HYDROGEOLOGICAL PROBLEMS RELATING TO THE CONSTRUCTION OF AN UNDERGROUND METRO SYSTEM IN BARI URBAN AND SUBURBAN AREAS

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SUMMARY: Many problems are related to the construction of an underground metro system in Bari urban and suburban areas, excavations involving namely dolomite-limestones in both anhydrous and saturated zones and low-thickness postcretaceous covers. A number of rock-sealing methods are reviewed. Consideration is given to the rock hydrodynamic characteristics of the urban area alongside impacts on groundwater flows.

1. INTRODUCTION

The construction of a combined surface and underground metro system serving Bari urban and suburban areas is a prime requirement which has long been debated in political, social and administrative circles.

Bari urban and suburban areas cover some 60 square kilometers of surface, originally satellite conurbations having become an integral part of the urban area.

Moreover, new outlying wards of the administrative district closely interact with the town, which in turn interacts with the industrial area, the airport and sports-facilities and the new increasingly peripheral residential parts (Fig. 1).

There has been a growing awareness that surface traffic congestion and town-environmental conditions could be alleviated by underground rapid transit.

However, the execution of underground works is bound to address a number of problems, as the areas involved are either densely built or acting as a link. Furthermore, the work impact on Bari hydrogeological environment has to be carefully assessed.

2. MORPHOLOGICAL AND GEOLOGICAL FEATURES

The metropolitan area most likely designated to accomodate underground construction works is located up to 100 m above the sea level. Many geological and morphological problems may be encountered in construction works, excavations involving a few lithological formations.

The morphological characteristics of the investigated area are typical few whole Murgia karst plateau. The latter degrades towards the sea, through a series of terraces and slopes subparallel to the coast.

Terraces lack in continuity on account of the hydrographic network, dug into the limestones by a sequence of WNW-ESE-oriented anticlines and synclines, which deeply erodes the carbonate rock plateau.

Many of the above erosions, the ones converging in Bari being occluded in the end portion by the town, are collected by a gutter designed to protect the town against heavy-rainfall-related floods.

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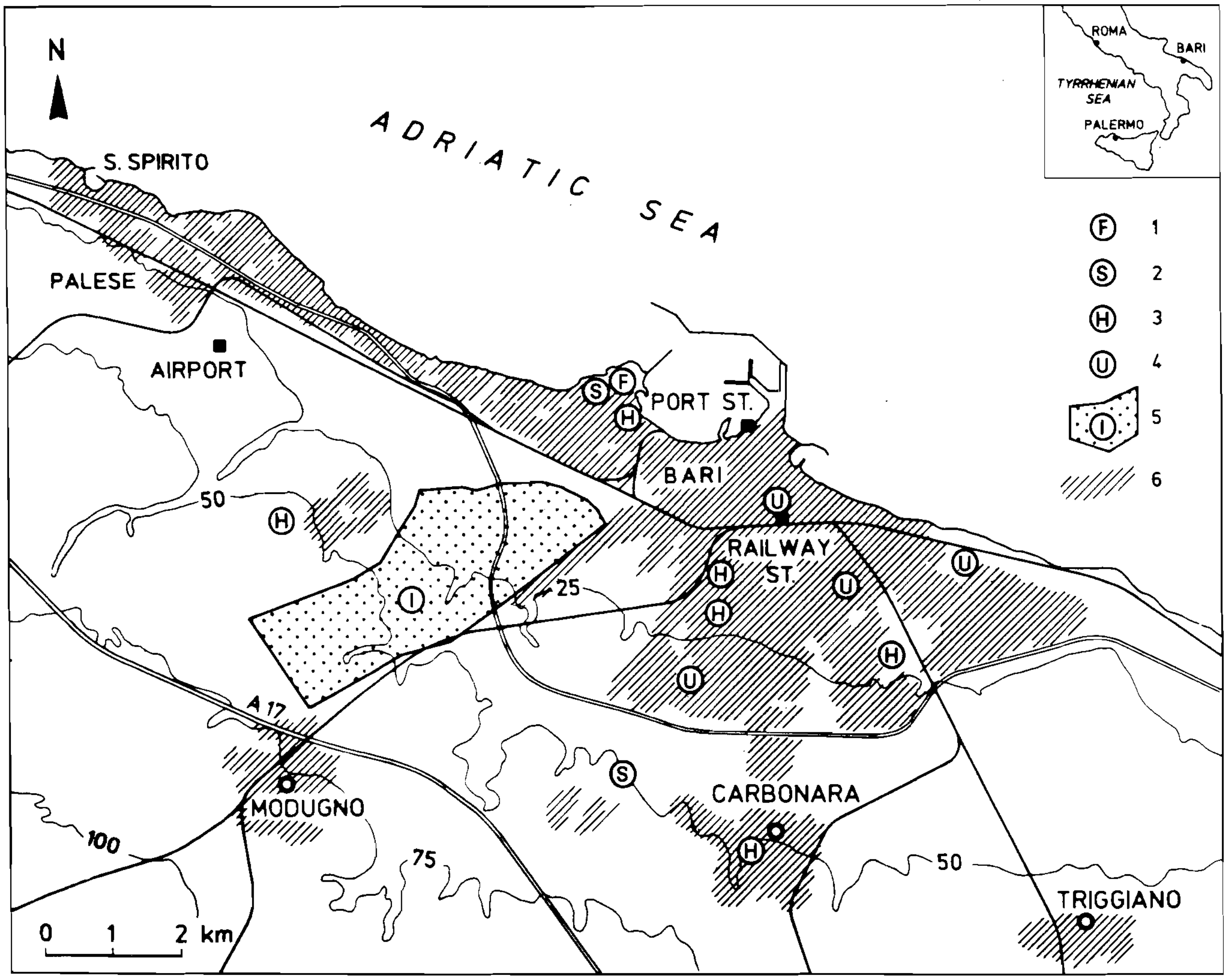

