Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 305-306

# THE CLIMATE IN DEEP ZONES OF KARST

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## ABSTRACT

*G.K.W.: speleology , meteorology in caves*
*Geogr.K.W.: France, Niaux, Italy, Trieste.*

The existence of a deep zone in karst massifs not influenced by the outside temperature is pointed out. The interest of studies particularly directed to the climate of this zone is emphasized and some general remarks are also given.

## INTRODUCTION

The climate of caves is essentially regulated by outside air, water and rock. As the distance from the entrance increases the influence of the outside air decreases. Such a decrease is particularly important in correspondence of some features of the passage as crawlings and, obviously, sumps.

Therefore, in karst massifs there is a deep zone where the influence of outside air becomes negligible in comparison to those of water and rock. Such a zone should include the part without ventilation of karst systems and nearly all the fissure networks, i.e. the greatest part of the "deep" karst.

There are hundreds of experiments carried out in the zone directly influenced by the outside air and it is worth while to quote here those performed by professor Silvio Polli in the district of Trieste (POLLI S. *et al.*,1961-1969; CHOPPY J.,1981).

On the other hand, only one series of measurements referring to a deep zone seems to have been published up to now: that of Claude Andrieux in the cave of Niaux (French Pyrenees) (ANDRIEUX, 1977). This research started when neither the existence of a deep zone was fully ascertained nor the necessity of special experimental procedures. Nevertheless an important result was obtained because the lack of any periodicity, not even yearly, was reported.

## GENERAL REMARKS

According to the best information now available, eccentrics and, more generally, mono crystalline formations are found nearly esclusively in such a deep zone. It is quite obvious the interest on this zone from the point of view of the show caves: whithin this framework it was therefore proposed to the International Show Caves Association a research on the climate of the deep zone (CHOPPY J., CIGNA A. A.,1990).

Some issues particularly relevant to a research on the climate of the deep zone are here listed:

- The studies in the district of Trieste above mentioned have shown that the rock temperature in the surface layer some ten of centimetres thick depends more on the air temperature than on the thermal flux in the rock itself. Therefore the temperatures measured within this layer are not representatives of the true rock temperature.

- In the deep zone, air is moved by convection: on account of the existence of a vertical thermal gradient, the most important heath exchanges occur at the top and at the bottom of passages. Temperature measurement points must therefore be chosen at different levels.

- Both temperature and $CO^2$ concentration measurements may give some indications on such convection movements which are rather difficult to be detected directly.

- Evaporation and condensation play an important role in the deep zone. Great care must therefore be taken to avoid that the measurement procedures introduce a perturbation larger than the local differences to be studied. E.g. the amount of water vapor released by evaporimeters should be negligible in comparison to that released by walls or ponds.

## CONCLUSIONS

On account of lack of nearly any knowledge on the climate of the largest part of the "deep" karst, a good coordination among the scientists interested to this argument should be established in order to define the best procedures to be followed and to assure a widespread exchange of the results obtained.

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## DISCUSSION

N.N.: Evaporation is surely an important factor in the deep zone climate but I suggest to include in your research programme also some studies on oxigen and hydrogen isotopes fractioning in water and vapor.

A commemoration of Mr. Roberto Baldoni, President of Consorzio Frasassi, is reported at page XVI of this volume

Proceedings of the International Conference on Environmental Changes in Karst Areas - I.G.U.- U.I.S.- Italy 15-27 Sept. 1991 ; Quaderni del Dipartimento di Geografia n. 13, 1991 - Università di Padova, pp. 307-324

# HYDROGEOTHERMAL MODEL OF GROUND WATER SUPPLY TO SAN NAZARIO SPRING (GARGANO, SOUTHERN ITALY)

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## ABSTRACT

*G.K.W.: hydrology*
*Geogr.K.W.: Italy, Puglia, Gargano,*

The S. Nazario spring in the north-west plain of the Gargano promontory has an exceptionally high water temperature (27° C) and relatively low salt content (2.5 g/l). Geological and hydrogeological investigations suggest that the spring water rises from deep levels along faults in the Mesozoic limestones.

A hydrogeothermal model based on the hydrogeological sections of the Gargano Promontory seems o rule out the possibility that the spring is fed only by rain water falling onto the Promontory.

A second model, based on hydrogeological sections of the plain, suggests that the spring water at San Nazario rises from a deep salt water bed. Probably, the hot brackish deep water and the cold fresh water from the Gargano mix slightly somewhere close to the spring.

## INTRODUCTION

The Gargano Promontory is an area of special interest as it represents a peculiar geological unit.

The regional hydrogeology of the area was previously investigated by COTECCHIA & MAGRI (1966).

The aim of this study is to explain the high temperatures of the San Nazario Spring waters in relation to their origin. The study is dictated by its scientific, as well as economic, importance because the spring's water can be utilized as a low enthalpy resource. As a logic starting point we have been working on the hypothesis that the spring draws its water from the Gargano Promontory.

## GEOLOGY AND HYDROGEOLOGY OF THE WESTERN DISTRICT OF THE GARGANO PROMONTORY

The Gargano promontory mainly consists of Late Cretaceous Limestones, referred (MASSE & LUPERTO SINNI, 1987) to three different geological environments: platform, talus and basin.

