A HYDROTHERMAL SYSTEM ALONG THE COASTAL AREA OF FRIULI - VENEZIA GIULIA REGION (NE ITALY)

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Key words:
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Abstract

In the Friuli-Venezia Giulia region thennal waters are present in mainly Quaternary confined aquifers along the Adriatic coastal belt between the Tagliamento and Isonzo rivers. A large number of wells, drilled to depths varying between 150 and 500 m, discharge water with temperatures up to 54 °C, which is utilized in direct uses.
Although characterized by low salinity, these waters belong to a regional circulation that mainly develops from Alps and Prealps areas. Geophysical data indicate the presence of an important structural ridge made up of a Mesozoic carbonate sequence along the coastal belt at depths of around 700 m. Temperature distribution maps at 300 and 500 m depth show that the temperature maxima correspond to the structural highs.
These observations suggest that the waters of the Quaternary aquifers could be heated by conductive heat transfer from the underlying carbonate formations. in which a convective circulation of thermal waters is hypothesized.
The thermal waters within the Mesozoic carbonate complex, a potential reservoir, could be a future target for a wider utilization of the low-enthalpy geothermal resources of this region.

1. INTRODUCTION

The Friuli-Venezia Giulia region is located in the north-eastern part of Italy (Figure 1)

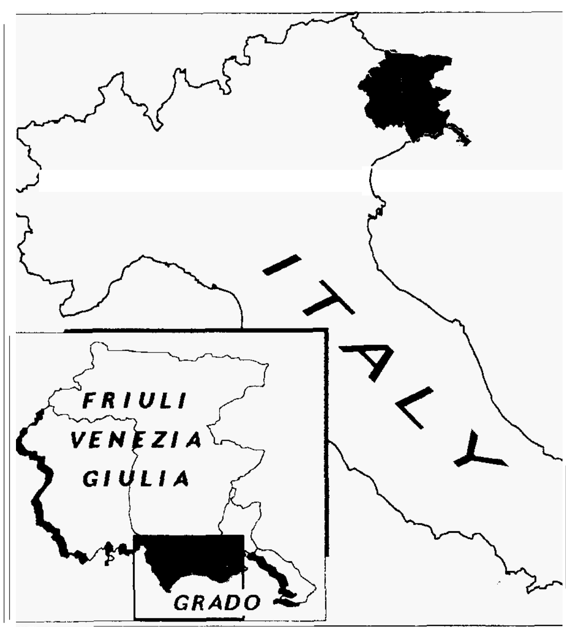


Figure 1. Friuli-Venezia Giulia region and location of the study area.

A study of the published thermal and structural data of this region led us to outline a large area of geothermal interest in the lower Friuli plain along the Adriatic coastal belt between the rivers Tagliamento and Isonzo. The thermal data consist mainly of the temperatures of the waters delivered by a large number of wells (up to 54 °C). These wells are fed by aquifers in Quaternary and Miocene clastic formations. The size of the area (~1000 km^2) and the temperature stability of the aquifers, that have been exploited for a number of years, mean that this area is of some commercial interest.

As the water temperature in several zones is a linear function of the depth of the aquifer exploited, it has been assumed that in the Quaternary and Tertiary formations the heat is transferred upwards by steady-state conduction from the top of the Mesozoic carbonate formations existing at depth. The temperature at the top of the carbonate formations has therefore been calculated by thermal gradients estimated in the overlying formations.

As the results obtained could be of a practical interest, a study has been undertaken to better define the targets at depths greater than the wells drilled so far. The aim is to evaluate the resource present in the carbonate formations. The presence of a thermal water circulation in these formations could lead to a wider utilization of low-enthalpy geothermal resources in this region.