FIG. 1- MAP OF THE METROPOLITAN AREA INDICATING MAJOR LINK ROADS AND PUBLIC-SERVICE FACILITIES. 1) F=exhbition; 2) S=Stadium; 3) H=Hospital; 4) U=University; 5) I=Industrial area; 6) Urbanized area.

The geological environment consists of the formation of Gravina calcarenites (Pleistocene). They are transgressive on the extended thick limestone-dolomite sequence of the Apulian Platform consisting of Bari Limestone formation (Lower - Upper Cretaceous) (Polemio, 1994; Ricchetti et al., 1988). In the investigated area, they either consist of dark-grey dolomites or of grey dolomite-limestones, interbedded with micritic or bioclastic white limestones (Fig. 2).

This formation exhibits largely decay-pitted layers and banks. The commonly widespread karst phenomenon, often resulting in interlayered caves or cracks, generally overlies a tectonic directrix. Karst caves, often filled in with deposits, such as *terre rosse* and calcareous debris, are true caves. Their role is all but negligible when planning engineering works in general and underground constructions in particular (Cotecchia, 1973; Grassi, 1974).

Bari limestones, where not directly outcropping, exhibit Pleistocene deposits on the top cover, most likely corresponding to three subsequent Tyrrhenian sedimentary stages (Pieri, 1975). They consist of coarse limestones, calcarenites, calcirudites, marly pelites, littoral or detrital-bioclastic deposits, along with sands, conglomerates and gravels.

On the whole, the Pleistocene cover is some 15-metre-thick, the maximum values corresponding to morphological depressions of Cretaceous top limestones. Overlying the cover, low-thickness

