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ASPECTS OF GROUNDWATER AND SEAWATER INTRUSION PHENOMENA IN THE PIANA DEI COLLI (PALERMO - ITALY): THE INFLUENCE OF GEOLOGICAL AND STRUCTURAL FEATURES

SUMMARY

The Piana dei Colli (15 km^2), which is the Northern part of the Plane of Palermo, is constituted by Pleistocene calcarenite. This lies partly on an Oligocene marly clayey complex, and partly on the calcareous-dolomitic subsided blocks of the Mesozoic relief which surround it.

In the calcarenite, which is verypermeable because of its porosity, there is fairly superficial groundwater, exploited for centuries through wells. Its flow is affected by several local factors. The most important ones are the relationships with the sea and with the surrounding carbonaceous complex. The irregular morphology of the marly clayey substratum is also of particular significance. Chemical analyses of the groundwater have shown concentrations of Cl, SO_4, Na and K ions whose ratios are the same as in sea-water. In order to depollute the groundwater it has been proposed to let partly softened waste water into the ground. For such a project, however, detailed knowledge of the morphology of the aquiclude and of the water flow is necessary. It can be anticipated that localized inlets into the calcarenite will spread differently according to the morphology of the subsoil. Where the calcarenite is very permeable they will spread over long distances, whereas where they will meet morphological highs of the impervious bedrock, they will not affect wide areas.

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1. INTRODUCTION

The Piana dei Colli (Fig. 1), located North of Palermo and part of the Plane of Palermo itself, has been the object of a hydrogeological study carried out through resistivity survey and analysis of the data from the numerous water-search bore-holes made in the area. The groundwater has shown high concentration of Cl and Na ions of seawater origin. This phenomenon, which had been already observed by Mouton in 1961 [10] and reported by Castany [3],

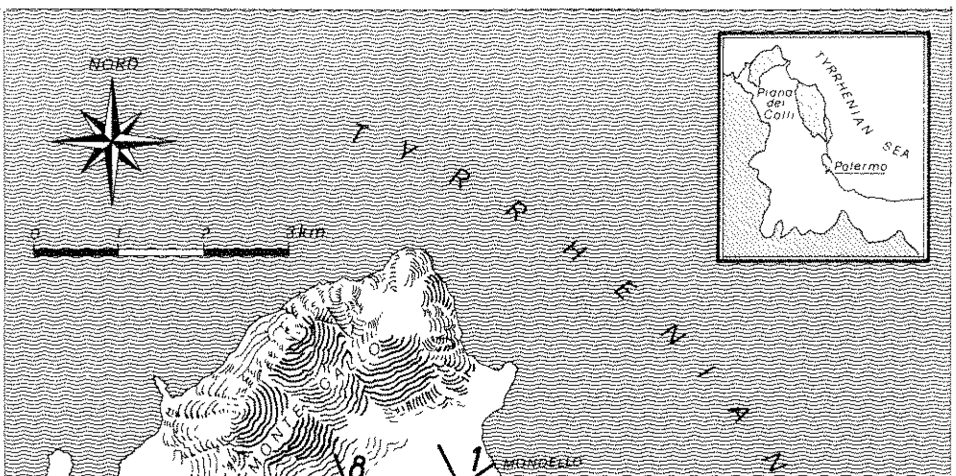

Fig. 1 – Chorography with marks of the sections.

was studied by Cimino et al. in 1971 [4], by Cusimano in 1974 [7] and by Alaimo et al. in 1979 [2]. The seawater intrusion phenomenon has considerably increased and widened in the latest years because of both water table exploitation and geologico-structural and hydrogeological features of the aquifer which affect the water flow.