2. GEOLOGICAL AND STRUCTURAL SETTING

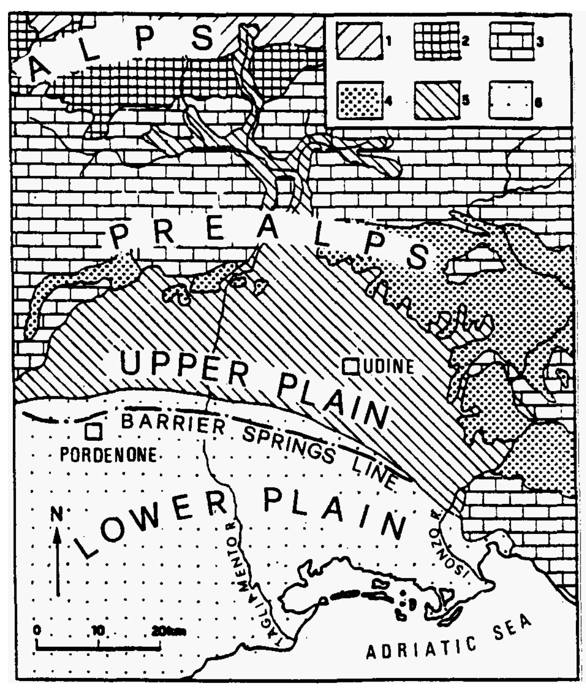


Figure 2. Hydrogeological sketch map of the Friuli plain and Alpine arc. 1) Low-permeability plutonic and metamorphic rocks (Palaeozoic-Triassic); 2) locally penneable sandstones, limestones. dolostones, mark and evaporites (Triassic); 3) high-permeability carbonate formations (Mesozoic); 4) low-petmeability terrigenous deposits (Eocene-Paleocene): 5) mainly gravelly continental deposits (Quaternary): 6) continental and marine gavels, sands and clays (Quaternary).

The geological setting of the study area (Figure 2) is characterized by a cover, made up of Neogene and Pleistocene clastic sediments. that has been deposited over Eocene-Oligocene Flysch formations; these formations overlie a Mesozoic, mainly carbonate sequence with thicknesses up to 6-7 km, known as the Friuli Mesozoic platform (Amato *et al.*, 1977; Cati *et al.*, 1987a,b; Harnaba, 1990). Due to the discontinuity of the Pliocene deposits. generally the Quaternary sediments directly overlie the Miocene molassic or Eocene flyschoid substratum.

In order to characterize the area structurally, all available geological and geophysical data were gathered and reviewed, including stratigraphy of wells, seismic lines and gravimetric data. These data were utilized to reconstruct the buried features in the study area. Three horizons were defined: 1) bottom of the Quaternary (Figure 3); 2) top of the Oligocene-Eocene Flysch (Figure 4); *3)* top of the Mesozoic Carbonate (Figure 5).

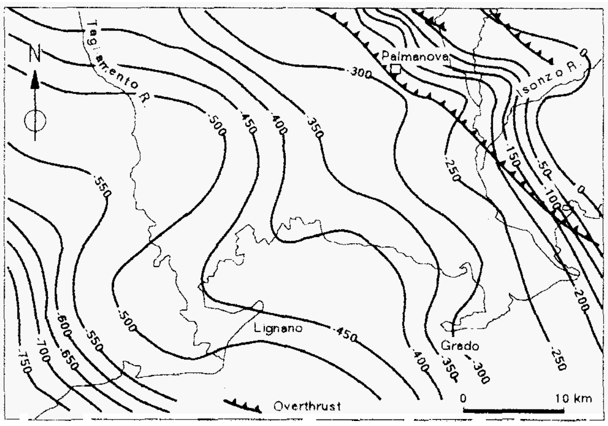
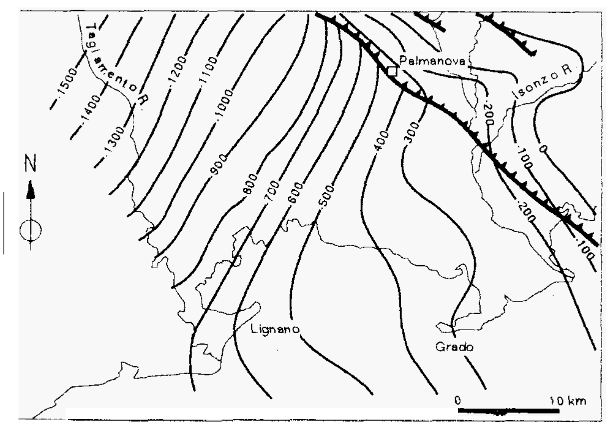


Figure 3. Isobaths (m) of the bottom of the Quaternary deposits



gure 4. Isobaths (m) of the top of the Oligocene-Eocene Flysch.

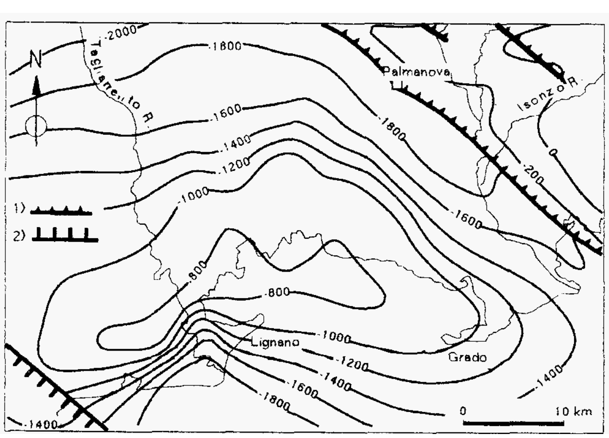


Figure 5. Isobaths (m) of the top of the Mesozoic Carbonate.
1) Overthrusts, 2) direct fault.