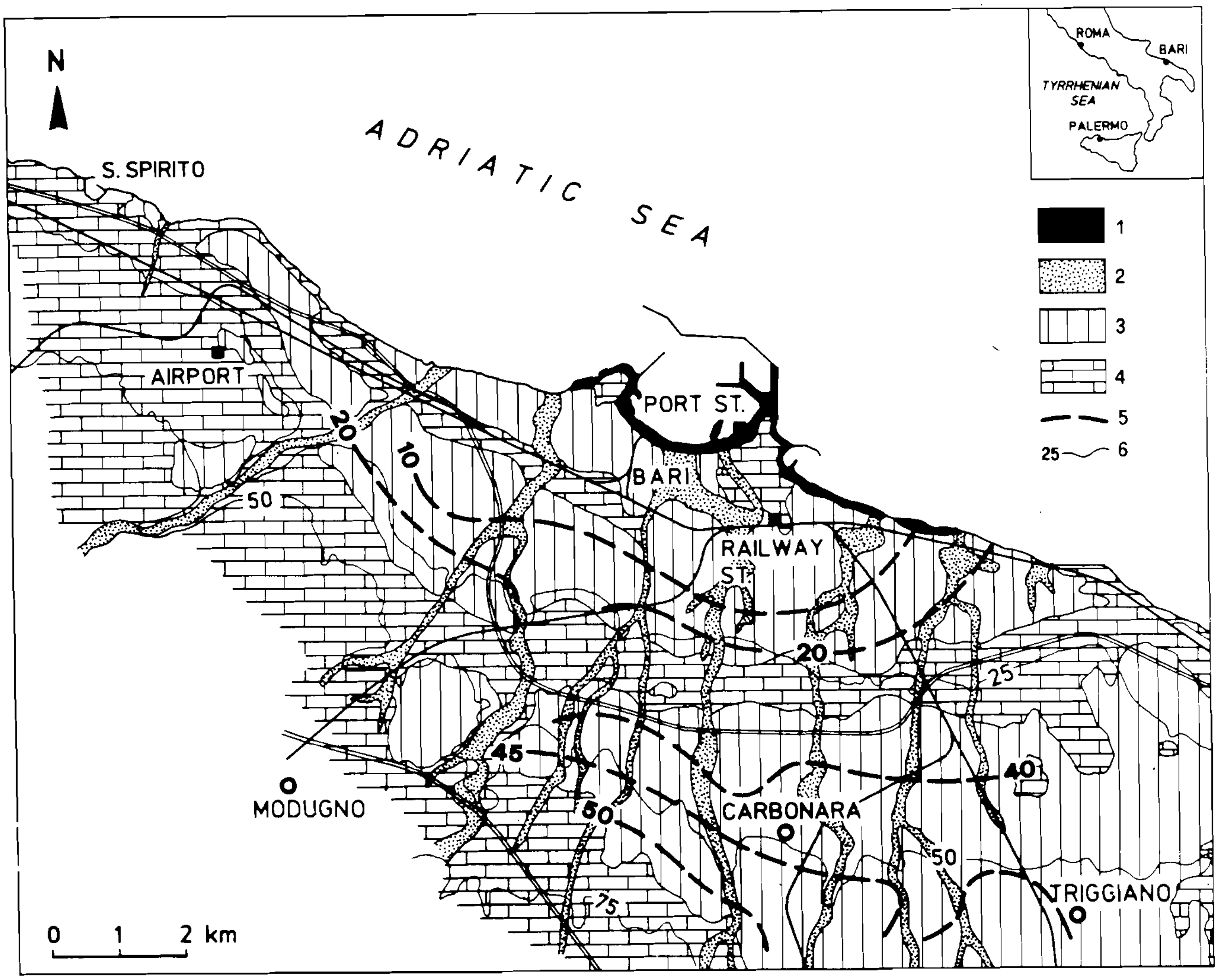

FIG. 2- GEOLOGICAL MAP AND LIMESTONE TOP. 1) Backfill; 2) Alluvial and marshy deposits, dunes and coastal deposits (Holocene; Upper Pleistocene); 3) Gravina calcarenites (Lower Pleistocene; some scattered bioclastic Tyrrhenian deposits); 4) Bari limestones (Barrhemian - Tyrrhennian); 5) Contour line of Bari limestone top (m a.s.l.); 6) Contour line (m a.s.l.).

Holocene alluvial and marshy deposits may be found. They consist of calcareous pebbles, sometimes cemented and immersed in a sandy-clayey or silty-clayey matrix, deposited along the morphological incisions, commonly called "blades".

It follows that the excavation work is bound to involve two largely differentiated geological formations at high topographical levels; whereas, given the limited thickness of postcretaceous deposits. it will essentially involve the limestone-dolomite formation at low topographical levels.

Borehole-derived stratigraphic results alongside surface geological data have aided greatly in reconstructing the basic top carbonate formation. The reconstruction indicates that the limestone top degrades with a modest slope in the inner part of the territory, gentle enough near the coast.

It is showed that the limestone top is found at 0 level, 1 ÷ 1.5 Km from the coastline and that in the N-W portion, the limestone top lies 10 m below the sea level (Fig. 2).

In Bari built-up area, quarters which are a long way off the sea are located some 20-25 metres above the sea level; whereas limestones are generally found 10 m above the sea level. The only exception is part of the *Murattiano* town-centre, where limestones are more or less outcropping.