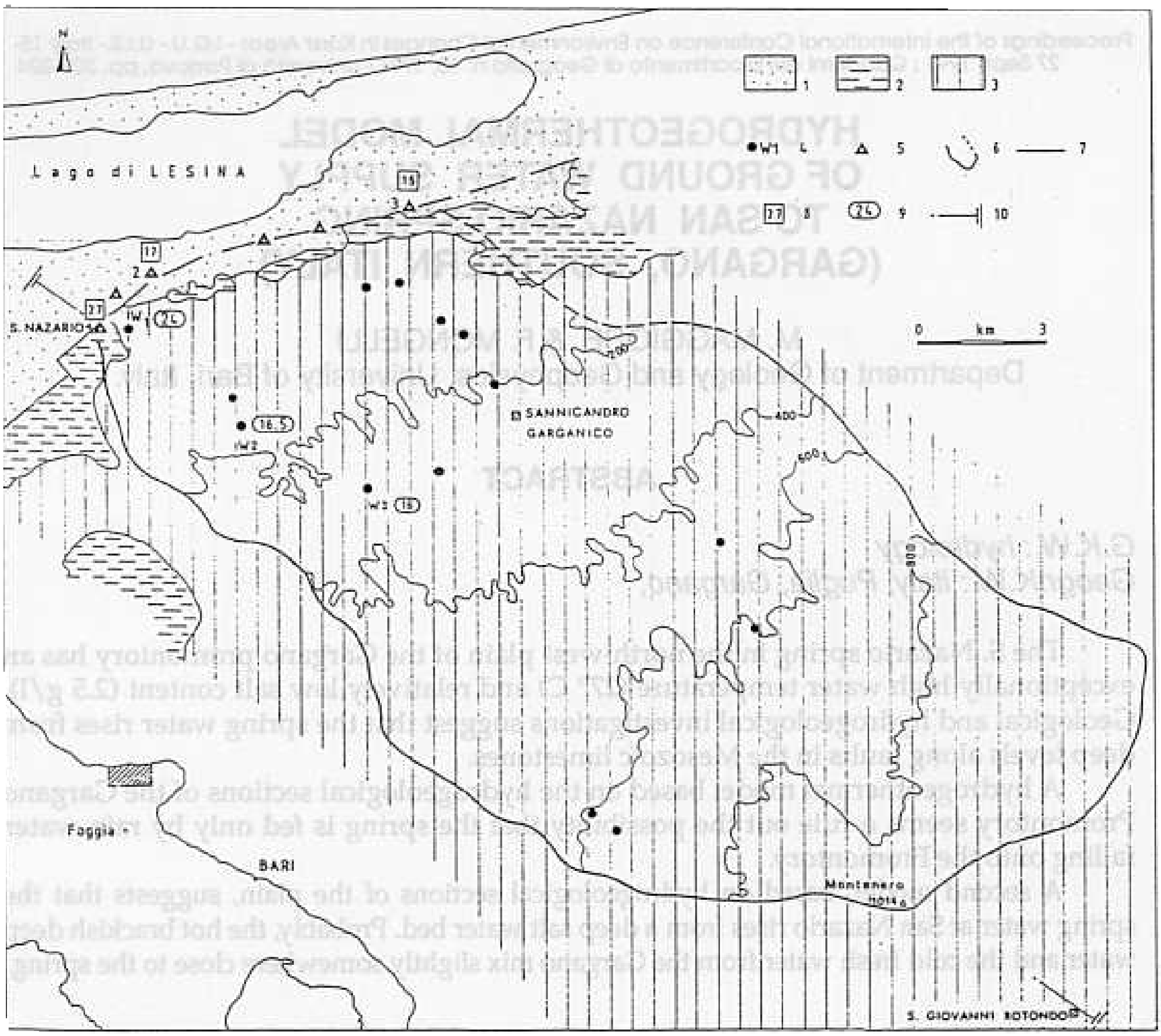


Fig. 1 - Hydrogeological schematic map of investigated area (and its location): (1) Quaternary fluvio-lacustrine deposits; (2) Calcarenites (Miocene-Pliocene); (3) Mesozoic Limestones; (4) Well; (5) Spring; (6) Hydrological basin; (7) Fault; (8) Water temperature measured at the spring; (9) Water temperature measured in well; (10) Line of section.

The platform limestones outcropping in the western portion of Gargano are bedded, jointed and subject to karst phenomena. Here rain water feeds a large karstic aquifer (COTECCHIA & MAGRI, 1966).

The aquifer's base level corresponds to sea level, with the ground water overlying sea water intrusions. A great many coastal springs drain the ground water along preferential flow paths where rock permeability is greatest.

The springs are grouped together along well-defined parts of the coast. An important discharge zone is located close behind Lake Lesina (Fig. 1) where, in an 8 Km-long stretch, many rising springs yield a total outflow of 1100 l/s (MINISTERO LAVORI PUBBLICI, 1953; COTECCHIA & MAGRI, 1966). Of these, the most important are San Nazario (average discharge: 200 l/s), Zanella (120 l/s) and Lauro Springs (450 l/s).

A peculiar feature about San Nazario Spring (n. 1) is its abnormally high

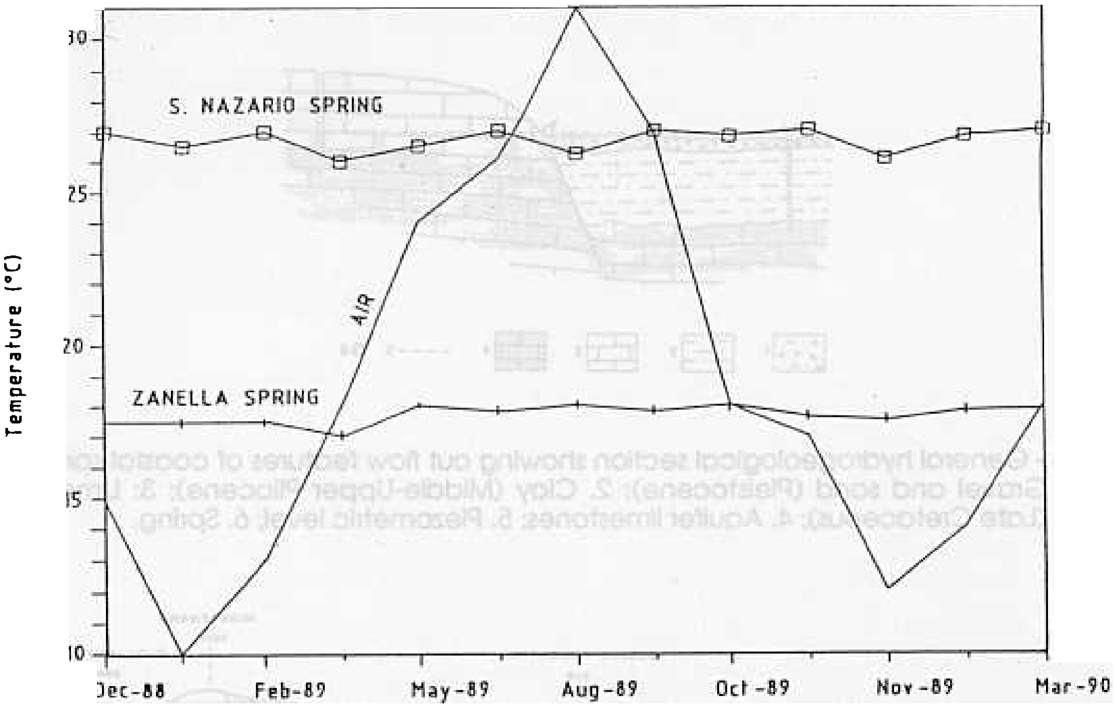


Fig. 2 - Air and spring water temperatures compared (San Nazario, Zanella)

temperature (27° C), especially if compared to the low temperatures (15° C - 17° C) observed, respectively, at Zanella Spring (n. 2), located no more than 1.5 Km away, and at Lauro Spring (n.3).

Characteristically, the springs show a constant thermal regime (Fig.2) indicating that the water travels at considerable depth. Salinity (ranging from about 2,5 g/l at San Nazario and 4 g/l at Zanella) can be ascribed to the influence of the intruding sea waters (COTECCHIA & MAGRI, 1966).

The springs are distributed around the north-western edge of the promontory, along the fault that marks the contact between the Fortore river plain deposits and the limestones of the Promontory (Fig.3).

The aquifer is confined and bears the characteristics of an artesian hydrogeological system along the coastal plain.

The hydrographic basin feeding the spring area extends to high elevations in the Promontory, as far inland as San Giovanni Rotondo (Fig. 1), and includes a large part of the extended doline plateau around San Marco in Lamis. While the western boundary of the basin is well defined by the promontory's western scarp, its eastern boundary is less well defined, mainly in its lower part, due to uneven surface morphology.

Stratigraphic and hydraulic data from wells were used to draw a cross section through the hydrogeological basin of the springs (Fig. 4). The section shows agreement between the hydrogeological and the hydrographic basins. Maximum distance from the recharge area to the springs, along the flow direction, is 23,5 Km and the amount of flowing water is estimated at 150 l/s for a 1 Km-long discharge area, i.e. 1.5 $cm^3/cm$ s.

The water table is confined at varying depths (20-100 m) below sea level; the hydraulic gradient is low (0,1%-0,06%). The groundwater is confined by impermeable or scarcely permeable limestones, depending on the state of tectonic fracturing and

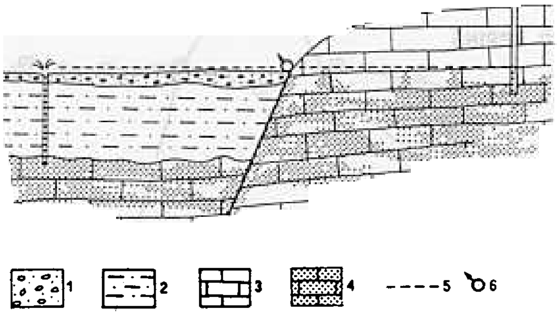


Fig. 3 - General hydrogeological section showing out flow features of coastal springs: 1. Gravel and sand (Pleistocene); 2. Clay (Middle-Upper Pliocene); 3: Limestones (Late Cretaceous); 4. Aquifer limestones; 5. Piezometric level; 6. Spring.