The Quaternary deposits thicken from NE to the SW. The Flysch unit thickens to the NE and adds a minimum thickness to the axis of the actual zone of the carbonate structural high. The most interesting structure of the Mesozoic carbonate formations, that constitute the continuous substratum of the region, is that present in the Cesarolo - Grado area (Figure 9). where a ridge can be found running E to W and reaching to as shallow as approximately 700 m.

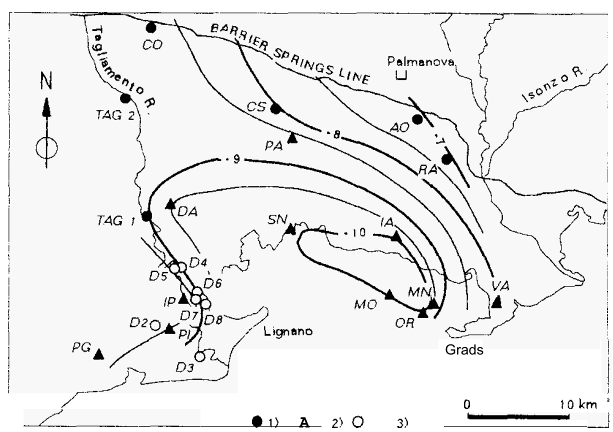
3. HYDROGEOLOGICAL FRAMEWORK OF THE FRIULI PLAIN

From a hydrogeological point of view, the Friuli plain can be subdivided into two sector with differing characteristics (Figure 2). The upper plain extends from the foot of the Prealps to the barrier springs. It is mainly made up of gravelly Quaternary deposits in which a unconfined aquifer is present. This aquifer is fed by streams originating in the eastern sector of the Alps and Prealps. It constitutes a reservoir with a remarkable capacity for absorption and storage of water that partly outflows at the barrier spring and partly feeds the less permeable deposits of the lower plain.

The lower Friuli plain is made up of Quaternary clastic deposits with different degrees of permeability. generally overlying Miocene molasse formations with a fair permeability, and, in some places, Pliocene sandy formations with low permeability. Below the Miocene formations are the alinost impermeable Paleogene flyschoid formations, which overlie a thick Mesozoic carbonate series (Cati et al., 1987 a,b) characterized in its upper part by a fairly good permeability. At least 8 different aquifers have been recognized within the first 450 m depth of the lower Friuli plain (Stefanini and Cucchi, 1977). In particular. the Quaternary sediments constitute a multi-layered aquifer, which, confined at the top. is possibly interconnected at depth. In general there is a gradual thinning of the aquifers, and reduction in the grain size of the lithic material, moving towards the sea. In the coastal area the deepest Quaternary aquifers with thermal waters are located at a depth of roughly 400 m, near the mouth of the Tagliamento river, and approximately 250-300 m in the area of Grado lagoon. Thermal waters are also present at the top of the Miocene formations that are tapped, however, by few wells.

4. GEOCHEMICAL CHARACTERISTICS OF WATERS

Table 1a reports the thermal, chemical. and isotopic data of water samples from 4 springs, 11 wells and the Tagliamento river. The geochemical characteristics of seven other wells, near the mouth of the Tagliamento river. are listed in Table 1b. and were taken from Dal Prà and Stella (1978). The location of the sample-points is shown in Figure *6.*



gure 6. Location of water sample-points considered and listed in Tables 1a,b, and $\delta^{18}O$ distribution from water - points 1 and 2. 1) Springs and Tagliamento river; 2) water-wells sampled in 1993; *3)* water-wells. from Dal Pra and Stella (1978).

With the exception of the Isola Picchi well. the well waters have a remarkably low salinity, between 300 and 800 mg/l, despite coming from circulation characterized by rather long residence times, as indicated by the low **tritium** content.

The isotopic composition values of oxygen and hydrogen fit in the world meteoric line (Figure 7). The contents in ^{18}O and ^{2}H gradually decrease as they approach the coast where, in an area between the coast and the lagoon islands. the $\delta^{18}O$ values are about -10‰ (Figure *6).*