2. GEOLOGICAL OUTLINE

The plane of Palermo (about 130 km^2) is surrounded by part of the « Palermo Mountains » to the S and W, by the Thyrrenian sea to the N and E and by the Eleuterio river to the S-E. Its height above sea-level ranges from a few metres to about 100 metres at the foot of the mountains. The Palermo Mountains are a part of the Appenninico-Maghrebide chain. This includes the Panormide Carbonate Platform, whose structural-stratigraphic units thrust over the units of the Imerese Basin in connection with the Plane. The grounds belonging to the Panormide paleographic unit are formed by a dolomitized limestone and limestone complex (Mesozoic-Paleogene). The grounds of the Imerese Basin (mesozoic-early Neogene) are made up of limestones, dolomitized breccias and marly limestones. All along the external boundary of the Plane, the carbonatic rocks cover the Oligo-Miocene formation (Numidian Flysch) formed by clay, marly clay with few lenses or thick layers of sandstones. On the Numidian Flysch (NF) and partially on the carbonatic rocks at the foot of the mountains, there are deposits of Pleistocene sandy clays and calcarenites. According to some authors the Plane is a graben, to others it is the result of a differential erosion of the marly-clayey substratum. We accept the first hypothesis for the Northern part of the Plane and the second for the Southern and South-Eastern parts. The Plane is divided into two sectors by a fractured carbonatic ridge from E to W, which links Pellegrino M. to Castellaccio M., passing through S. Lorenzo and Villa Spina (Niscemi). North of that ridge lies the Piana dei Colli and South of it the remaining part of the Plane (Conca D'Oro). The Piana dei Colli is a white calcarenite (CL) outcrop standard site. In the upper part it is quite hard, in the lower it is sandy (SC), friable and sometimes interbedded with sandy clayey layers (cm or dm), rich in Ostreidae valves. The calcarenites spread all over the Piana, except for a small area, Villa Raffo, where a small plate of Mesozoic limestone outcrops. They lie on the NF North of the carbonatic ridge, on subsided carbonatic and dolomitized blocks at the foot of Gallo M. and Castellaccio M. and on the NF and subsided limestones to the East (Pellegrino M.). In the middle part (Patti, Trapani, Villa Raffo) the calcarenitic complex from 9 to 12 m thick covers Pleistocene green sandy clays (S + LS) interbedded with white sands and remains of organic matter. These sandy clays lie partly on the subsided carbonatic rocks and partly on the NF. Morphologico-structural conditions determined by the structural highs of the dolomitized limestone complex (Villa Raffo) and the marly-clayey complex (Trapani-Pescia) which delimit a narrow depression, from NW to SE have favoured thick sandy-clayey sedimentation if compared to the overlying calcarenitic one. Near the suburb of Pallavicino (Villa Landolina) the calcarenites (40 m thick) lie on sands (S) and grey silty sands (LS) rich in fossiles, which are interbedded with thin layers of grey calcarenites (SCE) (early Pleistocene) (Tab. 1). Their substratum is the NF. The calcarenites thickness ranges from 5-7 to 70 m all throughout the Piana and depends on the morphology of the NF and of the dolomitized limestone substratum. Such morphology affects the flow of the groundwater. In the villages of Cardillo and Tommaso Natale the calcarentines (thickness range from 30 to 50 m) lie on Mesozoic dolomitized limestones. This feature, which widens Eastwards up to 2 km, has been verified through geoelectrical prospections and well observation and can be followed from NW (Tommaso Natale) to SE (S. Lorenzo). This feature can also be found along the Southern slope of Gallo M.

In the Eastern side of the Piana (Resuttana - P.zza Niscemi) both geoelectrical soundings and water-search bore-holes have gone through very thick calcarenites (40-70 m) which lie on dolomitized limestones similar to those of the Pellegrino M. (Fig. 2). The irregular morphology of the Pleistocene complex substratum is the result of Plio-Quaternary disjunctive tectonics, which determined direct faults from NW to SE. Such faults, which may show displacements of hundreds of metres, have interrupted the original thrust planes among the units which constitute the Palermo Mountains, with considerable effects on the Plane substratum.

3. HYDROGEOLOGY

Four lithological types with different permeability features can be found in the ground of Piana dei Colli.

1) Dolomitized limestone complex (CD): it is the Piana main aquifer and it is unevenly covered by the Quaternary calcarenitic plate. Its permeability depends on its high degree of jointing and karst. The tectonic phases have variously displaced the lithological sequences, giving rise to cataclasite bands and reducing the water flow in some areas (Tommaso Natale, Cardillo). Some boreholes and geolectrical prospections have reached the NF substratum of the carbonatic complex. It plugs the complex, determining preferential flow axes and water gathering in connection with drainage axes.

2) Marly-clayey complex (NF): it is the relative impervious of both the Pleistocene calcarenites and the dolomitized limestone complex, usually made up of a dark grey marly-clayey sequence and sometimes of crush breccias (cm). Interbedding with quartz sandstones is very rare.

3) Sandy-clayey grey complex (S + SCE + LS): this complex has been found through a series of direct surveys in the areas of ZEN Cardillo (Villa

TABLE 1 – Lithological types of the Piana dei Colli.

RECENT DEPOSIT	COVERING SOILS	R	Red organic silty soils	
PLEISTOCENE DEPOSIT	CALCARENITIC COMPLEX	CL	In the "CL" type it is possible to distinguish: * Cemented white calcarenites, frequently stratified. * Vacuolar white calcarenites, irregularly cemented. * Strongly cemented, irregularly shaped concretions ("ossa" or "noduli), with internodular voids sometimes filled with white sands.	Permeability coefficients range between 10^{-8} and 10^{-2} cm/sec
		SC	White sands, from loose to weakly cemented.	
		CC	Strongly cemented white calcarenite layers, from 5 to 10 cm ("cintuni").	
	SANDS and CLAYEY SANDS GREY COMPLEX	S	Grey sands rich in shell fragments, with layers of fine grey sandy gravels.	Permeability coefficients range between 10^{-8} and 10^{-6} cm/sec
		SCE	Grey cemented sands rich in shell fragments.	
		LS	Grey clayey silts with layers of grey sandy silts.	
OLIGOCENE MIOCENE FORMATION	MARL and MARLY CLAY ("CINOLFO")	NF	The marly clay formation includes weathered soft clay, tectonized clays, stiff marly clays and quartzarenitic layers or lenses.	Practically impermeable
MESOZOIC CARBONATIC COMPLEX	CARBONATIC ROCKS	CD	Limestones and dolomitized limestones.	High permeability due to fractures and karst