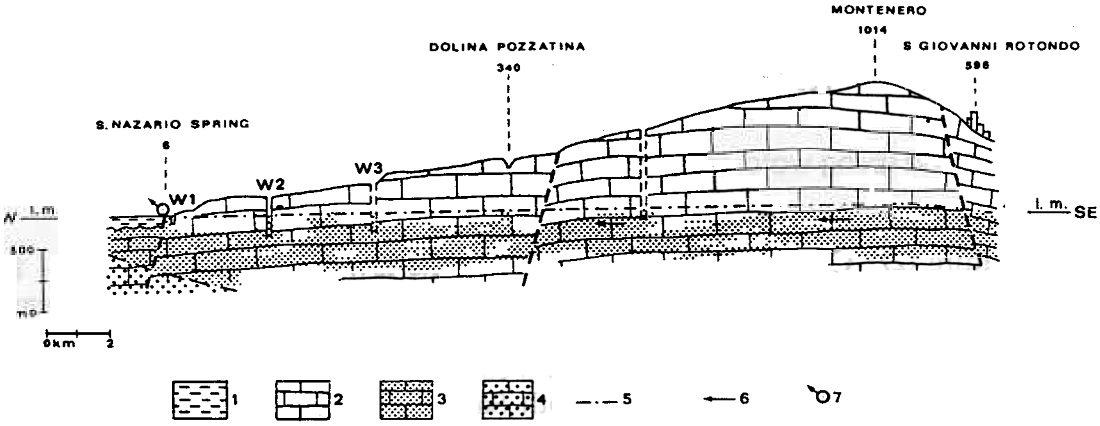


Fig. 4 - Section crossing the hydrogeological basin of San Nazario Spring area: (1) Quaternary impermeable deposits; (2) Mesozoic limestones; (3) Fresh water in limestones; (4) Salt water in limestones; (5) Piezometric level; (6) Flow direction of ground water; (7) Spring.

karst development.

The hydrostatic head decreases towards the coast and water flows northwestwards following the development of fractures and superficial hydrography.

Temperature measurements in several wells in the hydrological basin show that the highest value (24° C) was observed in well W1, near the spring. This is a constant value all down the water column (Fig. 5).

We have investigated whether this hydrogeological background can explain the high temperature recorded at San Nazario.

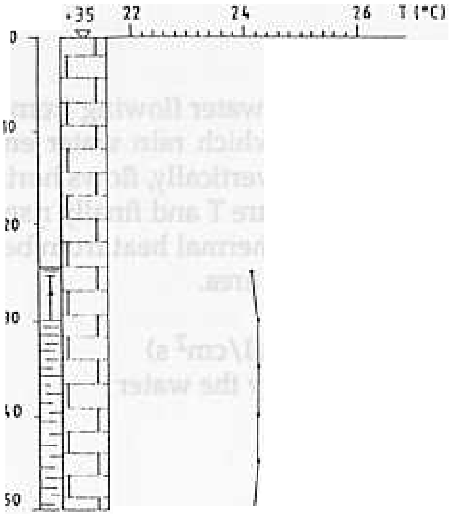


Fig. 5 - Temperature log of well W1.

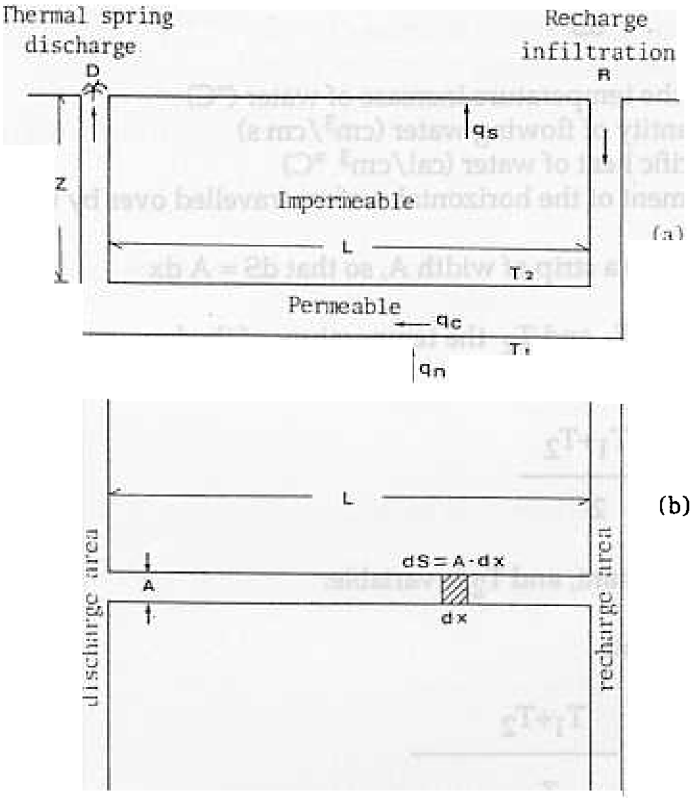


Fig. 6 - Schematic representation of the thermal model between recharge and discharge zones. a) vertical section; b) plan view.

## FIRST MODEL

To modelize the warming of the water flowing from the Gargano Promontory, we consider a simple circuit (Fig.6) by which rain water enters a recharge area R at T0 temperature, percolates to a z depth vertically, flows horizontally in a confined aquifer over a length L at a variable temperature T and finally rises along a discharge zone D to produce a spring. Caused by the geothermal heat from below, temperature T increases as the water approaches the discharge area.

By denoting by
qn the geothermal heat flow (μ cal/cm$^2$ s)
qc the portion of heat captured by the water
qs the heat flow at the surface

the following relation holds

$q_n = q_c + q_s$ (1)

$q_c$ is given by

$$wc = \frac{dT}{dS}$$

where dT is the temperature increase of water (°C)
w is the quantity of flowing water (cm$^3$/cm s)
c is the specific heat of water (cal/cm$^3$ °C)
dS is the element of the horizontal surface travelled over by water

Consider (Fig. 6) a strip of width A, so that dS = A dx

By denoting by $T_1$ and $T_2$ the temperature of the lower and upper surface of the aquifer, we assume

$$T= \frac{T_1+T_2}{2}$$

where $T_1$ is constant, and $T_2$ is variable.

On the other hand

$$qs = \lambda \frac{T_1+T_2}{z}$$

where λ is the thermal conductivity of the cover.

Finally, eq.(1) may be written as

$$qn = 1/2Wc \frac{d(T_1+T_2)}{A\,dx} + \frac{k\,(T_2-T_0)}{z} \qquad (2)$$

If the boundary condition $x=L;\ T_2-T_0=0$ is used

then the solution of eq. (2) is

$$T_2-T_0 = qn \frac{z}{k} \{1 - \exp[-\frac{2A\lambda}{Wc\,z}(L-x)]\} \qquad (3)$$

KAPPELMAYER (1957) proposed a similar model for a radially converging flow.