Tab. 1a

Sampling point		Symbol	T°C	Na	K	Ca	Mg	HCO_3	SO_4	Cl	TDS	$\delta^{18}O$	δ^2H	tritium
Tagliamento	River	TAG1	n.d.	3.1	1.1	87.3	26.6	225.7	170.0	5.5	519	-8.72	-59.0	15.7
Tagliamento	River	TAG2	n.d.	2.6	1.1	86.8	23.3	225.7	161.0	4.3	505	-8.70	-58.4	14.1
Castionis	Spring	CS	12.8	2.0	0.7	104.0	30.8	256.2	55.5	4.1	461	-8.03	-53.5	37.3
Codroipo	Spring	CO	11.7	2.2	0.7	96.6	27.6	211.1	112.0	5.6	460	-8.71	-56.6	15.7
Aiello	Spring	AO	13.0	4.3	0.9	94.6	27.6	305.0	26.1	8.0	471	-7.24	-47.6	17.9
Ruda	Spring	RA	12.3	2.1	1.3	93.2	21.6	286.7	16.4	6.6	432	-6.97	-43.4	12.3
Pampaluna	Well	PA	22.8	32.6	1.2	36.1	17.0	244.0	0.1	2.5	353	-8.80	-59.0	0.3
Pacchiega	Well	PG	43.0	72.1	4.6	8.3	2.4	219.6	0.1	1.2	332	-8.46	-56.1	0.0
Pasti	Well	PI	47.8	114.0	5.4	7.7	2.6	301.3	0.1	9.7	466	-8.93	-61.3	0.6
V.Artalina	Well	VA	20.0	32.2	6.6	40.3	18.7	250.1	10.5	4.7	381	-8.07	-52.5	2.6
Morgo	Well	MO	35.0	91.7	3.8	18.9	6.3	292 8	0.1	10.5	444	-9.96	-68.7	0.7
Isola.Picchi	Well	IP	43.4	404.0	17.1	7.4	3.5	549.0	0.3	317.0	1330	-8.24	-55.6	0.2
Orbi Marin	Well	MN	22.3	43.5	4.9	35.7	15.0	262.3	8.3	1.0	387	-8.91	-59.5	0.0
Idrovora	Well	IA	24.0	61.9	2.8	24.7	9.6	257.4	0.2	2.6	372	- 10.00	-67.2	0.9
S.P. D'Orio	Well	OR	23.9	130.0	5.3	18.2	5.5	311.1	0.1	53.2	539	-10.01	-67.2	1.1
Latisana	Well	DA	27.2	84.3	0.8	21.5	8.3	286.7	0.1	10.6	429	-9.58	-64.9	0.0
Spingion	Well	SN	22.4	46.8	1.2	30.7	13.5	248.9	0.1	1.0	357	-9.81	-66.8	0.0

Table 1b

Sampling point	Symbol	T°C	Na	K	Ca	Mg	HCO_3	SO_4	Cl	TDS
Well 2	D2	43.2	84.3	5.2	8.9	2.6	260.0	0.0	7.0	389
Well 3	D3	27.4	111.0	11.9	7.7	2.1	334.0	0.0	7.0	489
Well 4	D4	29.2	137.6	2.7	9.2	6.4	415.0	0.0	20.4	608
Well 5	D5	35.0	176.1	3.9	13.5	8.9	482.0	0.0	48.2	751
Well 6	D6	39.0	195.3	4.9	13.5	3.4	558.0	0.0	27.5	822
Well 7	D7	40.6	190.9	5.4	3.9	1.5	515.0	0.0	12.5	749
Well 8	D8	35.4	185.0	4.8	5.7	4.2	531.0	0.0	15.5	765

Tables 1a. 1b - Thermal, chemical and isotopic data of a few water samples from the lower Friuli plain. Chemical concentrations are in mg/l, $\delta^{18}O$ and δ^2H in permil vs SMOW, and tritium in T.U. The data in Table 1b are fiom Dal Pra and Stella (1978).

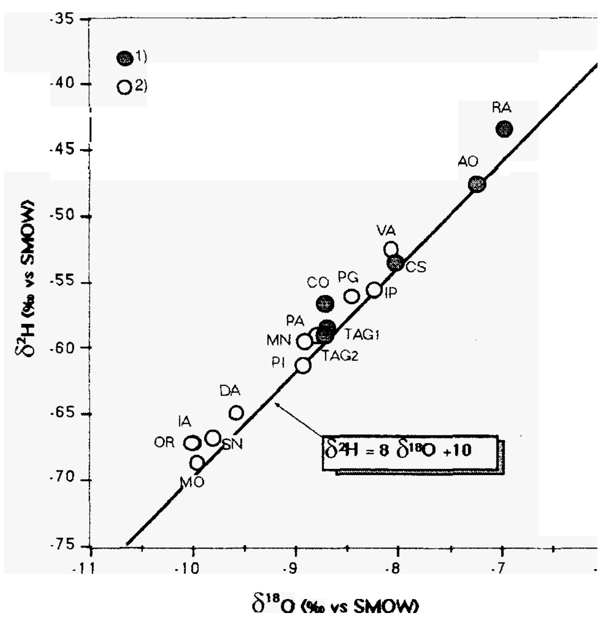


Figure 7. Isotopic composition of waters from the lower Friuli plain. 1) Springs and Tagliamento river; 2) water-wells (see Table 1a).