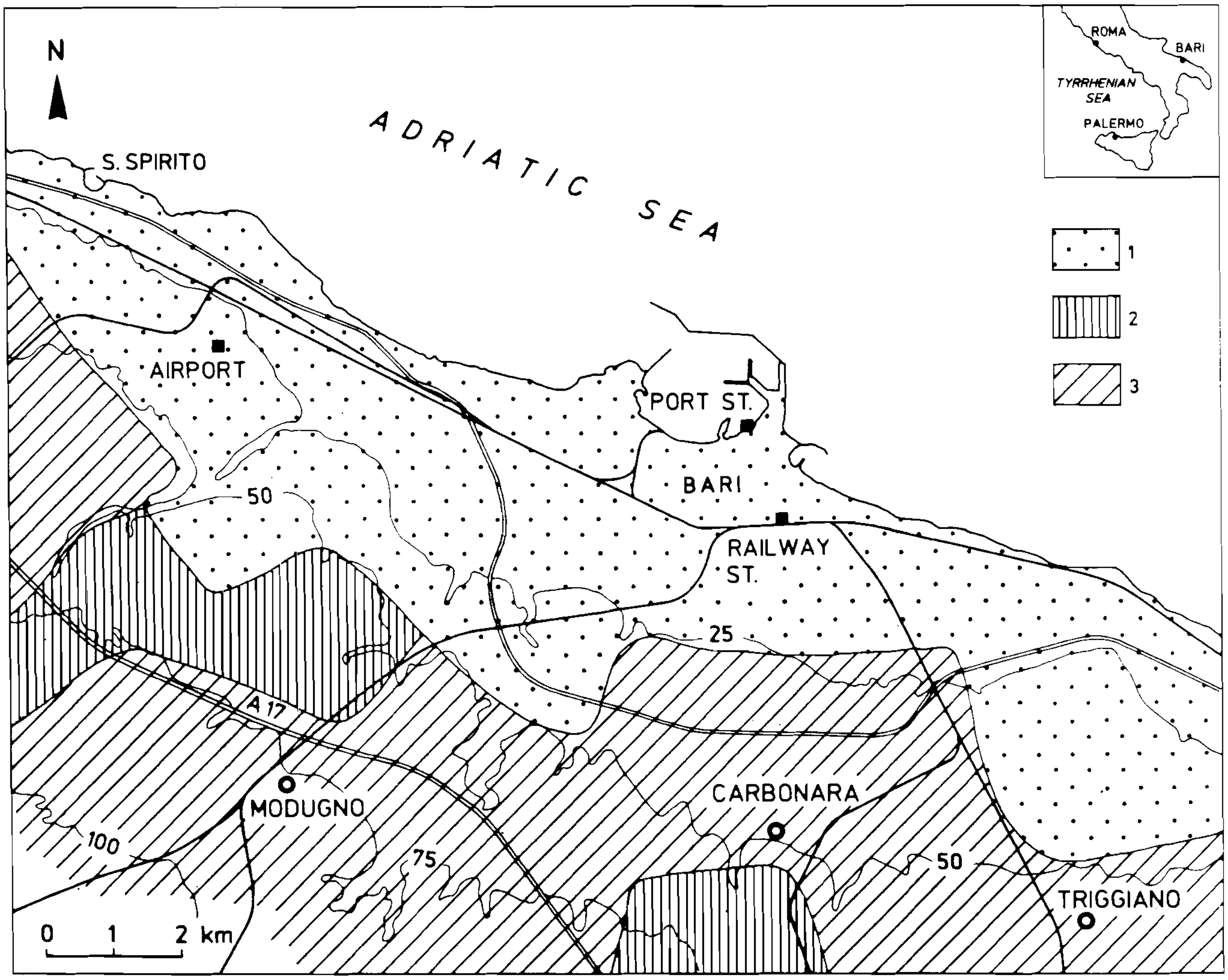

FIG. 3 -MAP ILLUSTRATING WATER TABLE CIRCULATION MODES. 1) Phreatic and slightly confined; 2) Confined down to -30 m; 3) Confined from -30 to -180 m below m.s.l..