By assuming

$qn = 1.5 \times 10^{-6}$ cal/cm$^2$ s, the heat flow of the carbonate platform (MONGELLI et al., 1983)

$\lambda = 5 \times 10^{-3}$ cal/cm °C, the conductivity of the limestone

$A = 1$ cm

$c = 1$ cal/cm$^3$ °C

$W = 1; 2$ cm$^3$/s cm

and setting $x = 0$, we can calculate the length L required to obtain a given value of $T_2-T_0$, for a given value of z.

With reference to $T_0$, it has been well established that, generally, there is no significant increase in temperature between the surface and the top of the water beds in karstic regions (COTECCHIA et al., 1978; LODDO & MONGELLI unpublished data). As a consequence, temperature at that surface is almost equal to surface temperature. Fig. 7 shows the $T_2-T_0$ increase calculated by using eq. (3) for different values of z.

In the study case, the horizontal travel of the ground water is about 25 km. One can infer that, even if the water penetrates into the aquifer down to 1000 m, the travel is not long enough for temperature to rise by about 12 °C at the San Nazario Spring either with w=1 or with w = 2 cm$^3$/s cm while we have an estimated w= 1.5. On the other hand, it is physically impossible for water to percolate more than a few tens of meters. Hence, the rise in temperature may only be around 1-2 °C.

This is confirmed by:

a) the cold wells located in the same hydrogeological basin;

b) other cold springs located east of San Nazario and fed by a similar system.

In conclusion, the hypothesis that the spring water mainly originates in the Gargano Promontory does not explain the thermal characters of San Nazario. Therefore, we have also considered the possibility that the water mainly flows from deep levels west of the promontory.

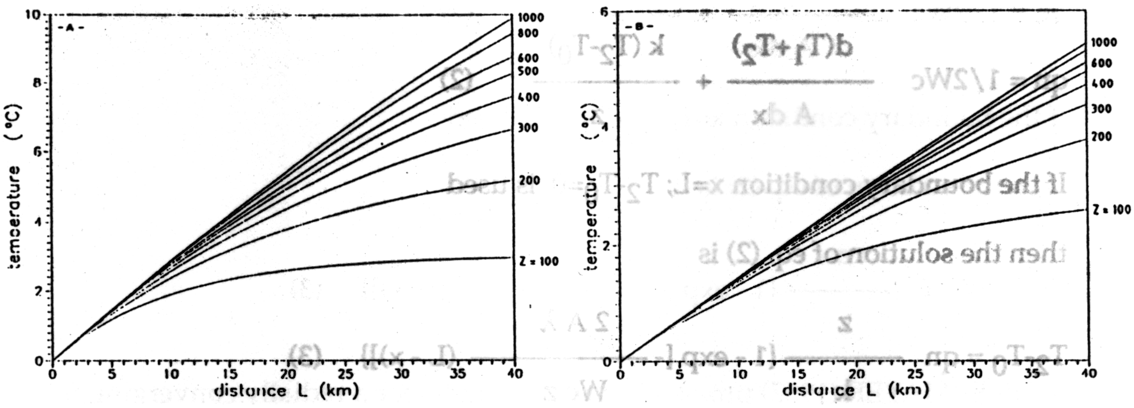


Fig 7 - Temperature increase at discharge zone versus distance from richarge zone:
a) for w = 1 $cm^3/cm$ s; b) for w = 2 $cm^3/cm$ s

## GEOLOGY AND HYDROGEOLOGY OF THE AREA WEST OF THE GARGANO PROMONTORY

We have investigated the ground water system west of the discharge area.

Our research work was carried out over a large section of the Fortore River plain as far off as the eastern edge of the Apennine chain (Fig. 8).

The main structural features are already known (BALDUZZI et al., 1982; MOSTARDINI & MERLINI, 1986) and are here shown by the deep geological sections (Fig. 9) drawn on the basis of subsurface data relative to hydrocarbon or to water wells.

West of the Gargano Promontory, the Mesozoic limestones of the Apulian Platform subsided along normal faults and lie beneath a large cover of the predominantly clayey Plio-Pleistocenic units; maximum thickness was observed in the central part of the Periadriatic Foredeep.

The platform limestones are displaced in a series of steps at increasing depths down to 1607 m below ground surface at the "Torrente Tona 1" borehole (Fig. 9).

To the west, the Apenninic allochthonous sequence is mainly of Miocene Age. The thickness of this sequence increases westwards.

The geological section also shows the pattern of the ground water circulation inside the platform limestones.

Where permeable, these are reservoir rocks, containing formation water and, in restricted areas, also hydrocarbons (mainly gas). Other traps, such as lenticular reservoirs, consist of Plio-Pleistocenic sands.

Formation Test data by Oil exploration provide important information on the characters of the deep calcareous layers which contain brackish water. The values of the main parameters obtained from measurements taken in a 1800 m deep pumping well are of special importance:

P = 172 Kg/cmq (formation pressure);
p = 0.15 (water yield);
$k_o = 10^{-4}$ cm/s (horizontal hydraulic conductivity )
$k_v = 10^{-5}$ cm/s (vertical hydraulic conductivity)