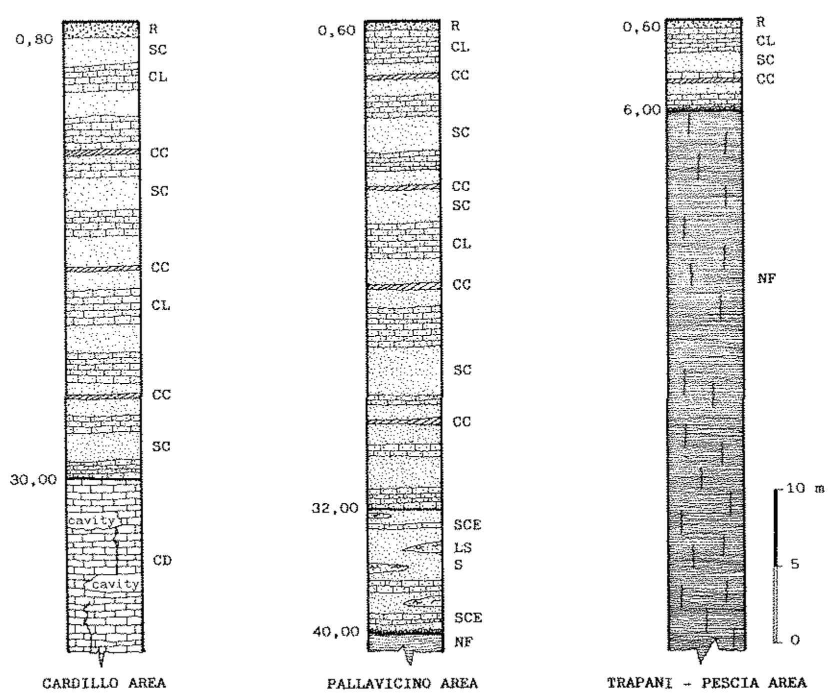

Fig. 2 – Lithological sequences typical of the Piana dei Colli.

Raffo), Fondo Bacchi, Patti and Pallavicino. Geoelectrical prospections have defined the bedrock, which is made up of the dolomitized limestone complex in the areas already mentioned, and of the NF East of them.

4) Calcarenitic complex (CL): it is the Piana dei Colli upper aquifer. It is formed by even grain size calcarenites which can be either friable or highly cemented but always fairly porous. Sometimes the aquifer is formed by cemented sands interbedded with calcarenite thin layers (5-10 cm) called « cintuni » (CC).

These layers coincide with the groundwater and can be found at various depths in the complex, according to the water levels occurred in the past.

4. GROUNDWATER MORPHOLOGY AND WATER FLOW

The upper groundwater piezometric lines have been outlined. They have been used to deduce the hydrodynamics of the Piana, since they permit the outlining of the water flow whose piezometric lines are almost parallel to the coastline. The groundwater flows from W to E, that is, from the higher elevation above sea level which corresponds to the recharge area, to the sea. The piezometric surface morphology conforms to the substratum, especially the NF. In the NF morphological highs areas the Quaternary plate thickness decreases. Consequently, the saturated calcarenite and the water productivity of the wells which reach that depth (Trapani and Pescia areas) decrease as well. High values of hydraulic gradient (2-4%) are found along the bands at the foot of the mountains, whereas low values (1% or less) are been found in the lower elevation areas. The water contour line distance widens in the Resuttana Colli area, where the hydraulic gradient is lower probably because of the calcarenite greater permeability. In situ permeability tests on some wells of the Piana have provided K values which differ greatly according to the areas, with higher values both near the Gallo, Castellaccio and Pellegrino Mounts and in connection with the drainage axis South of the subsided limestone foot of Gallo M. (Fig. 3). Filtration depends on hydraulic boundary conditions and other factors, such as: I) the NF irregular morphology, II) the stratigraphic limits between the Quaternary plate and the highly fractured and karstified dolomitized limestone complex, III) the calcarenitic complex different permeability coefficients, IV) the relation between the calcarenite and dolomitized limestone complex and the sea-water intrusion. Fig. 4 shows the calcarenite substratum morphology. Comparing the water contour line patterns to the substratum morphology, it can be clearly seen that the structural-morphologic features of the Piana dei Colli affect the water flow, borne by the calcarenitic aquifer and by the lower aquifer which lies along the carbonatic mountains subsided external boundaries. These are directly recharged by the surrounding outcropping carbonatic complexes. There is a relationship between the two aquifers. The very permeable lower aquifer determines the sea-water intrusion phenomenon along the tectonic lines. So, the lower groundwater is held up by the sea-water. Breaks in the fresh sea-water equilibrium gave occurred in the past, due to intensive exploitation of the lower groundwater and to the reduced contribution from the Castellaccio M. water structure. In the calcarenites the groundwater is unconfined and shallow (few metres below ground surface),

