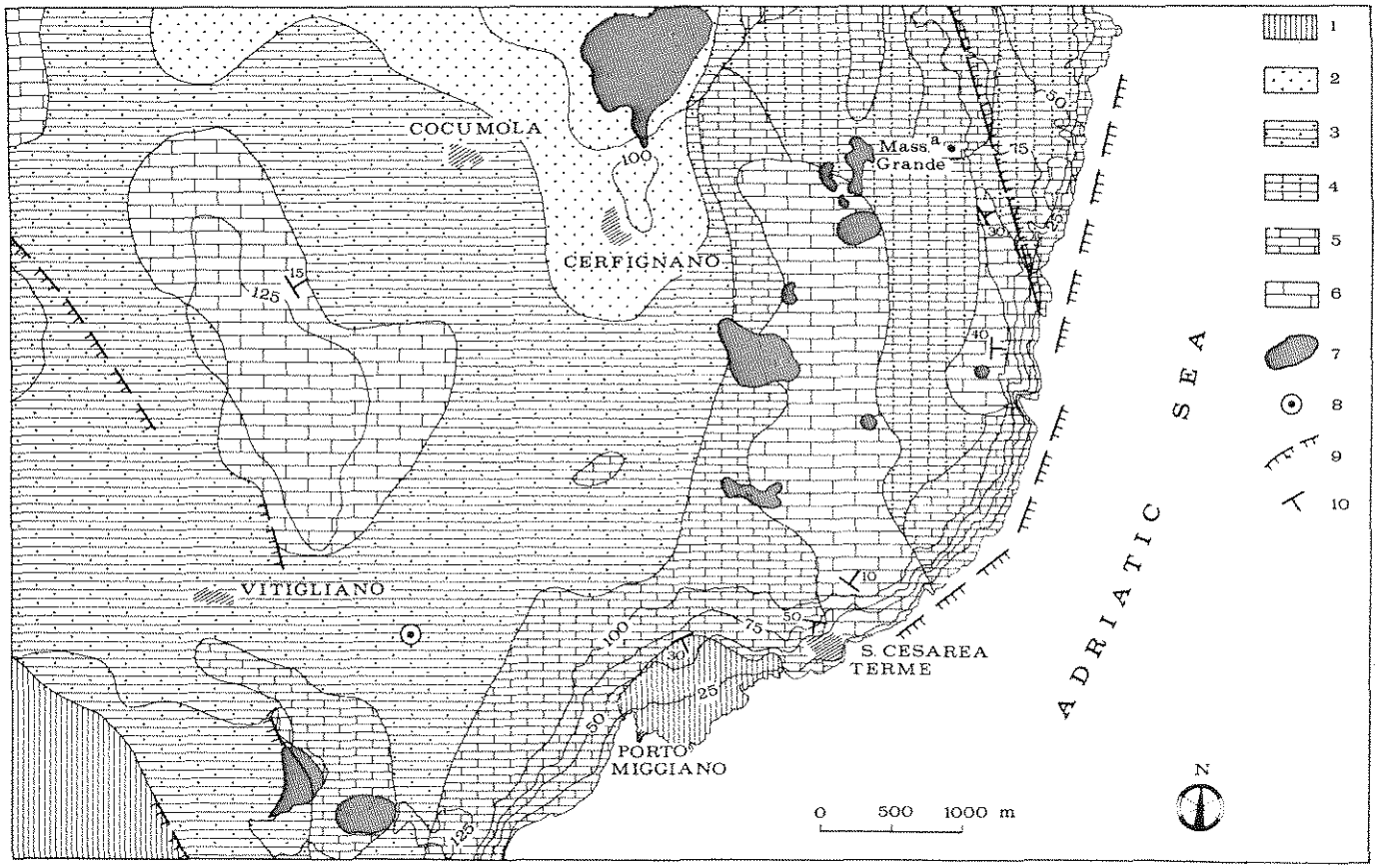

Fig. 2 – Geological and morphological map. 1: Yelloish calcarenite (QUATERNARY); 2: Weakly clayey sand (PLIOCENE); 3: Light-grey, at time, marly calcarenite (MIOCENE); 4: Whitish biocalcarenite (OLIGOGENE); 5: Whitish bioclastic and reef limestone (EOCENE); 6: White, at times, dolomitic limestone (UPPER CRETACEOUS); 7: Dolines; 8: Sink-hole; 9: Fault (probable if dashed); 10: Direction and slope of the layer.

Locally the rock seems crushed and yellowish reddish and greenish-coloured.