3. HYDROGEOLOGICAL CHARACTERIZATION

Based upon the lithological and hydrogeological data available, in most of the investigated area the water table circulates in the carbonate aquifer, at a considerable depth below the sea level, and follows the extremely erratic trend of the aquifer top (Grassi and Tadolini, 1974 and 1985).

Moving from WNW to ESE and from the coast inland, the ground water is found at increasing depth. In the vicinity of Adelfia and Valenzano, the presence of a fault system, roughly parallel to the shoreline, enables a recovery depth ranging between 30 and 60 metres below the sea level.

The aquifer top isobaths (Fig. 2)) show that some 5 Km from the shoreline, in Bari industrial area (A.S.I.), the groundwater is intercepted down to -180 m m.s.l.. Limestone and limestone-dolomite impermeable rocks, 60-to-200-metre thick, are found in this area. They confine the aquifer, thus holding back its free flow and protecting against inland seawater intrusion.

Stratigraphic and hydrogeological reconstructions obtained by interpolation of data available have enabled to perform a zoning of the investigated area in three main blocks (Fig. 3).

A. In the first block, water either circulates under phreatic conditions or under limited pressure heads. The area covers S.Spirito and Palese neighbourhoods up to a distance of some 3 Km from the shoreline. In the area between S. Spirito and Bari, the situation is visible up to 2 Km, whereas in Bari urban and suburban areas the distance reaches 3.5 Km. Last but not least, in the south-eastern stretch the phenomenon is apparent 4 Km from the coast.

B. In the second block, stretching between Modugno and Palese, some ten-metre-thick carbonate rocks keep the aquifer confined down to -150 m m.s.l. and deeper.

C. In the third block, a slightly permeable carbonate formation is found down to max -30 m m.s.l.

Therefore, water circulation under phreatic conditions is restricted to some areas. However, it would be misleading to assume the lack of any connections in the impermeable rocks between the soil surface and the deep aquifer.. Connections were found, indeed, in vertical karst forms through which the natural recharge of the aquifer and surface human inlets occur.

A detailed geohydrological reconstruction of the areas involved in underground excavation works can only be the result of specific surveys and investigations aimed at better defining such peculiar phenomena.

The aquifer idrodynamic features, depending on the degree of carbonate rock fissuring and karst development have been assessed following the analysis of pumping tests run in the available wells.

The inferred specific discharge has helped define rock permeability values and draw isograms showing that in the more coastal areas, up to a max. inland penetration of 5 Km, corresponding to Bari and Triggiano, rocks are highly permeable, as a rule, with specific discharge exceeding 10 l/sm; whereas, moving inland, values are considerably decreased, down to 0.5 l/sm along the fringe area. In the North-western part of the aquifer the limestones and dolomite formation is poorly permeable, due to mild fissuring and karst phenomena.

The reconstructed configuration of the piezometric surface (Fig. 4.) shows that groundwater flows from the upper Murgia towards the coast with unusually high hydraulic heads and piezometric slopes, and this is the case along Bari Northern coastline, as well.

Given the aquifer relatively low permeability, in the investigated area static heads exceed 20 metres above the sea level and reach 35 metres South-West of Modugno; whereas piezometric slopes range between 0.2 - 0.6%. Furthermore, moving a few kilometres inland, and precisely 1.5 Km in the area between Palese and Bari, the piezometric head may reach 5 m above the sea level.

Some preferential path flows, which are oriented towards Bari, can be clearly identified. This drainage may be the result of farming, domestic and mostly industrial activities.

Drainage occurring between Carbonara and Triggiano towards the coast can be ascribed to farming activities.

Note that the strip of aquifer between 5 m and 10 m isograms is particularly narrow on the western side because of the aquifer reduced permeability.

Groundwater level fluctuations are basically related to: groundwater intake and depletion processes, periodical and non periodical sea-level variations, groundwater withdrawals as a result of human activities and waste water inlets. The overall extent of fluctuations over the hydrological year totals some decimeters. Therefore, they play a minor role among the problems relating to the execution of works below water table.

4. RELATIONSHIPS BETWEEN GROUNDWATER AND SEA WATER IN THE INVESTIGATED AREA

As the aquifer is a coastal aquifer, fresh water flows above intruding sea water. Its equilibrium is governed by hydrodynamic laws correlating groundwater piezometric heads to the fresh and sea water interface depth (Cotecchia, 1977, Cotecchia et al., 1991; Tadolini and Tulipano, 1977).