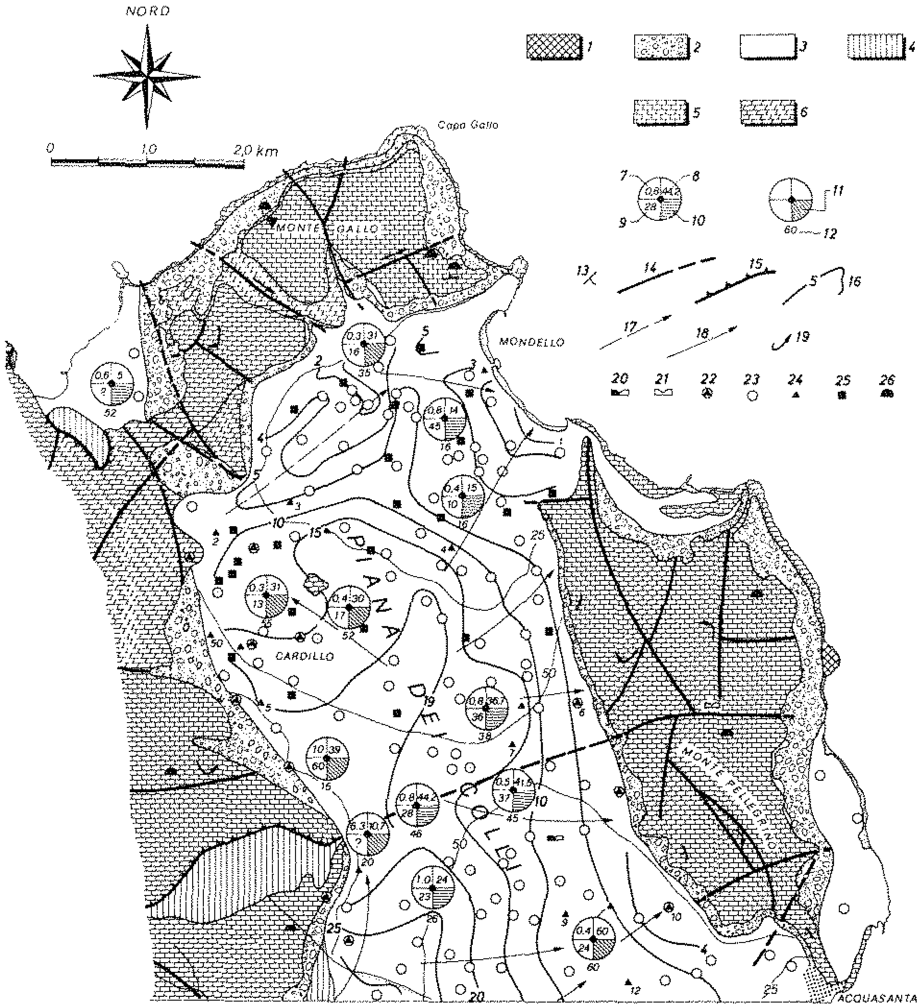

Fig. 3 - Hydrogeological map. - 1) filling material, 2) talus, 3) Pleistocene organogenic calcarenites: high permeability due to porosity and partly to fissures, 4) Marly clayey complex (Numidian Flysch, Oligocene-Miocene): impervious complex, 5) Limestones (upper Lias - middle Eocene): High permeability due to fractures and karst, 6) Dolomitized limestones (upper Trias - early Lias): high permeability due to fractures.

The circular diagrams show the bore-holes data of some water-wells:

7) thickness of superficial ground, 8) thickness of outcropping formation, 9) water level in the wells, 10) bedrock (limestones and dolomitized limestones), 11) bedrock (marly clayey, Numidian Flysch), 12) depth of bore-holes, 13) dipping layers, 14) main fault, 15) thrust lines, 16) piezometric lines above sea level, 17) drainage axis, 18) water-flow axis, 19) flow direction in aquifer (carbonatic rocks), 20) thermo-pluviometric station, 21) pluviometric station, 22) town water-wells and bore-holes, 23) private water-wells, 24) bore-holes, 25) V.E.S. (vertical electrical sounding), 26) cavities.

particularly where the NF is near the ground surface. Drainage and discharge lines depend on the NF geometric configuration and, sometimes, on the hidden faults which caused the different collapses at the foot of the dolomitized limestone surrounding mountains. The impervious top deepens both near the coast-line (Mondello Beach) and where it reaches the subsided carbonatic rocks (West). The upper aquifer isopaches (Fig. 5) show maximum thickness along the bands at the foot of the mountains and minimum thickness in the middle of the Piana. The relationship between the hydrogeologic complexes and the structural-morphologic pattern are shown in some hydrogeologic sections (Fig. 6).