The Oligocene outcropping north Cesarea Terme is placed over eocene-soils and subordinately cretaceous ones, and it is prevailingly constitued by stratified biocalcarenites and by a sometimes coral-like whitish limestones.

Both lithotypes show a stratification with E-SE dip which, along the coastal-strip, causes an arrangement of downhill layers. The thickness of the whole formation is about 150 m.

At the roof of Paleogene and Cretaceous formations, transgressively miocenic calcarenites are found; they broadly outcrop at the back of the coastal strip. They are light grey calcarenites sometimes marly and glauconite with the presence of basal rudite at times containing phosphate-nodules [14]. The thickness of such deposits, for the studied area, does not exceed 20 m.

Pliocene sediments constitued by weakly clayey sands, scarcely cemented, outcrop in the zone surrounding Cerfignano village.

W-SW Santa Cesarea Terme and SW Vitigliano on Paleogene limestones, yellowish sometimes clayey calcarenites of the Quaternary are transgressively found.

Generally these last are well stratified and dip towards SE with inclinations of about 20° in middle-low parts till they become subhorizontal in the top part.

3. TECTONICS AND MORPHOLOGY

Probably shortly after the Cretaceous and before the Miocene, the Salento has been influenced by disjunctive tectonic phenomena which have dislocated and folded the calcareous rocks forming hörsts and some depressed areas mostly stretching towards NNW-SSE [8, 11, 12].

In the zone under examination cretaceous and paleogenelimestones, from the coast to inland, form two hörts; the interposed are is partly filled with miocene and pliocene rocks. The present contour has also been affected by additional tectonic phases being sometimes located on the previous ones of the late Miocene and the late Quanternary.

Generally, fault alignments characterizing calcareous cretaceous and paleogene rocks are not very evident on the soil owing to miocene and quaternary covers.

Some probable alignments having a NNW-SSE trend can be seen at Masseria Grande, N, NE and SE Vitagliano.

Faults with a considerable displacement, NNE-SSW and NE-SW directions, have been supposed to influence the calcareous masses behind the coastal strip. The various tectonic, phases have caused calcareous rocks of the Cretaceous and the Paleogene to be markedly fractured, above all near the coastal strip; the main direction of fractures is N-S followed by NW-SE one as the diagram in fig. 3 shows.

It is to be stressed, however, that such a marked fracturing, well evident along the coastal strip, generally is less and cemented in depth while going inland.

Moreover the morphology is affected by the evolution of karst phenomenon that in land is evident through its charateristic forms (dolines and sinkholes).

Generally such forms are normally alligned and parallel to the coast-line. Along the steep and uneven coast-strip, owing to its lithological nature and structure, there are some cavities located along fractures and faults where sulphureous waters emerge.

4. FIELD INVESTIGATIONS

As previously mentioned, during the first phase of the study, attention has been drawn on the Gattulla grotto in order to determine the relationships between spring waters and sea water.

Two points have been previously detected to such a purpose: one into the sea and the other in the innermost recesses of the grotto.

The exact measurement of the topographycal difference in level (0.131 m) has been carried out making reference to such points.

On the two high points, the two water-level recording gauges have been stationned for the measurement of the sea-level and the grotto water level variations. The reconstruction of the collected data has made sure that the dif-

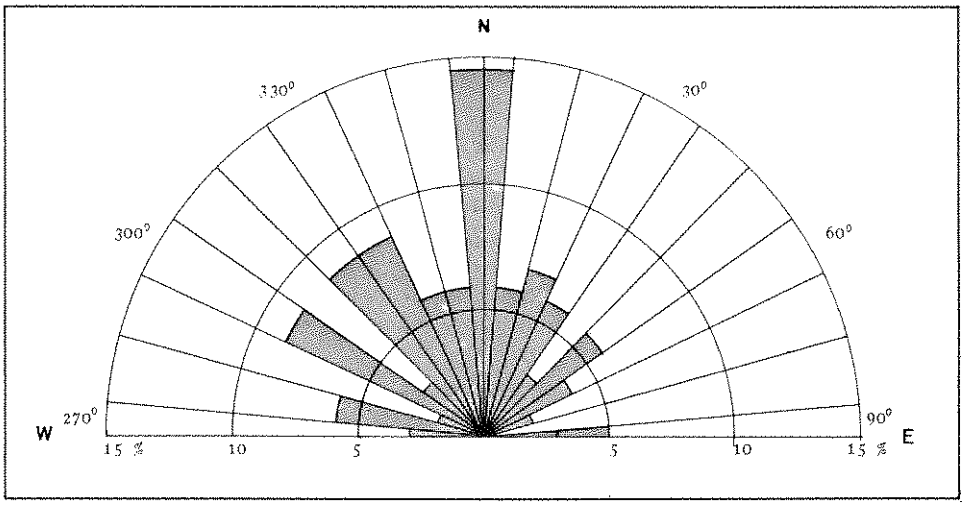

Fig. 3 – Frequency and direction of fractures in calcareous rocks.

ference in level between the sheet of water of the grotto and the sea one is very modest (of the order of a few centimetres) and that the level variation, brought about by tides, are of the same size and penecontemporary.