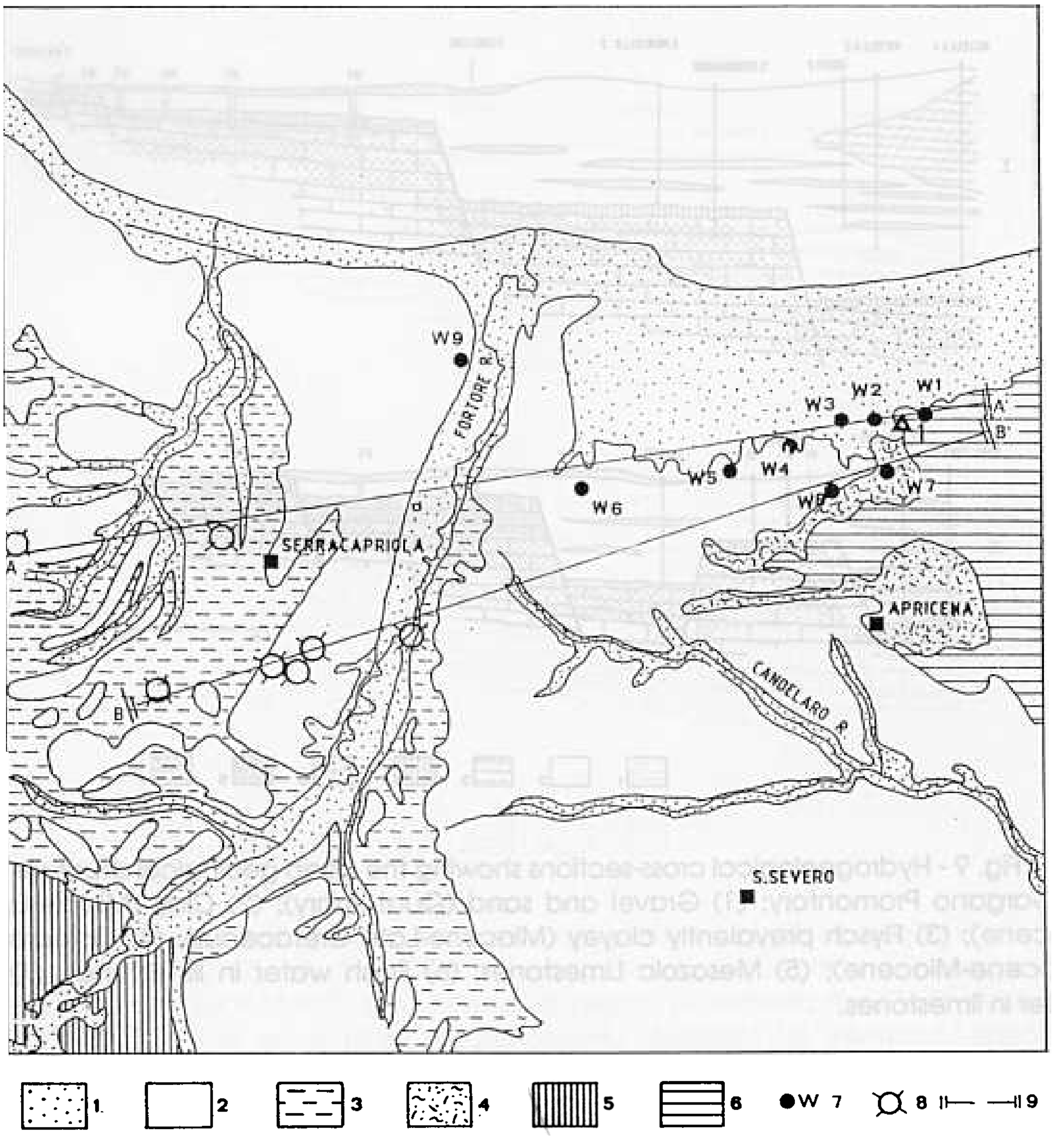


Fig. 8 - Geological map of area west of the Gargano Promontory: (1) Fluvio-lacustrine deposits (Quaternary); (2) Gravel and sand (Quaternary); (3) Clay (Middle-Upper Pliocene); (4) Calcarenites (Pliocene-Miocene); (5) Flysch, prevalently clayey (Miocene-Late Cretaceous); (6) Mesozoic limestones; (7) Water well; (8) Hydrocarbon well; (9) Line of section.

These values indicate that porous and permeable limestones also occur at great depth.

Given the value of hydrostatic pressure, the level of brackish water is about 100 m above sea-level. Consequently, it may well be that the formation waters is in hydraulic communication with the ground water contained in the outcropping limestones in the surroundings of San Nazario spring.

In Piper diagram (Fig. 10), the chemical composition of formation water from hydrocarbon well and of Adriatic Sea water are compared. Besides, the water chemical properties of San Nazario Spring and of nearby pumping wells (COTECCHIA & MAGRI, 1966) are represented.

Based on the water's main constituents, the diagram shows that both the ground

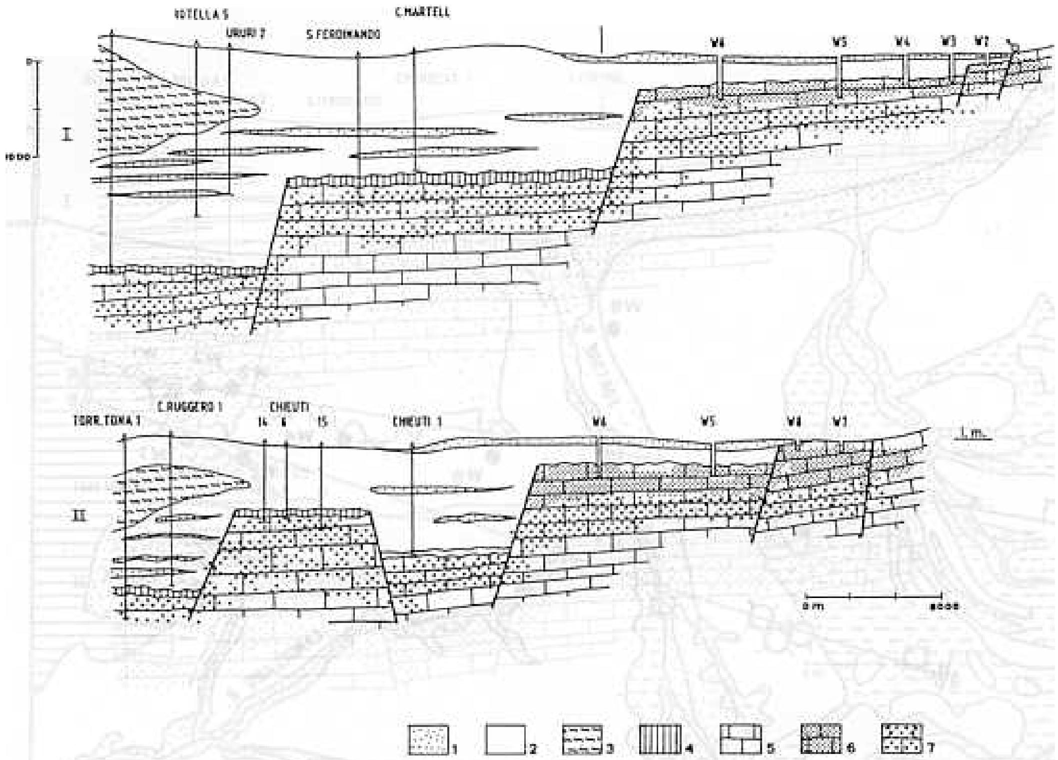
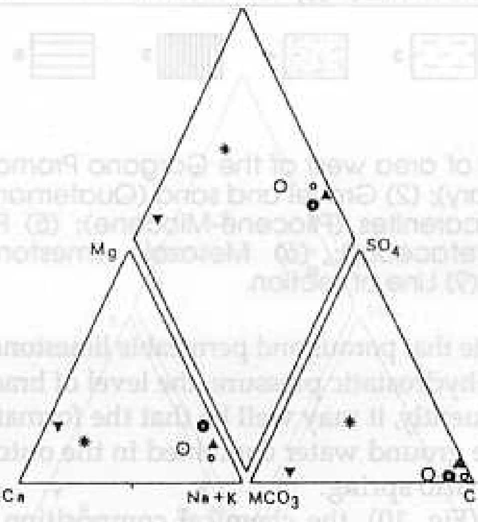


Fig. 9 - Hydrogeological cross-sections showing the deep geological structure west Gargano Promontory; (1) Gravel and sand (Quaternary); (2) Clay (Middle-Upper Pliocene); (3) Flysch prevalently clayey (Miocene-Late Cretaceous); (4) Calcarenites Pliocene-Miocene); (5) Mesozoic Limestones; (6) Fresh water in limestones; (7) Salt ater in limestones.



ig. 10 - Chemical composition on Piper diagram: (1) Adriatic sea water; (2) Formation water from a hydrocarbon well; (3) Ground water from well; (4) San Nazario spring-water; (5) Rain water; (6) Perched spring water.

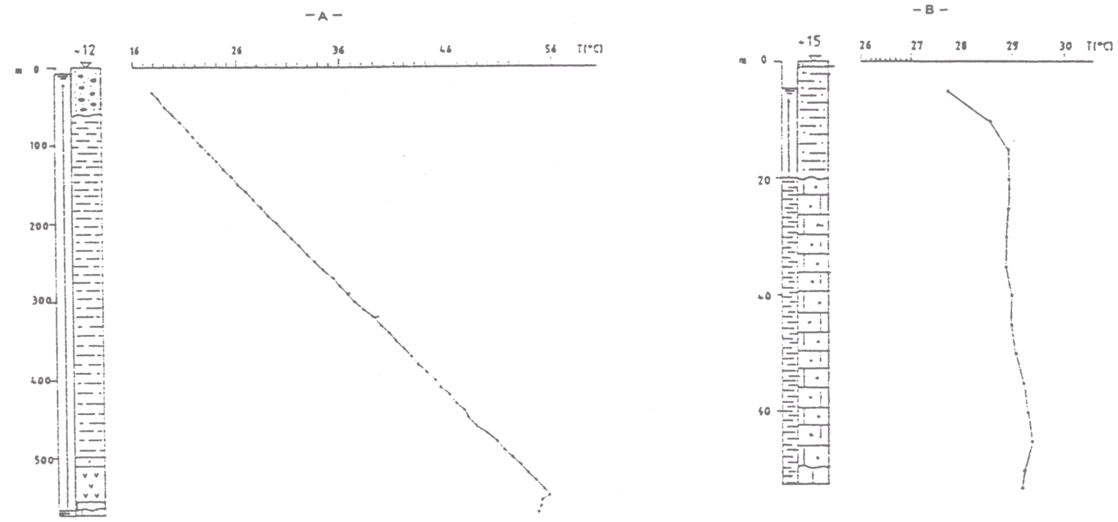


Fig. 11 - Temperature log of well W9 (a) and well W2 (b)

water pumped from the well and the formation water can be classified as chlorurate-alkaline waters and have the same composition as sea water, while the point representing the San Nazario Spring is located between the points representing those waters and the rain water collected at San Marco in Lamis, or the water of the perched spring uncontaminated by sea water.