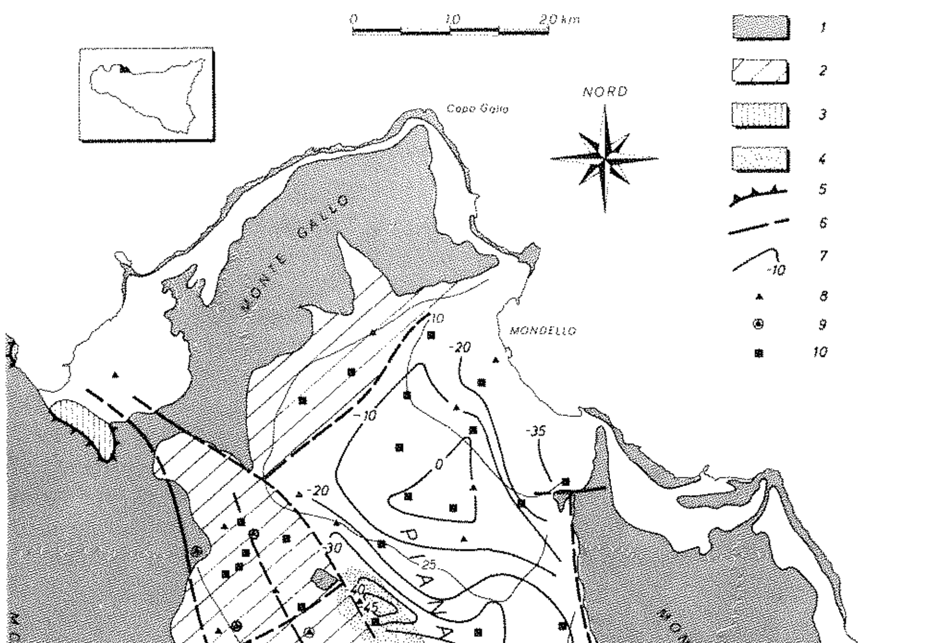

Fig. 4 – Reconstruction of the bedrock of the Pleistocene calcarenites, 1) limestone and dolomitized limestone complex. 2) subsided limestone and dolomitized limestone complex, 3) marly clayey complex (Numidian Flysch), 4) Pleistocene sandy clay and sands interbedded in the calcarenitic complex, 5) thrust lines, 6) fault, 7) isobath (in metres) of the impervious top, 8) bore-holes, 9) town water-wells, 10) V.E.S.

5. GROUNDWATER HYDROCHEMISTRY

The quality of the Piana groundwater was studied by Mouton in 1961 [10]. More accurate analyses have been carried out by Cimino et al. (1971) and Cusimano (1974). Further data on the groundwater qualitative characteristics have been acquired from an investigation requested by the Tribunal of Palermo [2]. Intense sampling has been made in the areas where the fresh sea-water equilibrium has been upset. In 1961 (Fig. 7) seawater poured into the wells of Fonfo Scalea and the salinization concerned both the aquif-