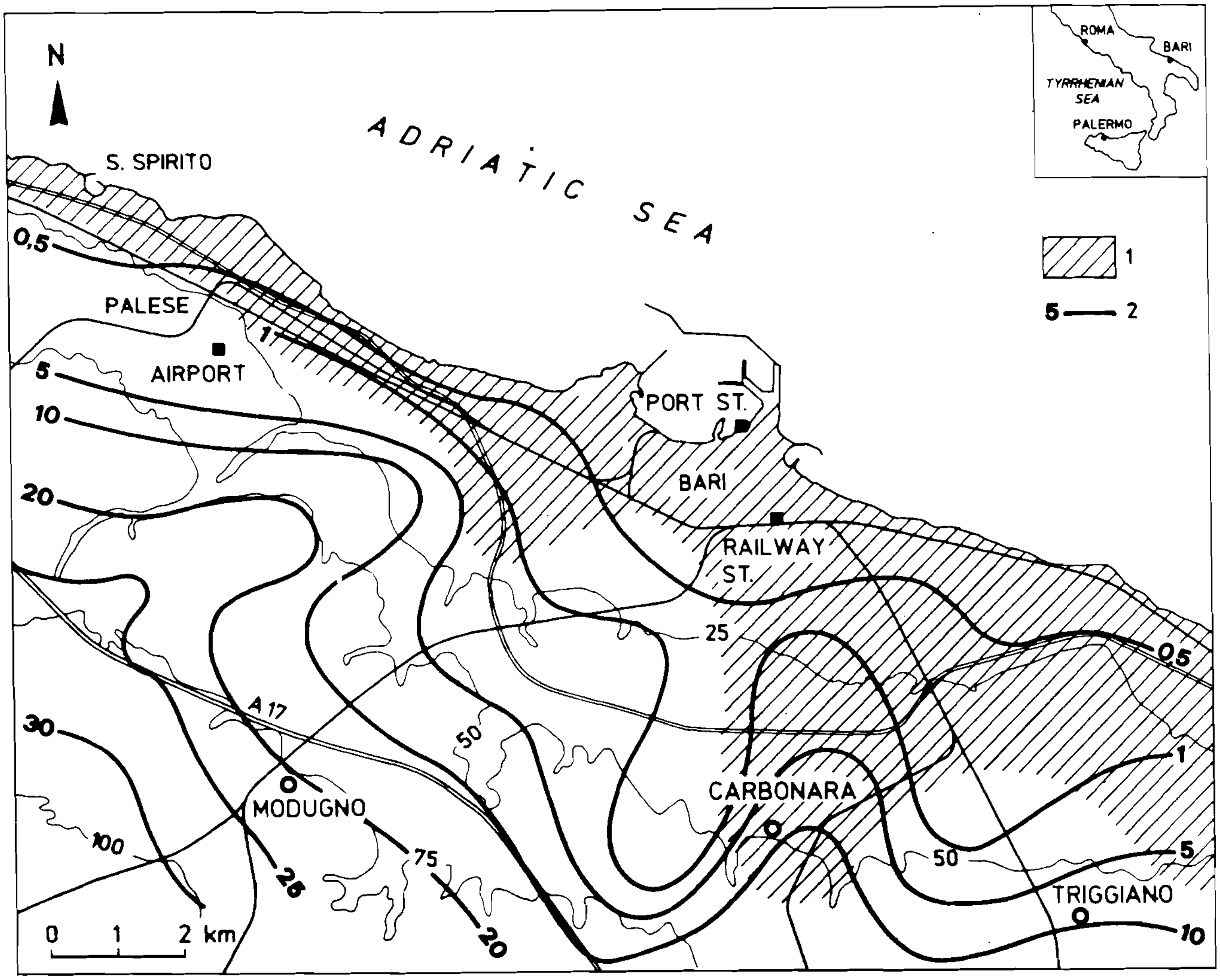

Fig. 4 - THE AREA INVOLVED IN SEA WATER INTRUSION BOUNDED BY 3 g/l (1) AND MORPHOLOGY OF THE PIEZOMETRIC SURFACE (2) (m a.s.l.).

The presence of a karst network and of high rock fissuring in the area under study enables sea water to flow freely from and to inland.

