STUDIES ON DIFFERENT KINDS OF SALINISATION IN THE GROUND WATERS OF THE IONIAN COASTAL PLAIN OF THE BASILICATA REGION

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Abstract

The research by now carried out on the Ionian coastal plain of the Basilicata region allowed defining, for the first time, that the coastal plain is constituted by a hydrogeological system formed by three kinds of aquifers, well confined at the bottom by the blue clay basement. The tectonic evolution of the region affected the clay basement during its sedimentation, followed by the erosion by five rivers and subsequent deposition of alluvial sediments. As a consequence of faulting and fissuring, and following sea level changes, the hydrogeological system and the basement have been subject in geological times to seawater intrusion episodes. Mainly the construction of 17 dams and small barrages for water storage, together with the diversion on the five main rivers or in their basins, but also the land reclamation during the 20th century and practices, deeply modified the hydrology of the coastal plain by strongly reducing natural superficial flow and by changing periods and areas of recharge. The geomorphologic features of the coastal border, the recent sea level changes and the human activities, added to the above complexity, brought forth the conditions in the hydrogeological system for the existence of a number of salinisation sources whose effects somewhere overlap: salt water from superficial intrusion of seawater in the rear dune ponds or in the river mouths, salt water from overexploited alluvial aquifers, salt diffusion from interstitial water of the over-consolidated marine blue clays, solution of sulphates from evaporite deposits and salt concentration due to recycling of irrigation water. Specific situations of salt concentration from human activities have been also recognized in some sites. The high amount of water used for irrigation and, in the dry seasons, the overexploitation of groundwaters, act, in the different environments, favouring or limiting the salinisation. A detailed study, which was carried out on the base of stratigraphic data, temperature and conductivity logs, and chemical analyses of groundwaters, contributed to discriminate the different salinisation sources.

Keywords: hydrogeology; Basilicata Region; Ionian coastal plain; salinisation processes; blue clays; temperature; sulphate reduction; anoxic sediment.

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Introduction

The hydrogeology of the Ionian coastal plain of the Basilicata Region (southern Italy) and the whole processes connected to groundwater development represent the most important research themes of the LABIA group of the Basilicata University.

The stretch of the Ionian coastal plain, which belongs administratively to the Basilicata Region, locates on the water front of the physiographic unit named Fossa Bradanica, delimited to NE from the limestone hills of the Murge and to SW from the Apennine nappe. The coastal plain is set up on the alluvial sediments of five main rivers (Sinni, Agri, Cavone, Basento e Bradano) discharging into the Ionian Sea (Figure 1); the related coastal area is characterized by sandy flat beaches, locally pebbled, and limited inland from swampy zones or dune belts.