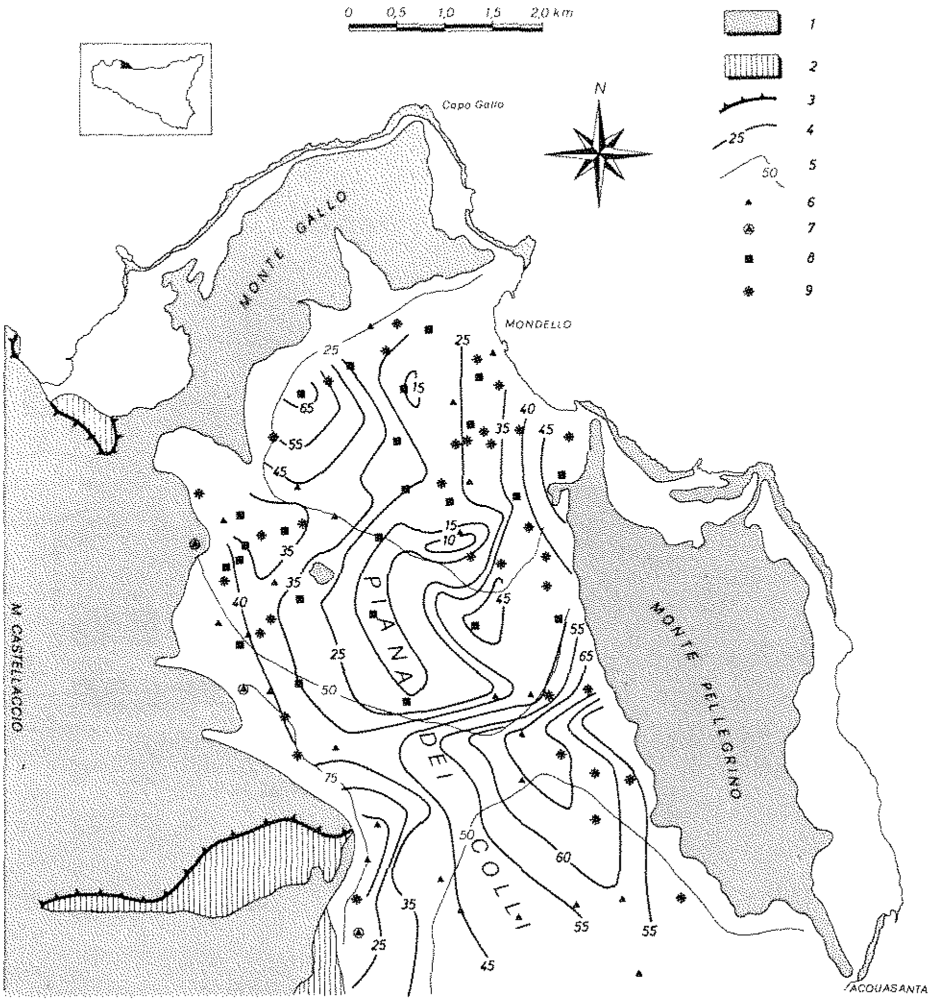

Fig. 5 - Isopaches of the Pleistocene aquifer. 1) limestone and dolomitized limestone complex, 2) marly clayey complex (Numidian Flysch), 3) thrust lines, 4) isopaches in metres, 5) contour lines (isoipse), 6) wells, 7) town water-wells, 8) V.E.S., 9) polluted water-wells.