Water from pumping wells also contain hydrogen sulfide.

## NEW MEASUREMENTS

In order to define the thermal regime of the area west of San Nazario, and the salt content distribution in that area, several series of mesurements were taken from a Fig. 9 number of wells.

### Temperature logs

Temperatures were measured in winter, when the aquifer is not disturbed by pumping. A three-lead platinum resistance probe connected to a four decades Wheatstone bridge was used; the device senses temperature changes as low as 0.01 °C. In each well, temperature measurements were taken every 10 m.

The area was found to have varying temperature gradients: those observed in the clay cover are higher than the average regional value which is about 21 °C/km (MONGELLI et al, 1983); hence, deep temperatures are abnormally high, up to about 55 °C at 500 m down the well W9 (Fig.11a); the gradients observed in permeable carbonate rocks are almost null, but shallow temperatures are high: well W2 is an example (Fig.11b).

Fig. 12 shows the geological and geothermal cross-section obtained by using temperature data: isotherms follows the carbonate basement and rise abruptly along the fault close to the San Nazario spring.

This figure seems to suggests that thermal supply to the spring originates in the

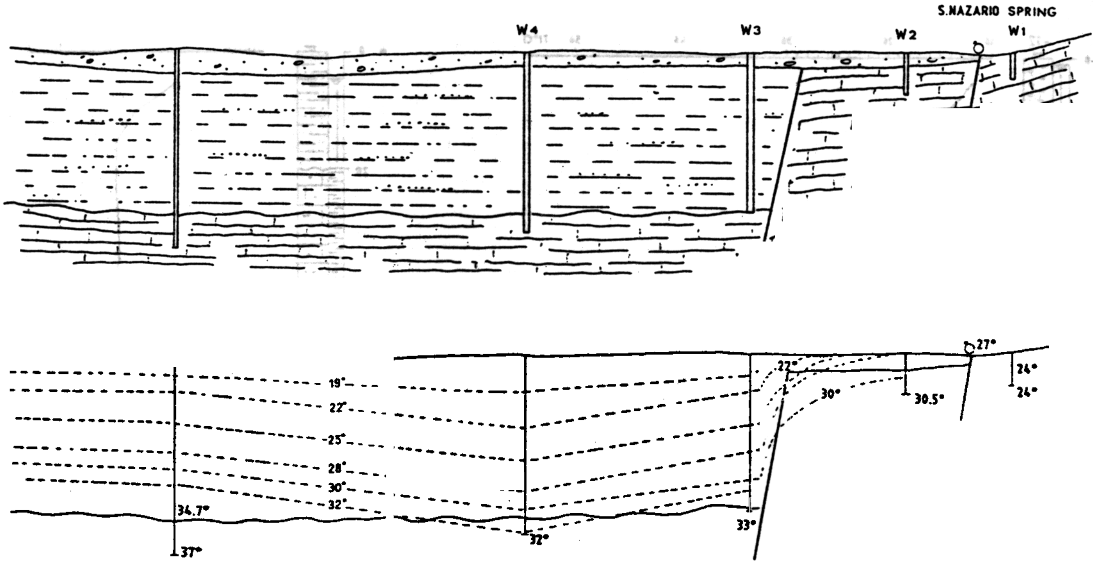


Fig. 12 - Geothermal cross-section of the area East of San Nazario spring; temperature values are in ° C.

deep limestone to the west: but where the heat actually comes from is yet to be understood.

## Salinity and piezometric level measurements

Water salinity and piezometric level were measured in several wells.

Water salinity in the wells (salinity logs) was evaluated by in-situ resistivity measurements with instruments incorporating a Wheatstone bridge. Maximum depth of measurement was 200 m.

Salt content in the water column was found to vary little from the watertable to the bottom of the wells.

The highest increase (about 2g/l), was recorded in the well W7, located along the fault at the western border of the promontory (Fig. 13).

Salinity of pumped water samples was also evaluated by measuring conductivity at ambient temperature.

Generally, lower salinity levels (1-2 g/l) are found in the wells yielding cold waters; higher salinity (2-5 g/l) was recorded in the wells with warmer waters. It was also found that the highest increments in salinity and higher temperatures are related to the position of faults.

All the data obtained are relative to 18 °C and are plotted vs. temperature (fig.14) measured with a mercury thermometer with an accuracy of 0.1 °C. The graph shows that the two parameters are linearly correlated.

Water levels were measured with the electric-tape method, without pumping, in order to acquire information on the hydraulic gradient and the direction of ground water flow. Ground water inflows SW of Lake Lesina are supplied by rain water falling onto the Poggio Imperiale-Apricena area; the hydrostatic head decreases North-Eastward and the gradient is 0,3%. These data confirm the results of COTECCHIA & MAGRI (1966).

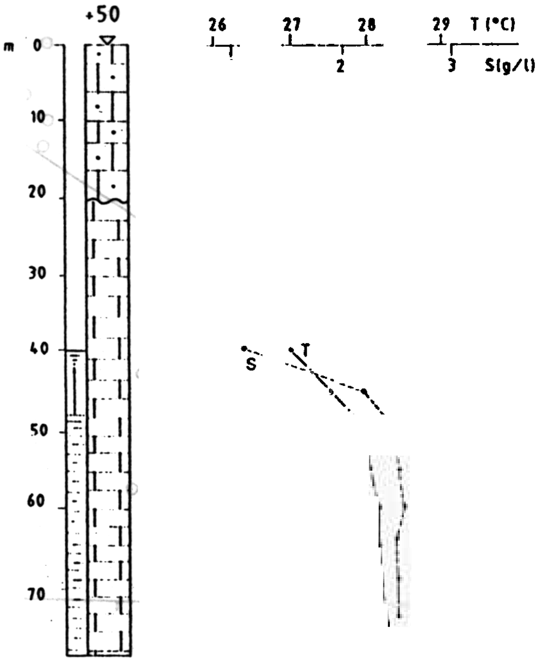


Fig. 13 - Temperature-salinity log of well W7.

## SECOND (OR FAULT) MODEL

In order to evaluate by how much ground water temperature changes as water rises along a fault and flows at a shallower level, we propose the following model.

Consider (Fig.15) an aquifer of thickness h at a depth $d+d_1$, in which water flows in the x direction and suddenly ascends along a fault (lying in the x,y plane) into the perched aquifer at depth d.