Moreover it has been observed how temperature and salt content of the sheet of water inside the grotto during a tidal phase and over one year change.

In the first case the observations were related to a system of 18 points and the collected data have shown that occurrence of hot water with a lower salt content takes place in the innermost part of the grotto. Furthermore, such observations have pointed out that during low tide the range of temperature (29-27 °C) is rather modest between the innermost parts and those near to the outlet to the sea.

On the contrary this range of temperature increases remarkably during high tides (26-19 °C) (Fig. 4).

Thermic measurements carried out over one year on Gattulla waters have turned out to be very meaningful as far the regimen of springs and sea contamination are concerned.

These systematic measurements, always run on the same point at the same hour, correlated with grotto sea-level, show how the thermosaline variations of sulphurous waters are generally affected by both sea water and fresh groundwater (Fig. 5).

The trend of the graphs presented, according to Schoeller scheme, is a valid proof of what we have asserted (Fig. 6).

This diagram contains the chemical characteristics of Gattulla waters taken at three different temperatures, of sea waters and of fresh ground-waters related to two wells located in the immediate inland (Tab. 1).

As you can see the sea and the aquifer influence turns out to be clearly evident.

At this point, once attained the basic information on grotto Gattulla waters, inland investigations are been carried out in orden to obtain information about the hydrogeology of the zone behind the sulphureous springs.

In Salento Peninsula, the hydrogeological environment is comparatively more uniform and far less complex than the remaining part of the region.

TABLE 1 – Variations of the main chemical constituents present in Gattulla grotto waters at different temperatures.

		GATTULLA 28.4°C	GATTULLA 27.5°C	GATTULLA 23.0°C	SEA	W.3
Ca^{++}	meq/1	54.96	38.59	19.49	54.0	4.18
Mg^{++}	»	86.10	78.97	11.75	87.7	2.70
$Na^{+} + K^{+}$	»	453.10	376.38	89.08	526.7	8.33
Cl^{-}	»	532.28	452.38	107.31	607.4	10.01
SO_4^{--}	»	53.38	45.49	10.83	49.1	1.23
HCO_3^{-}	»	3.19	3.33	4.48	2.4	4.35

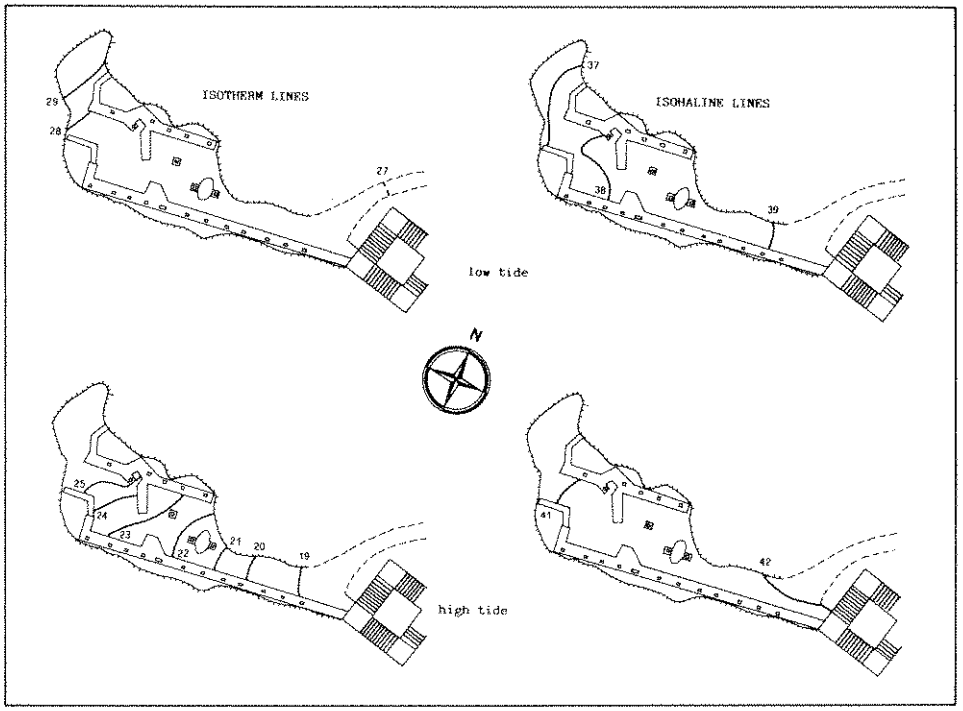

Fig. 4 - Thermo-saline variations in Gattulla grotto.