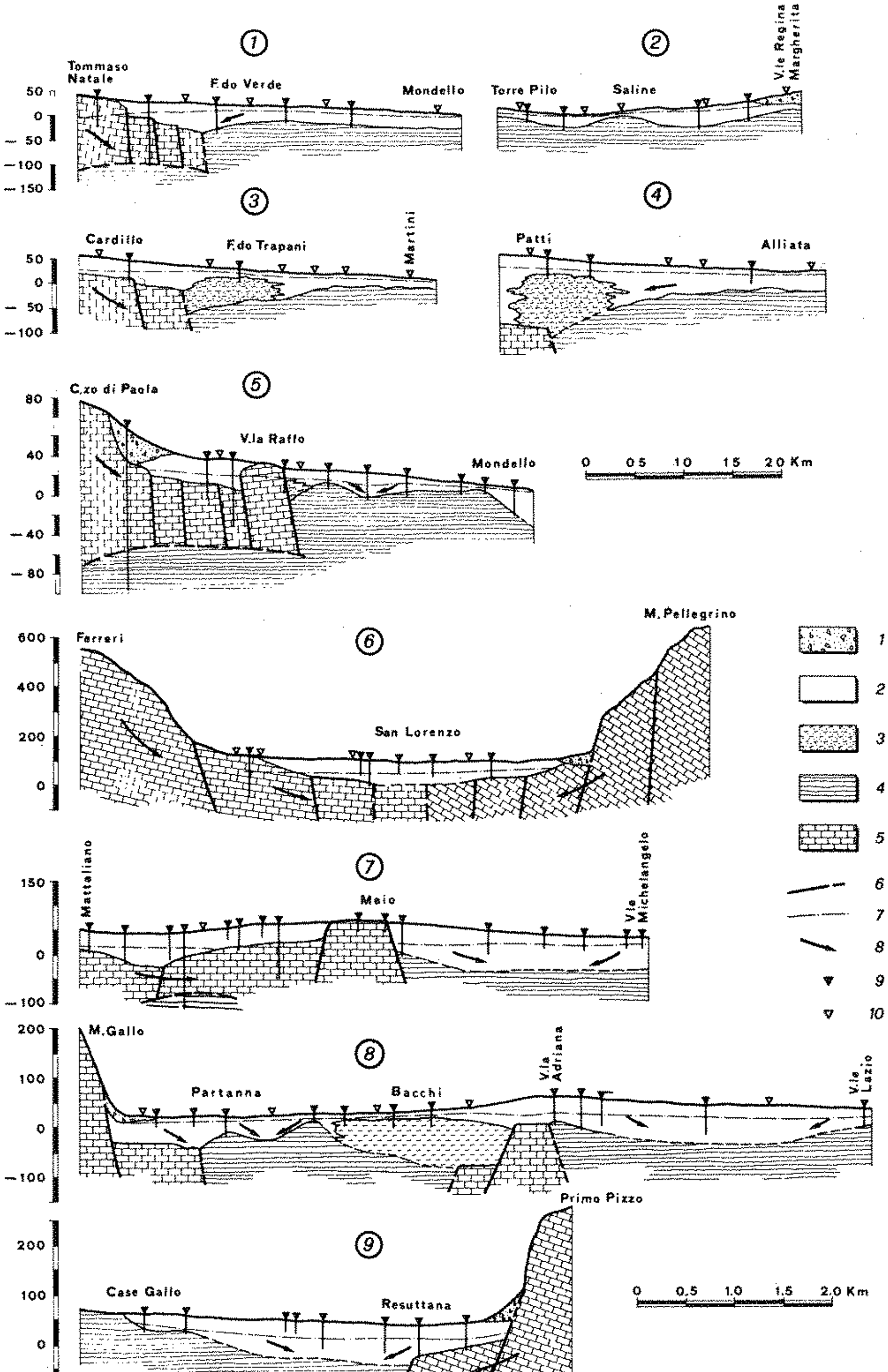

Fig. 6 – Hydrogeological sections. 1) talus, 2) calcarenite, 3) sandy clay and sands, 4) Numidian Flysch, 5) limestones and dolomitized limestones, 6) faults and abnormal tectonic contacts, 7) piezometric level, 8) flow directions, 9) wells and bore-holes, 10) V.E.S.

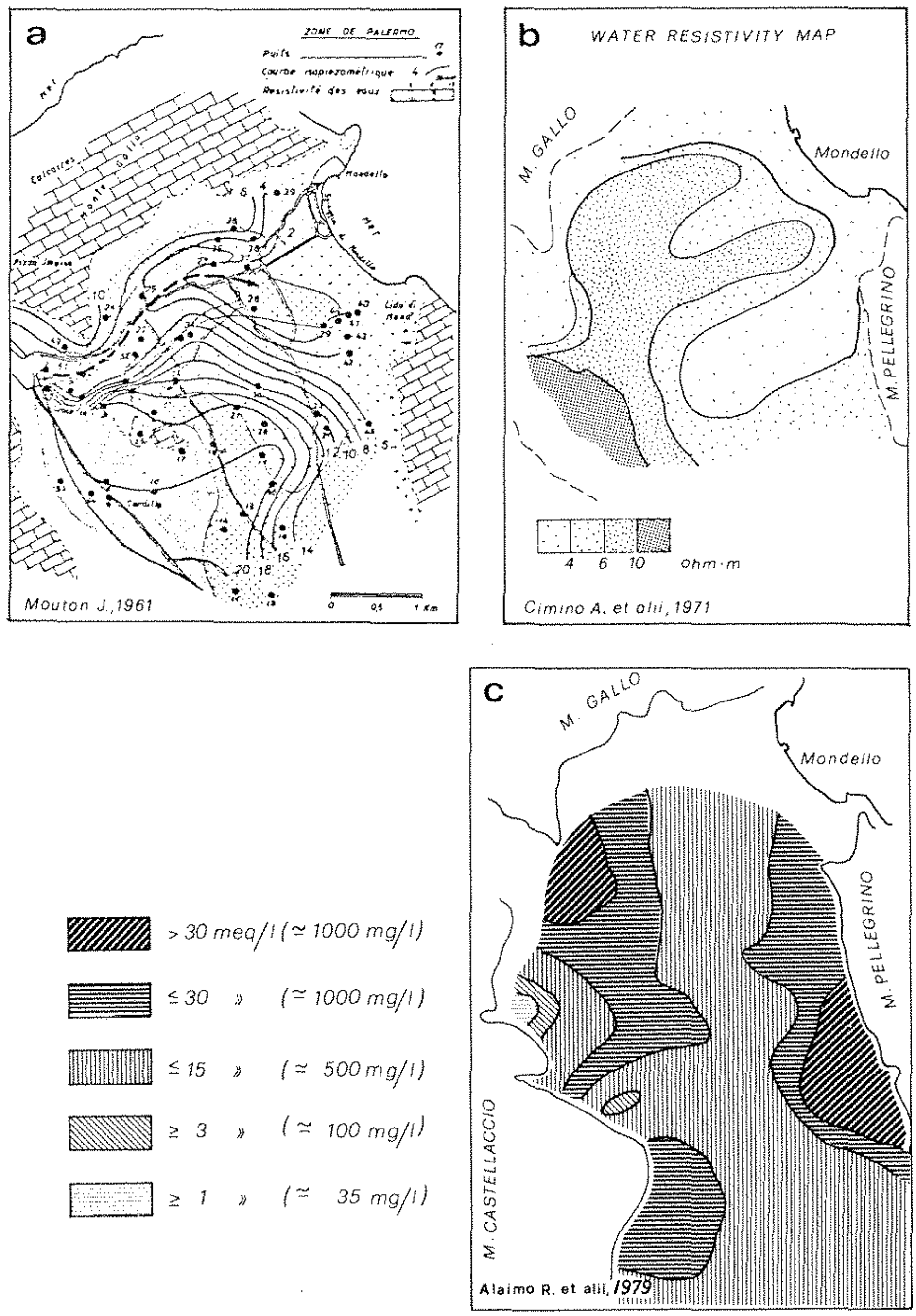

Fig. 7 - A - Water resistivity map from Mouton [10].
B - Water resistivity map from Cimino et al. [4].
C - Chlorine ion distribution from Alaimo et alii [2].