In the positive x-region, heat flow density is given again by

$$q_n = q_c + q_s$$

where $q_c = h\,m\,c \cdot \frac{dT}{dx}$ is the heat flow density gained by the water

$m = v\,\gamma_w\,p$ (Kg $m^{-2}$ $s^{-1}$) is the mass-flow rate of the water
$v$ = pore velocity
$\gamma_w$ = water density
$p$ = porosity (water yield)
$c$ = water specific heat

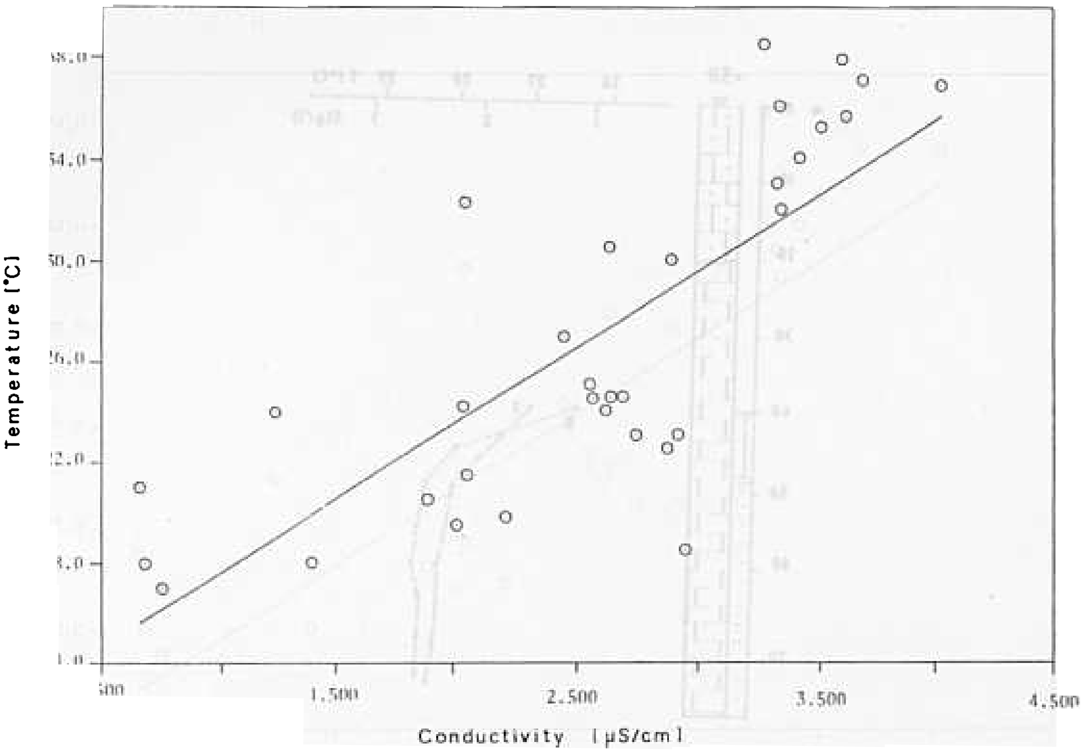


Fig. 14 - Conductivity (at 18 °C) vs. temperature in water samples from wells.

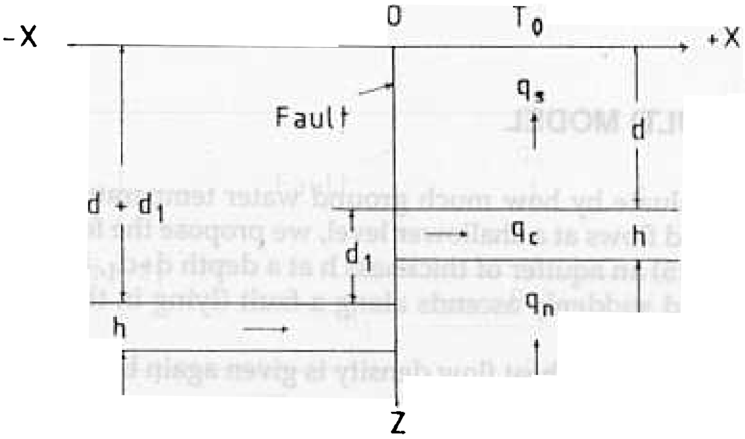


Fig. 15 - Thermal model of flow influenced by the presence of a fault (by HEANEL & MONGELLI, 1988).

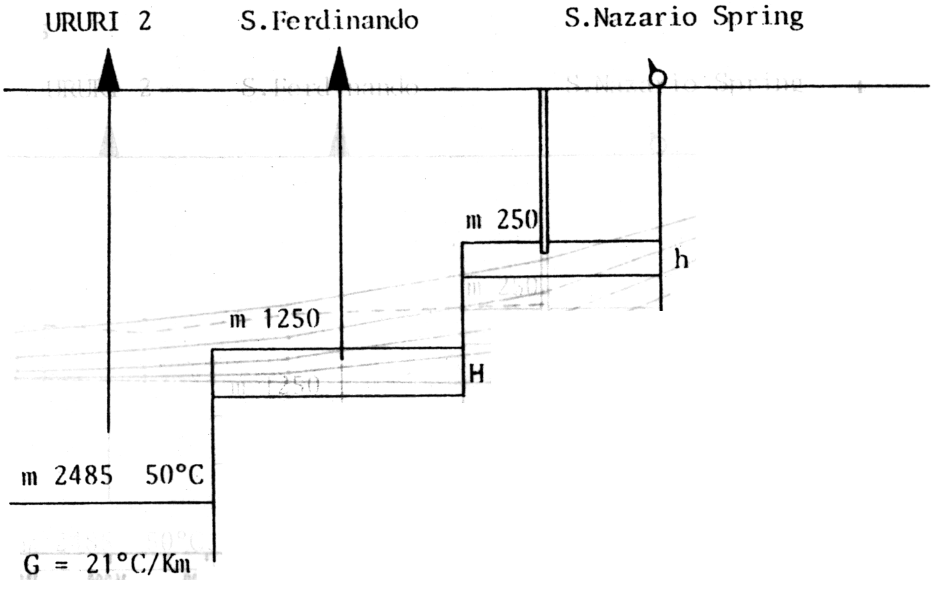


Fig. 16 - Schematic model of the hydrogeological cross-section shown in fig. 9a.

Using the approximation that in the aquifer

$$\frac{\delta q}{\delta z} = \frac{qc}{h}$$

then the temperature for the positive region at the top of the aquifer is (HAENEL & MONGELLI, 1988):

$$T(x)=T_0+d\ \mathrm{grad}T+d_1\ \mathrm{grad}T\ \exp\left(-x\ \lambda/h\ m\ c\ d\right)$$

where $T_0$ = temperature at ground surface

gradT = undisturbed temperature gradient
$\lambda$ = rock conductivity

Fig. 16 is a geological sketch from the San Nazario spring to the "Ururi 2" well. From this well a geothermal gradient of about 21 °C/Km has been obtained (MONGELLI et al., 1983). Using this data, the temperature at the top of the limestone is ~50 °C at 2485 m b.g.l. The water first jumps along the first fault to 1250 m b.g.l.; then along the second fault up to 250 m.