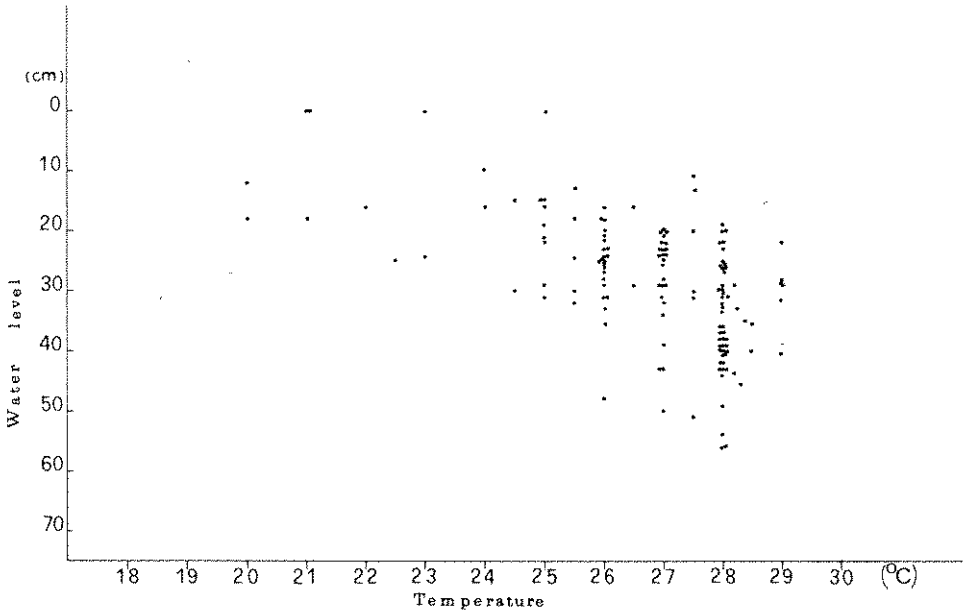

Fig. 5 - Gattulla grotto: Water level - Temperature diagram.