The isohaline 3 g/l is located 3-6 Km from the shoreline in the South-eastern area of Bari; whereas along the coastline between Giovinazzo and S. Spirito and in Bari industrial area, given the presence of slightly fissured impermeable rocks, lacking in significant karst canalization, sea water intrusion is restricted to a couple of kilometres from the shoreline. It follows that, in the remaining part of the investigated area, water close to the surface of the aquifer has a salt content never exceeding 1 g/l and often below 0.5 g/l. This is also due to high piezometric heads which imply considerable depths of continental intrusion sea water, ranging from dozens to hundreds of metres.

5. INTERVENTION-RELATED PROBLEMS

The above hydrogeological characterization shows that the tunnelling of an underground metro system is bound to address a wide range of troubles, many of which inherent with engineering geology features.

Excavation works are planned to be performed from the anhydrous zone, to the saturated zone, the letter having pressure heads which do not exceed 20-metre water depth. Tunnelling operations would be very complex. Equally demanding would be the lining works, as a result of the wide variety of permeability of the various lithotypes involved. Major difficulties are predictable when tunnelling the saturated zone with strong overlying water heads and in the presence of highly fissured and karstic limestone-dolomite formations.

Significant lining problems have been already successfully addressed and solved while carrying out other civil-engineering works in Bari, mostly consisting of lining basements located some 10 - 15 metres below the road-level, exhibiting water heads of 10 metres and more (Grassi, 1971).

In general terms, cement-bentonite mixtures were used for grouting and epoxy resins for sealing operations. Maximum sealing against water inflows was obtained and, after many years, interventions still ensure perfect sealing. Excavation and grouting works executed so far have covered modest areas only, with injections dropped from the surface, that is in open excavations, mostly vertically and rarely through crossed interventions.

Another important problem concerns tunnelling works below town-buildings, the aim being to avoid interference with old masonry surface foundations and more recent building pile fondations.

Current technical trends are in favour of shallower underground metro lines, the layout of which follows the surface road network (RODIO, 1987). However, there is a risk of running into the underground public-utility network (sewer, telephone, gas, etc.) and foundation works.

Methods to be used in preliminary tunnelling works may consist of the following surface operations:

-grouting dropped from the surface and subsequent blind hole excavation by means of a milling-type shield or other moles;
- execution of structural diaphragms and open-trench excavation, following tunnel bottom grouting;
- execution of large diameter piles, sealing injections and tunnel bottom grouting, followed by open-trench excavation.

Blind hole operations can also be envisioned in which case closed-faced-wheel moles are required. Thus, prefabricated track sections are connected to the ones already in place, thus ensuring continuous construction.

The operational choice may be conditioned by different situations occurring along the way. It is worth recalling that grouting prior to tunnelling is the most flexible and least traumatic solution, avoiding surface life disruption.

Any grouting treatment must envisage the execution of sections of pregrouted and cemented soil, enabling an almost continuous tunnelling, without any interference with the surface.

Around the profile of the tunnel an adequate layer of treated soil must be ensured.

The whole work impact on groundwater circulation needs to be carefully checked, by optimising the network development according to groundwater flow direction. Briefly, tunnels might develop parallel to water flow or orthogonally, yielding decidedly different effects on groundwater.

Moreover, the tunnel cross section is likely to be partially involved in or totally overlain by the water level.

In more coastal tunnels, sections might be located at the bottom of the fresh groundwater reservoir, that is in the transitional zone between the fresh water and the continental intrusion sea water.

In all the above mentioned cases of section positioning, which always complies with the water flow, the impact caused on the water table by a work with a cross section of some 20 to 30 metres in diameter, is practically negligible, as it does not affect water flows towards the coast and the water table keeps the hydraulic continuity.

By contrast, if the work is set perpendicular to groundwater flow, a barrier effect is likely to occur with relative pros and cons. The barrier effect is bounded to increase as the thickness of the portion of the aquifer containing freshwater is reduced. Yet in the vicinity of the coast, if the work is located inland enough, the water flow will find its natural pathway. Water will flow above and below the work, causing limited backwater phenomena. If the work is located at the interface, inland sea water intrusion is likely to be hampered.

It goes without saying that any works involving a fissured and karst aquifer will lead to local modifications in groundwater circulation. Besides, the flow will take new configurations, over time, depending upon the degree of fissuring and karst development, typical of the portion of aquifer surrounding the work.

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