Assuming an altimetric variation in ^{18}O for the meteoric waters of 0.25 permil/100m (Eriksson, 1983), the feeding elevations of the groundwaters should differ by about 1200 m, with the isotopically lighter waters precipitating at an elevation of approximately 1500 m (Della Vedova *et al.*, 1987). The isotopic data indicate, therefore, that the circulations begin in the Prealps and/or the Alps and flow towards the sea.

The trend hypothesized for these waters is presented in Figure 8, which shows their Ca concentration as a function of Na, with symbols proportional to the total salinity. Most of the waters lie along a curve, which begins with a composition typical of the waters of the springs and the Tagliamento river, and continues, with a rapid loss of Ca and a

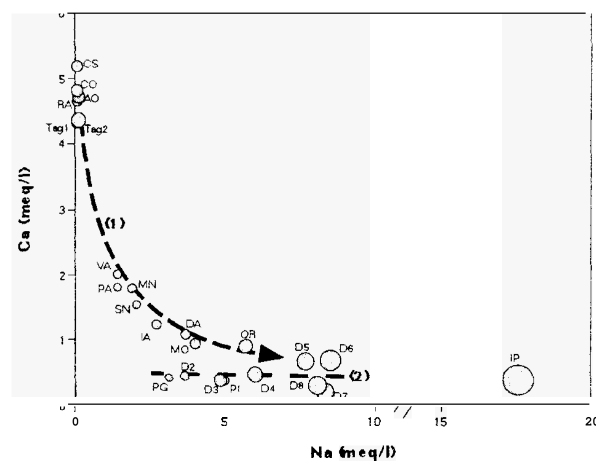


Figure 8. Ca vs Na with symbols proportional to total salinity. Curve 1: waters from the lower Friuli plain; curve 2: groundwaters from the mouth of the Tagliamento river.

general decrease of its stable isotope content (Table 1a), towards waters that are increasingly rich in Na, more saline and warmer, i. e., similar to those of the Tagliamento river mouth (Tables 1a, 1b). One possible explanation to this trend is that the fluids. originally of the Ca-HCO_3 type, gradually become saturated in calcite, partly because of the increase in temperature during their deep circulation. The gradual increase in HCO_3, probably of biogenic origin, is neutralized by their acquisition **of** Na. The temperature increase near the tup of **the** carbonate structure would trigger the release of Na by both ionic exchange and hydrolysis of feldspars (Grassi, in press).

5. TEMPERATURE DISTRIBUTION

The temperature data in the study area come **from** 2 deep oil wells (Agip, 1977) and about 200 shallow water wells drilled to a maximum depth of 600m (Dal Prà and Stella, 1978; Stefanini, 1980; Berlasso **et al.**. 1989; Barnaba, 1990; D.I.N.M.A., 1993). The location **of** these wells is shown in Figure 9. The available data are:

- non-stabilized temperatures measured during drilling stops in the Cavanella and Cesarolo deep well drilled for hydrocarbon exploration. The corresponding stabilized temperatures were estimated by an empirical statistical method developed by Squarci and Taffi (1984);

distribution at depth it has been assumed that the fonnations overlying the Mesozoic carbonate substratum are heated by a steady-state conductive heat transfer. This hypothesis is supported by the fact that in various zones of this area the temperatures of multi-layered aquifers tit in the temperature profile characteristic of this heat transfer mechanism (Figure 10).