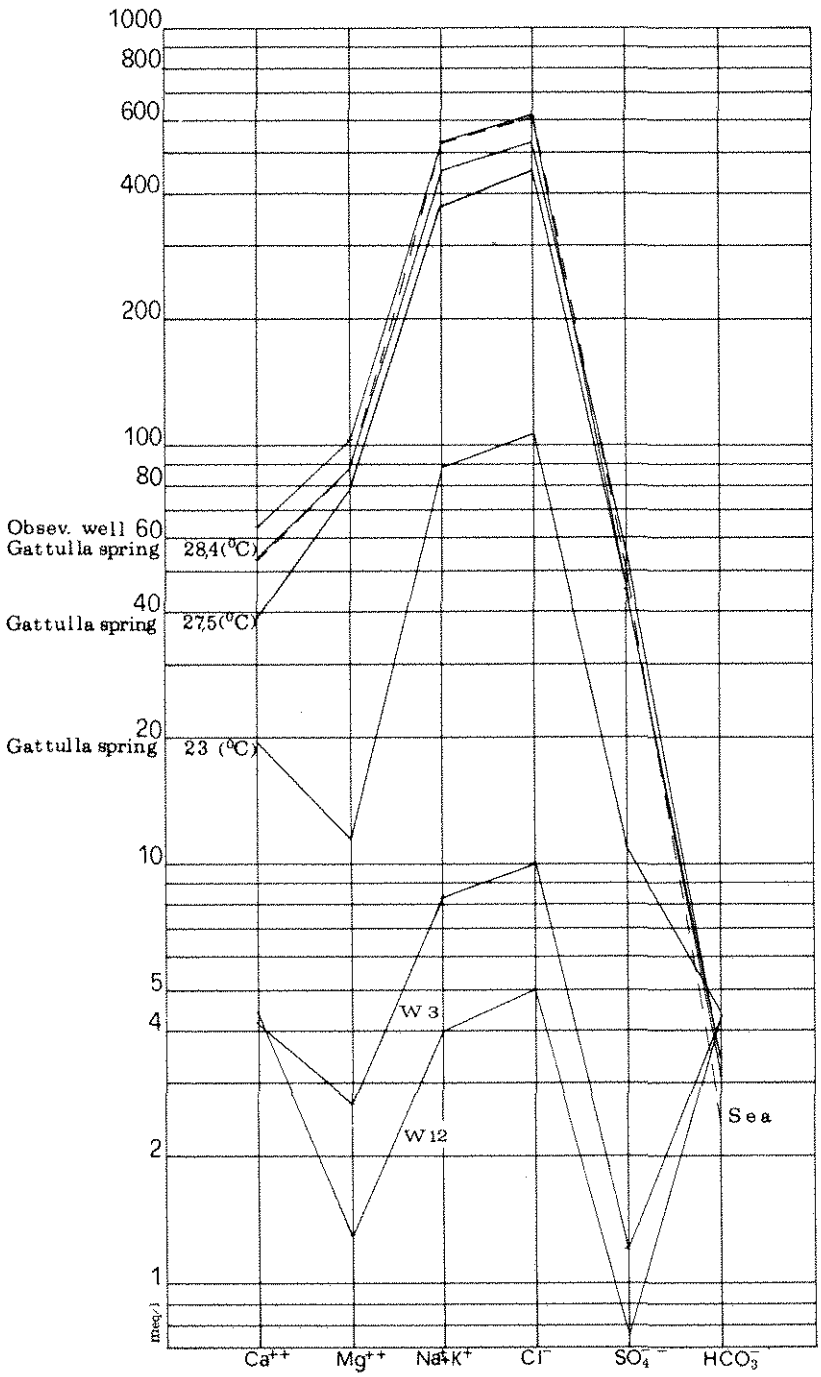

Fig. 6 – Schoeller's diagram.

In mesozoic carbonatic rocks being permeable by fissuring and karst-phenomena, a groundwater circulates continuously; it is called deep aquifer and is supported, at the base, by intruding sea waters.

The aquifer, because of its lacking in surface hydrography, is feed by a large quantity of rainfall, penetrating the subsoil in a spread or concentrated form and then finds its hydrological equilibrium by a number of series of springs generally flowing at sea level, as the sea horizon stands for the base level of water circulation [2].

As for the hydrogeology of the zone sourrounding Santa Casarea Terme a first series of information has been obtained by fifteen wells located between Vitigliano and Cocumula, all being present in the deep aquifer which generally is confined.

During the carrying out of the investigation some thermosaline logs have been implemented on some wells to detect the waters thermosaline stratification.

The Fig. 7 shows the two main logs: the one on the left concerning the observation well, and the one on the right concerning an inland well.

As you can notice the observation well, located behind the grottos clearly visualizes the presence of surface fresh waters which, however, are remarkably polluted by the underlying sulphureous ones.

On the contrary the thermosaline stratigraphy of the inland well is completely regular, in agreement with the features of the Salento Peninsula groundwater.