To calculate the temperature trend at the top of the aquifer, we assumed the values K= 10-4 and 10-6 m/s for the permeability of the limestone and the values 20, 50, 70, 100, 150 m for the thickness of the aquifer (that is, the shallower part of the aquifer which participates in the flow). In this way we obtained several sets of curves for the first and second fault and we compared the temperature measured at the top of the aquifer east of the Fortore River to the curves obtained for the second fault. The best fit is obtained with the curves characterized by K= 10-4 m/s, the thickness H between

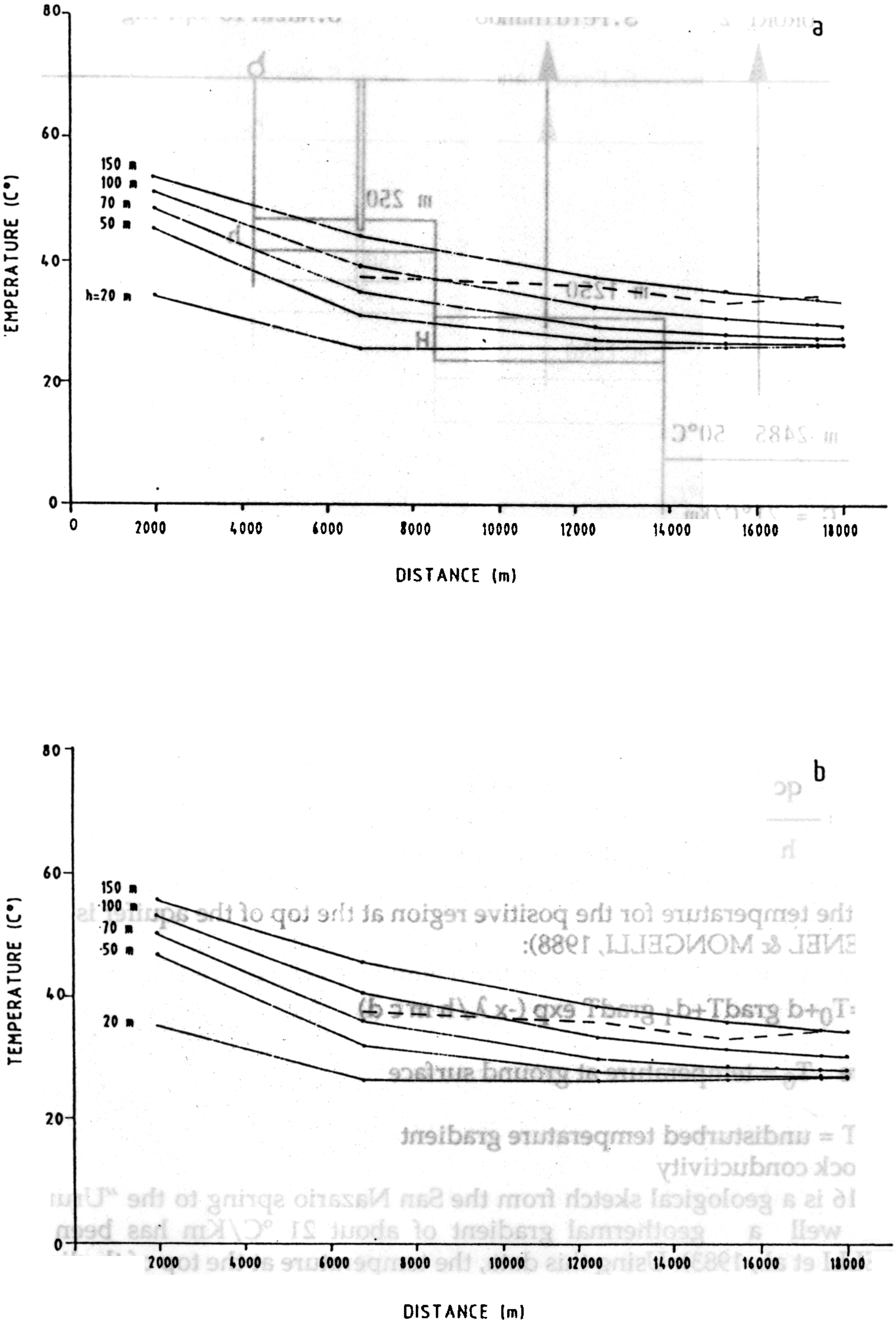


Fig. 17 - Fitting of observed (dashed line) and calculated temperatures (continuous lines) for $K=10^{-4}$ m/s, d+d1= 1250 m; a) H = 100 m; b) H = 150 m

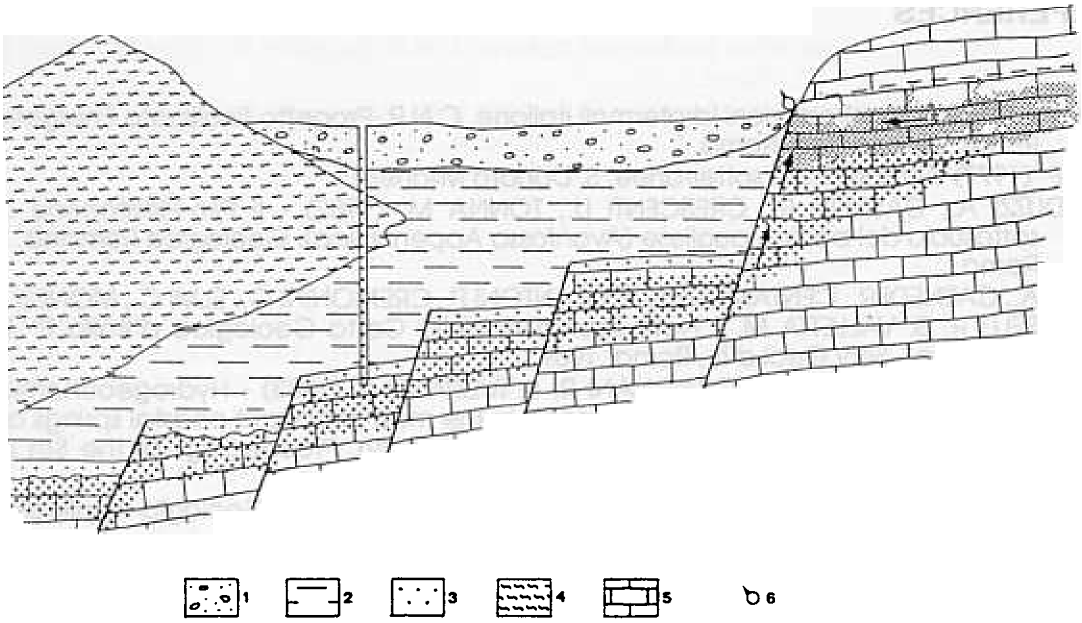


Fig. 18 - Schematic hydrogeological cross-section showing the thermal water circulation system in Mesozoic limestones and the mixing between waters flowing from the deep horizons and from the Gargano.

50 and 150 m and thickness h between 70 and 150 m (Fig. 17a,b).

In the last section of the profile, from borehole W9 to the San Nazario spring, water temperature at the top of the limestones drops by 4-5 °C over 2 Km.

We believe that this strong decrease may be attributed to the mixing of the water from deep levels with the cold fresh water flowing from the Gargano Promontory.

## CONCLUSIONS

This study suggests that San Nazario thermal spring is mainly a surface manifestation of the deep ground water rising along a permeable fault zone.

Schematically, the circulation is as follows (Fig. 18): brackish warm waters, confined at 1500-2000 m in the fissured limestone layers beneath the clay cover, flow upwards to the surface while retaining most of the heat. Near the surface, these waters mix with the cold fresh water from the Gargano Promontory.

The faults represent the preferential upward paths of the warm water, and allow them to travel deep without losing much heat.

The proposed hydrogeological and physical models can also apply to others similar hydrogeological situations, where thermal ground waters spring along contacts by faults between Mesozoic limestones and the quaternary impermeable deposits.

It is important to note that thermal springs can also be found in areas characterized by a low geothermal gradient if groundwater can flow up towards the ground surface.

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