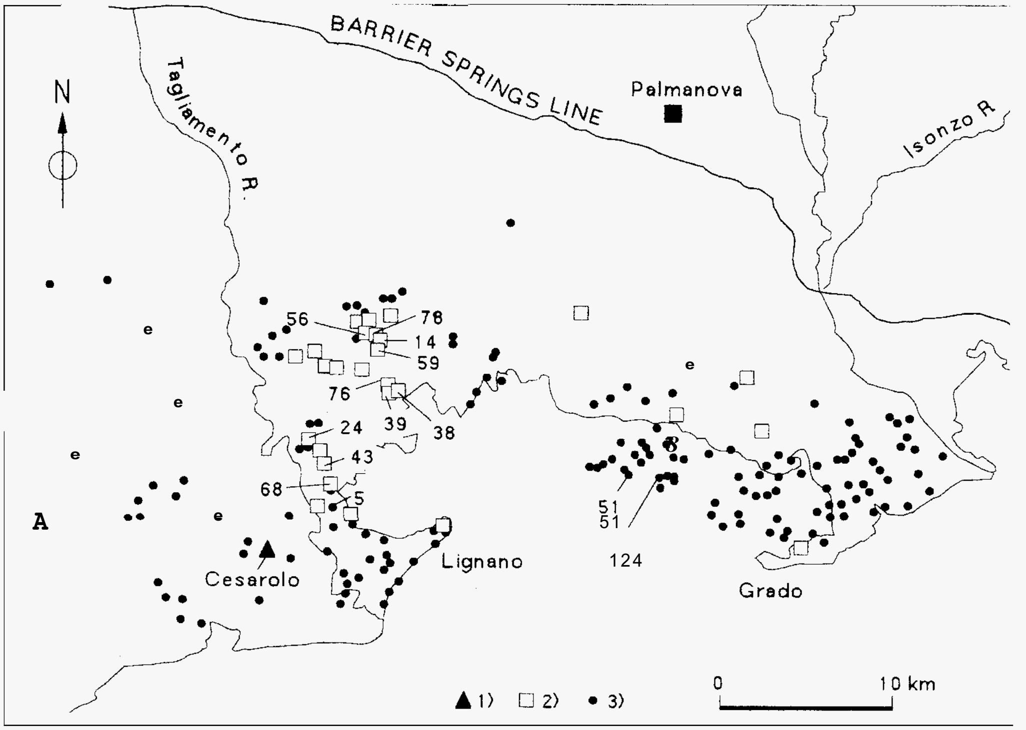


Figure 9. Location of the wells considered for the reconstruction of the temperature distribution at depth. 1) Deep wells for hydrocarbon exploration. 2) Water wells with continuous temperature logs. 3) Water wells with temperatures measured at the well head.

- delivered fluid temperature, measured at wellhead for most of the water wells;

- continuous temperature logs run in flowing water wells (Berlasso *et al*.. 1989).

No stabilized temperature profiles were available for deep wells spread over the entire study area. Therefore, to reconstruct the temperature

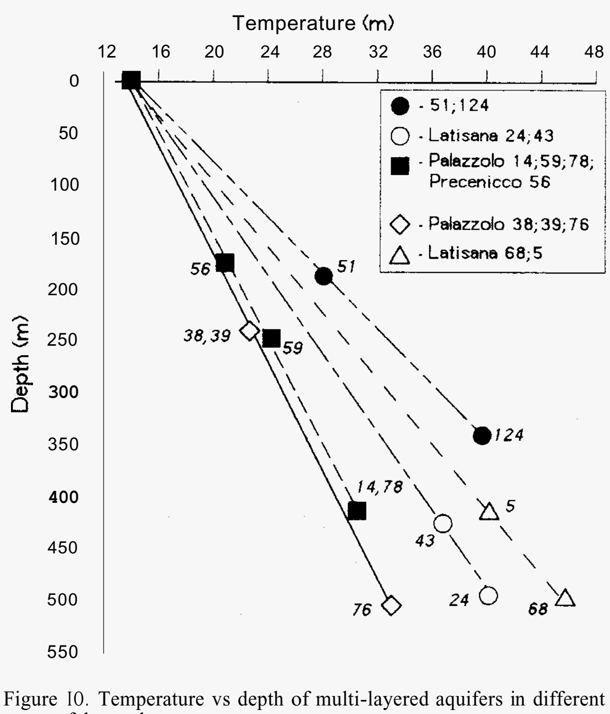


Figure 10. Temperature vs depth of multi-layered aquifers in different zones of the study area.

The temperature at given depths for a selected number of wells was then calculated using Bullard's equation (1939). The thickness of the formations overlying the Mesozoic carbonate substratum was evaluated from the structural reconstruction. Thermal conductivities of 1.8, 2.3 and 2 W/m K were assigned to the Quaternary and Miocene sediments, and the Flysch unit, respectively. Temperature maps at 300 and 500 m dcpth were then compiled (Figures **11** and 12). These maps show that the temperature maxima, –40 °C at 300 m and 50 °C at 500 m, correspond to the eastern and western summits of the structural high of the Mesozoic carbonate platform. Outside these zones there is a wide area where the temperatures arc higher than 25 and 30°C at 300 and 500 m depth, respectively. Thus, there is a wide area of interest for low-temperature direct uses.