ers. Stretches of the wells of some polluted wells were cemented, but the continuous exploitation both there and above the recharge area made the phenomenon widen. Some town water-wells, which supplied several suburbs of the Piana, where also affected. The sea-water intrusion proceeded from N to S, that is from the foot of Gallo M. as far as the foot of Castellaccio M. The NF morphologic high in the middle of the Piana hindered the progressive sea-water spreading. Another polluted area was located along the Pellegrino M. southern slopes. There too, the fresh sea-water upset equilibrium made sea-water pour into some wells. The polluted area comprised the Favorita Park and some nearby zones. Fig. 8.1 shows the diagrams of some samples water chemical composition [7]. For each sample the ratio rCl/rSO_4, which permits to discover the sea-water influence in fresh water, has been computed. The samples have been divided into three groups:

i) A, with very low sea-water influence;

ii) B, with high sea-water influence;

iii) C, with very high sea-water influence.

Most values of the rCl/rSO_4 ratio range between 7 and 13, with average value 10. The 1978 investigation located two maximums of salt-water encroachment: one is between the Favorita Park and the Pellegrino M. slopes, the other along the band from Sferracavallo to the Cervello Hospital, a little South of Maio, at the foot of the mountains. The coast-line bands as well are directly affected by the salinization. The Cl anomalous values in the Favorita band must be related to the widespread karst phenomena of the Pellegrino M. complex. The Cl anomalous values in the Sferracavallo-Cervello Hospital band are related to the tectonic lines, pointed out by cataclasite bands which

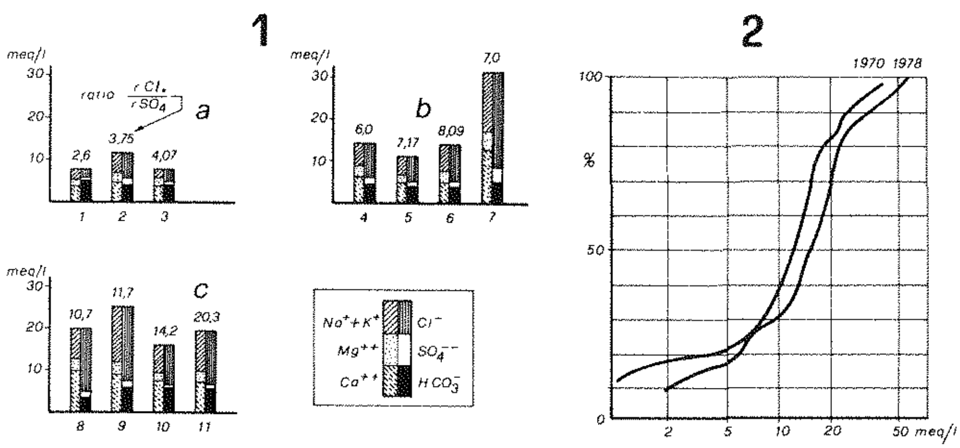

Fig. 8 - 1) Water chemical compositions. a) very low sea-water influence, b) high sea-water influence, c) very high sea-water influence.
2) Variation in time of Cl content in groundwater.

have been exploited as crushed stone quarries. Cl may be taken as a useful parameter in order to compute the variation in time of salinization. The 1978 sampling shows an average increase of Cl values of 3-4 meq/l (= 100 mg/l) compared to 1971 values, but in 20% of the samples it can increase up to 10 meq/l (= 350 mg/l), (Fig. 8.2).

6. CONCLUSIONS

The Piana dei Colli is a typical area of sea-water intrusion. This everincreasing phenomenon affects more and more Southern areas (8 km from the coast-line - Ferreri, Cervello Hospital), following the tectonic lines. The two aquifers show different salinization degrees. The lower groundwater is almost always influenced by sea-water, whereas the upper is very little salty in some areas. This depends on the Oligo-Miocene impervious interposition between the upper aquifer and the sea. Hydrochemical characteristics and hydraulic relationships show that water exchanges between the two aquifers occur upwards only. So, the only available water resource is the non-polluted lower groundwater of Castellaccio M., which at present supplies several new industrial and housing estates. The Piana lower groundwater salinization does not allow its exploitation for drinking purposes (cfr. Scalea, Milone, Ferreri town wells, etc.). In the past, the lower groundwater potential was more than 100 l/s. The upper groundwater potential was 15-30 l/s with lowering of the water-table of not more than 5 m. The aquifers cycles depend both on the rain and on the underground water exchanges with the surrounding carbonatic relieves. Long dry spells occurred in the latest years and the continuos exploitation of the water resources have caused water-table lowering and drying up of some wells. In order to depollute the groundwater it has been proposed to let partly softened waste water into the ground. For such a project, however, detailed knowledge of the morphology both of the impervious and of the subsided carbonatic structures and their tectonics is necessary. The study of the karst phenomenon, whose widening depends on the sea-water effect upon the lower aquifer, is also very important [12]. Water-taking and new wells drilling prohibition is also necessary in order to reorganize the groundwater exploitation.

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