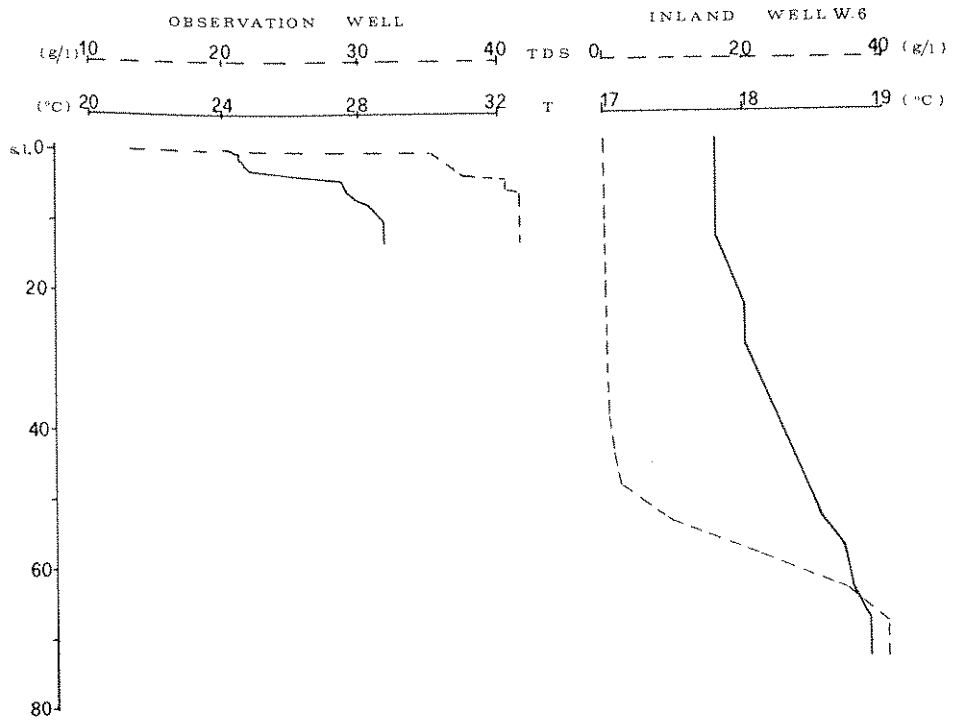

Fig. 7 - Thermo-salinometric logs.

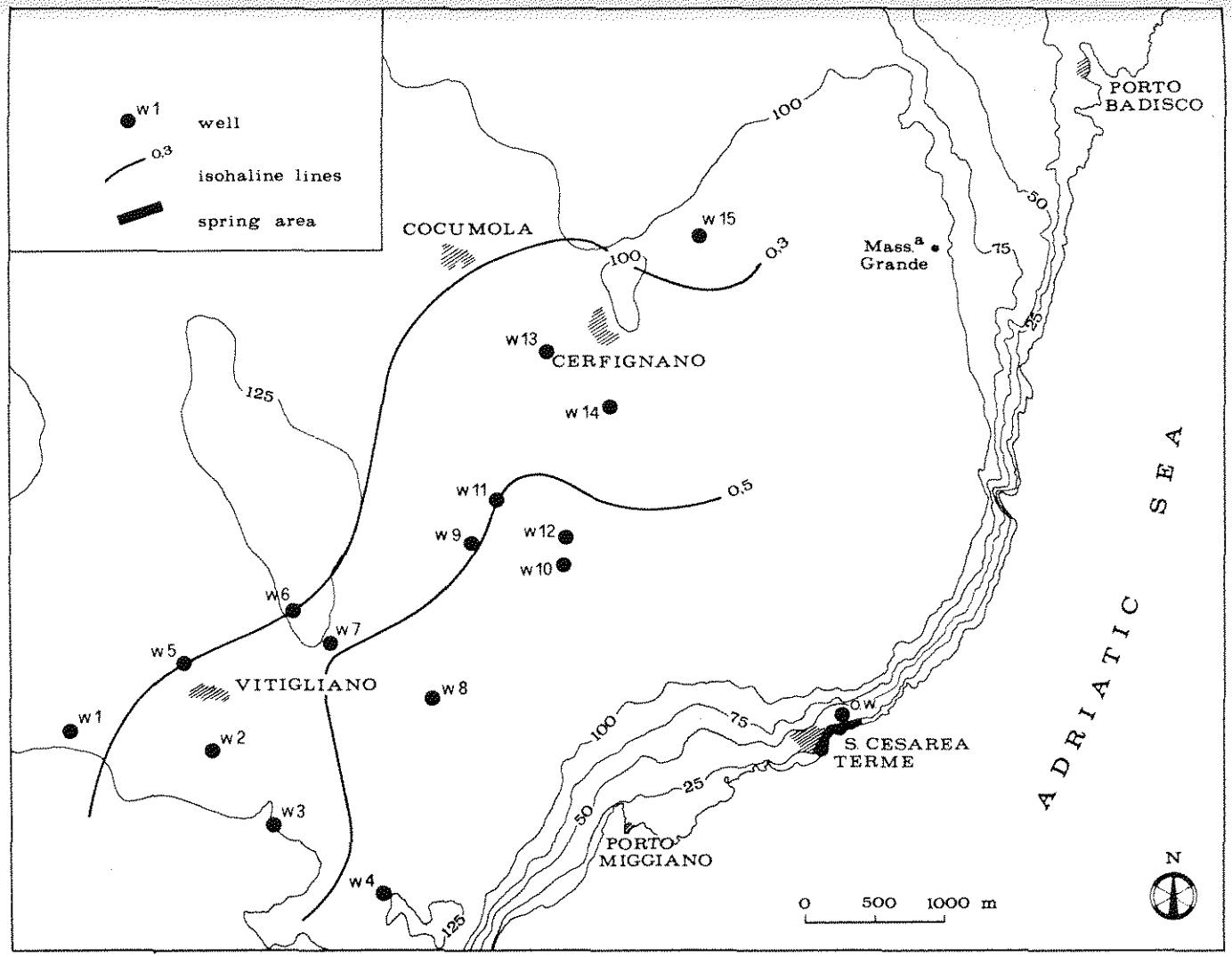

Fig. 8 – Salt content distribution on the watertable.