The temperatures estimated at the top of the carbonatic complex (a potential reservoir) are 60 - **70** °C in correspondence to the summits of the structural high; they decrease abruptly southwards and gradually northwards, especially **in** the Tagliamento river zone (Figure 13). The non-uniform temperature distribution at the top of the carbonate complex could be due to the presence of convective cells in the more permeable part of this complex

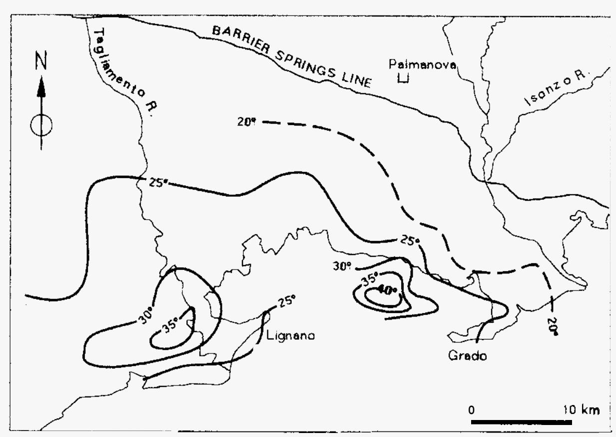


Figure 11. Temperature distribution at 300 m depth.

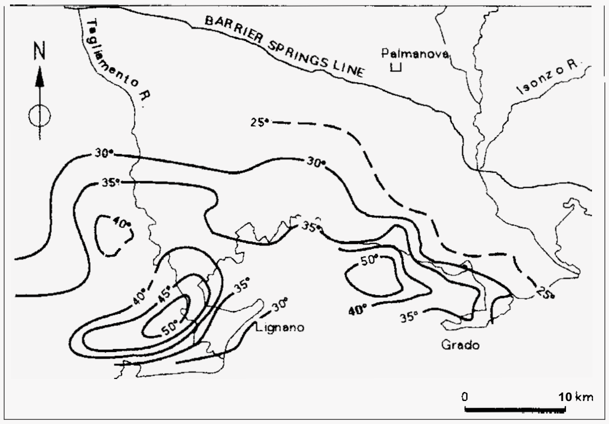


Figure 12. Temperature distribution at 500 m depth.

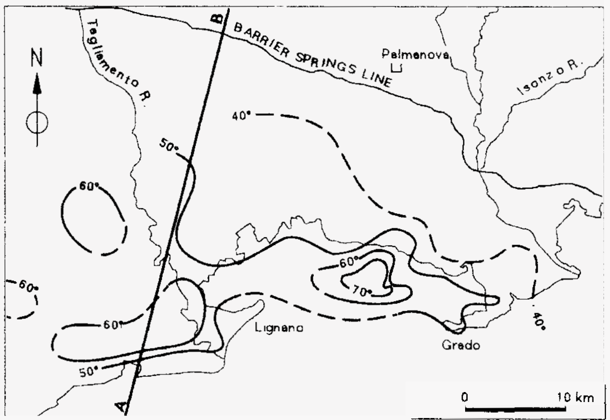


Figure 13 Temperature distribution at the top of the Mesozoic carbonate formations AB. trace of cross-section of Figure 15

A thermal gradient of 30°C/km is estimated in the impermeable interval between 2700 and 4300m depth in the Cesarolo well. This gradient and the thermal conductivity of the dolomitic **rocks, 3.7** W/m K, give a deep conductive heat-flow density value **of** 110 mW/m^2. This is similar to the mean surface heat-flow density value, since the mean thermal gradient in the area of the Cesarolo structural high is 60 °C/km in the Quaternary cover, which has a thermal conductivity of 1.8 W/m K.

6. CONCLUSIONS

In Friuli-Venezia Giulia region meteoric waters from the Alpine and Prealpine areas, as indicated by isotopic data, flow within Quaternary and Miocene clastic deposits towards the coast, where, with temperatures up to 54°C, they are utilized in direct applications.

Despite belonging to a regional circulation, these fluids have a low

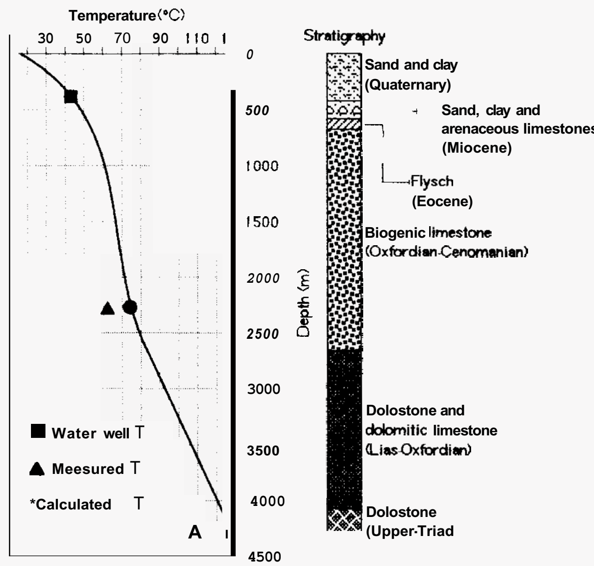


Figure **14.** Stratigraphy and temperatures of the Cesarolo well.