Indeed, no lack of balance between fresh waters and sea waters takes place.

A synthesis of the derived information is given by the isohaline map (Fig. 8).

The curves trend is determined by both limestones reduced permeability and the tectonics in the zone. The influence of the reduced permeability of limestones is pointed out by the low salt content occuring also at short distance from the coastline; while the influence of the tectonics is represented, locally, by the trend itself of the isohaline.

Particulary, this trend in the area S-E Vitigliano is determined by the fault running eastwards of the same village.

Similar considerations apply also to the two flow preferential paths visible by the isohaline curves; the one below on the left, for instance, are perfectly alligned with the direction of greatest fracturing found east Vitigliano.

The schematic section in Fig. 9 gives a clear representation of the hydrogeological state in the zone. As one can see, sea water intrusion area is very modest and limited to a narrow coastal strip.

As for the presence of sulphides, it has been found in both the « observation well » and an inland well 3 Km from coastline. In the two wells in question, water samples at various depths have been taken, such samples have been chemically analized (Tab. 2).

The main factor emerging from the reading of the table is that sulphides occur in two different types of water.

For, while in the observation well sulphurous waters are tipically marine, in the well w.6 sulphurization affects only fresh groundwater; the different nature of waters provides a full justification about the remarkable differences in sulphide content.

As for sulphides presence in waters, such a phenomena can be genetically ascribed to the reduction of sulphates in waters which are in contact with organic matters residing in calcareous and calcarenite rocks, which sometimes prove to be very rilevant.

The considerable presence of sulphides in the observation well is to be ascribed to sea water notoriously rich in sulphates.

To such a purpose is to be remembered that isotopic analysis carried on a sulphur sample of Gattulla Grotto, during previous study [14], have established the organic origin. About the temperature of sulphurous waters, it is assumed that both the deep origin of waters and the sulphurization phenomenon itself, in a likely way exothermic, exert a certain influence on it.

5. CONCLUSIONS

At present the geological and hydrogeological study carried out on the considered area provides the focusing of the following steps:

a) Santa Cesarea Terme inland hydrogeology generally shows the typical

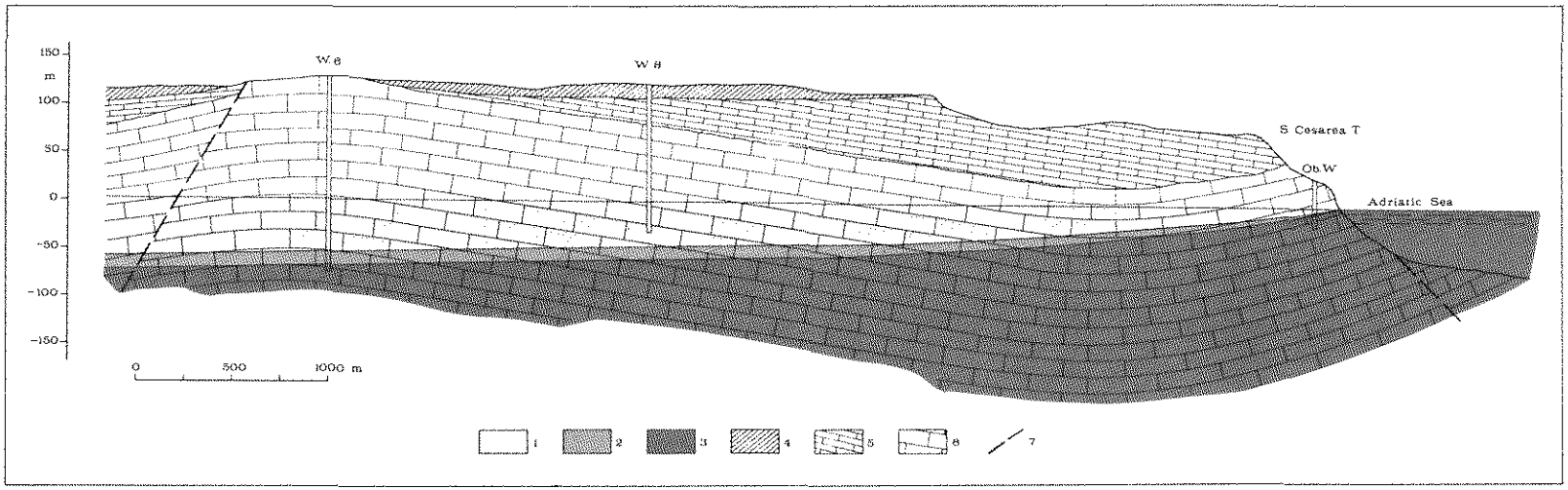

Fig. 9 - Hydrogeological section. 1: Fresh groundwater; 2: Diffusion zone; 3: Sea water intrusion; 4: Calcarenites (MIOCENE); 5: Limestones (EOCENE); 6: Limestones (CRETACEOUS); 7: Probable fault.

TABLE 2 - Variation of chemical-physical parameters of the waters of some wells.

Well sample altitude		W. 6 + 1.3 m	W. 6 − 23.2 m	W. 6 − 43.2 m	W. 6 − 63.2 m	Ob. W. − 3.0 m	Ob. W. − 14.0 m	W. 12 + 0.20 m
T	°C	17.8	18.0	18.3	18.8	24.5	28.2	17.9
pH		7.60	7.85	7.35	7.20	6.95	7.10	7.35
TDS 110°C	g/l	0.133	0.272	0.853	30.673	37.112	44.345	0.644
TDS 180°C	»	0.131	0.268	0.823	29.281	34.737	41.480	0.591
Ca^{++}	meq/l	1.020	2.367	4.591	24.948	49.875	64.050	4.387
Mg^{++}	»	0.454	1.400	2.109	84.777	88.763	103.014	1.293
Na^{+}	»	0.713	0.935	7.344	410.595	452.785	527.597	3.871
K^{+}	»	0.017	0.021	0.249	9.386	9.974	10.767	0.097
Li^{+}	»	<0.0001	<0.0001	<0.0001	0.0250	0.0712	0.1095	<0.0001
Sr^{++}	»	0.0001	<0.0001	0.0060	0.2010	0.3572	0.4462	0.0066
NH_4^{+}	»	—	0.0016	0.0020	<0.0011	0.1552	0.1996	<0.0011
HCO_3^{-}	»	0.986	3.271	4.137	3.181	2.637	3.110	4.258
Cl^{-}	»	1.218	1.587	9.353	437.109	574.407	612.206	5.045
SO_4^{--}	»	<0.001	<0.001	0.864	48.160	43.687	44.786	0.743
Br^{-}	»	0.0029	0.0062	0.0180	0.8130	1.3010	1.4070	1.0160
F^{-}	»	0.0041	0.0046	0.0080	0.0280	0.1140	0.1390	0.0150
NO_3^{-}	»	<0.001	<0.001	0.088	1.286	<0.001	<0.001	<0.001
NO_2^{-}	»	<0.0002	0.0004	0.0005	0.0003	0.0028	0.0005	<0.0002
S^{--}	»	0.0716	0.1068	<0.0001	<0.0001	1.4272	3.3540	<0.0001
CO_2	»	0.020	<0.001	0.362	0.231	0.372	0.251	0.171
Alkalinity	mg/l $CaCO_3$	49.34	163.69	206.85	159.05	131.97	155.64	213.09
Hardness	°F	7.37	18.83	35.50	548.62	693.19	835.32	28.40

characteristic of Salento aquifer characterized by a water circulation taking place within calcareous rocks of the Cretaceous and, locally, of the Paleogene. Such rocks in the zone have a considerable fracturing layer mostly towards N-S and S-E, affecting the discharge into the sea of groundwaters;

b) The rilevant presence of sulphurous waters can be localized in zone immediately behind the grottos characterizing only sea waters; locally, isolated sulphurization phenomena affecting fresh groundwaters are found too;

c) within the grottos three types of mixed waters are found: sulphur thermal waters, sea waters, fresh groundwaters; their degree of mixing extremely variable, is prevailingly linked to tide oscillations and relatively to the aquifer level;

d) sulphur-thermal waters are characterized by high values of salinity and temperature; such parameters let one assume that sulphurization phenomenon is to be ascribed to sea water which, coming to contact with organic matters present in calcareous rocks, undergoes in depth the reduction in sulphates.

As for, we have outlined only the first stage of a just undertaken study which will be carried out in a better way, when broader investigations provide a more detailed account about the hydrogeology in the zone and a better understanding of a sulphurization phenomenon.

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