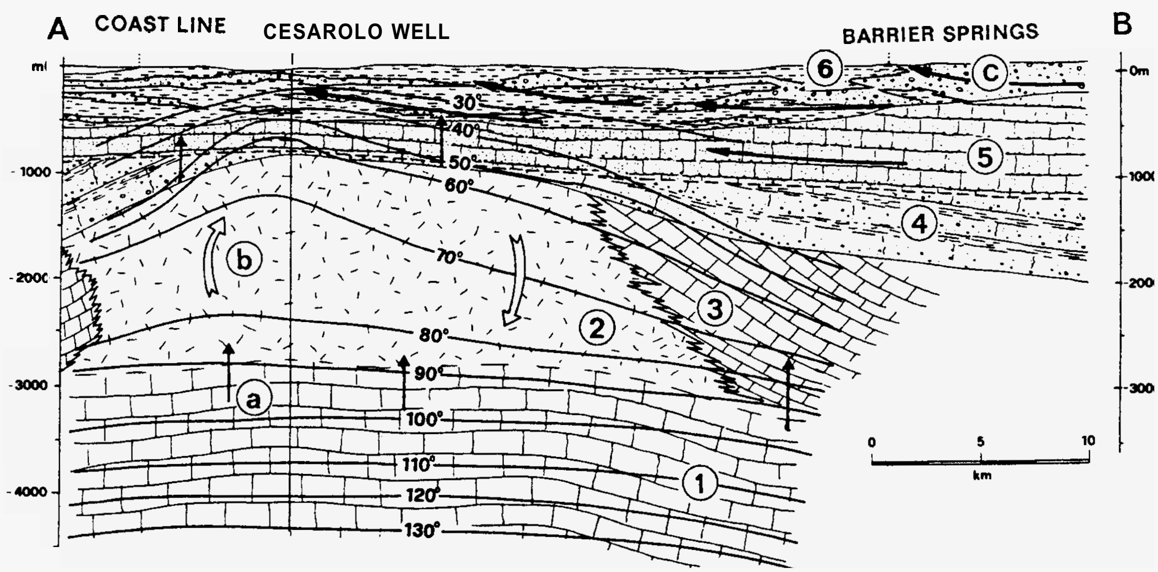


Figure 15 Schematic model of the hydrothermal rystem of the lower Friuli plain 1) Dolostone and dolomitic limestone (Upper Tnas-Lias), 2) platform l ıgenic limestone (Dogger-Upper Cretaceous), 3) slope and basin limestone (Dogger-Upper Cretaceous), 4) Flysch (Paleocene-Eocene), 5) arcosic sa lstone (Miocene), 6) fluvial and marine deposits (Quaternary), a) mainly conduction, b) mainly convection, c) shallow circulation path

From geocheinical observations and the reconstruction of the temperature distribution at depth we can infer that there is no need to hypothesize a rise of hot fluids through fractures to justify the 54 °C measured ın a well at about 500 m depth The anomalous temperature distnbution in the clastic aquifers can be explained by the convective circulation in the more permeable part of the carbonate formations (see Cesarolo well, Figure 14), by the presence of the structural high and by the conductive heat transfer in the overlying formations (Figure 15)

salinity. Their chemical coinposition indicates that they do not coine from the carbonate formations, as pointed out by the presence of brackish (1 < TDS ≤ 25 g/l) and saline (25 < TDS ≤ 250 **g/l**) waters in the study area at depths of over **600** m (Cesarolo and Cavanella wells; Agip. 1972). Fluids rising from the carbonate reservoir would have a much higher salinity. and would probably be more positive isotopically, a characteristic that has not been not found in the clastic aquifers so far.

The temperatures of these fluids are tied to conductive heat transfer from a geothennal reservoir in the more permeable upper part of the Cesarolo ridge, characterized by a nucleus of platform carbonates that overlie dolomitic fonnations and are laterally confined by low-permeability carbonate formations. This is a particularly favourahle setting for developing a convective circulation. The presence of a poorly permeable Flysch cover between the top of the carbonate and the Miocene and/or Quaternary aquifers limits heat transfer mainly to conduction.

This interpretation provides new objectives for research in the area of the lower Friuli plain. The presence of a vast carbonate structural high with a major axis of more than 40 km and a minor axis of 10 km suggests that deeper drillings should be targetted at exploiting the thermal waters within this structure. Temperatures between 60 and 70°C are expected at the top of the structure, at economically accessible depths (700 - 1200 m). Little is known as yet about the composition of the fluids in the Mesozoic carbonates. but comparison with analogous situations and the surveys carried out in the Cavanella and Cesarolo wells, indicate the presence of fluids with a medium-to-high NaCI content. With modem technology these fluids could be utilized efficiently and economically.

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