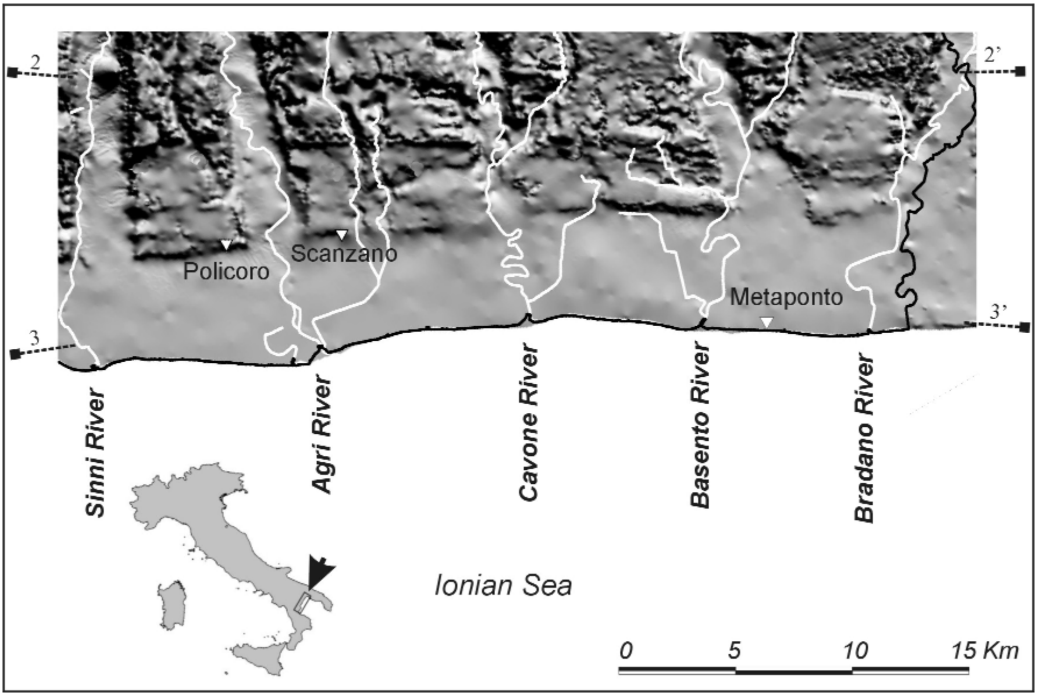

Figure 1. Digital elevation model (DEM) of the Ionian coastal plane, with location of the course of the five main rivers and main towns. The 2-2' and 3-3' traces refer to the geological sections of Figure 3 (from Spilotro, 2004a, modified).

The above-mentioned rivers come from the Apennine units and run, in their middle and final parts, in the Bradanic unit. The rivers have almost parallel courses, which develop at first from West towards East; then they turn towards SE and, in the lower tract, they organise perpendicularly to the coastline.

In the last 50 years, human activities strongly modified the surface and subsurface hydrology of the physiographic unit basin. In fact, a complex set of large works, which concurred to the transformation of the agricultural and industrial economy of the Ionian coastal plain and also of the surrounding regions, has been completed: the construction of 17 dams and minor barrages on the river courses (Spilotro et al., 2004) determined a deep modification of the hydrogeology of the whole area due to the important reduction of the recharge from the rivers into the aquifers of the coastal plain, and to the contemporaneous contribution of the new recharge sources as a result of the increase of irrigation practices.

The research studies carried out in the last decade (Spilotro et al., 2002, Spilotro and Caporale, 2003) have clearly outlined that the coastal plain is constituted by a hydrogeological system bounded from below by a blue clay basement and composed by three types of aquifers. The first type is represented by marine terraces, which are constituted by sands and gravels (MT in Figure 2) that overlap the blue clay basement. The second type is constituted by the coastal deposits (representing the present water front between the river mouths, CP in Figure 2) of sandy gravels with silt lenses, which have a maximum thickness of 30 m. The third type is represented by the alluvial deposits (AD in Figure 2) of the part of the river mouths presently closer to the sea front. They are constituted by silty sands and layers of sandy gravels with significant silty-clayey interbedding, and their thickness can be higher than 100 m.

The clay basement, as well as the sediments forming the hydrogeological system, have been faulted and fissured according with the extensional tectonics that interested the region until the late Pleistocene: consequently, large fractures allowed the ingression of seawater, both in the clay basement and in the overlying aquifers. This configuration, the geomorphologic features of the coastal border, the sea level changes during late Thyrrenian period and the human activities, determined the conditions for the presence of different kinds of salinisation sources, which effects occasionally overlap. In the groundwaters of the studied area the salt content increase has been recognised to originate from: salt water from superficial intrusion of seawater in the rear dune ponds or in the river mouths; salt water from alluvial aquifers overexploitation; salt diffusion from interstitial water of the over-consolidated marine blue clays; solution of sulphates from evaporite deposits and salt concentration from recycling of irrigation water. Moreover, in the area exists the influence of concentrated seawater released by human activities as the fish breeding.

The high amount of water used for irrigation and, especially during the dry seasons, the overexploitation of groundwater, act, in the different environments, favouring or limiting the salinisation phenomenon.

Geological setting

The coastal area of the Basilicata region (Figure 1) corresponds to the southernmost outcrop of the sediments of the Bradanic trough. The structure of the area is well known thanks to the extensive deep drilling for oil (Casnedi, 1988; Sella et al., 1988). The trough is filled with stiff fissured blue marly clays of Plio-Pleistocene age, having a thickness varying from several thousand of meters to the SW side of the trough, to a few hundreds or dozens of meters to the NE, where clays overlay the Cretaceous bedrock of Apulian foreland. The maximum elevation of the trough filling on this side is about 440 m a.s.l. Sands and gravels constitute the regressive cover lying on the blue clays, with a thickness normally not exceeding 80 m.

The Bradanic trough is located in an intermediate position between the Lucanian Apennine, a fold and thrust belt, and the Apulian platform, on the old western passive continental margin. Deformations and displacements of the Apennine front and of the Apulian platform have had different extents in the geological periods and in the space, as a result of the tectonic activity and of the bulging process, after the integration of tangential stresses into normal forces in the thrust zone, or as a consequence of the bending of the Apulian platform in its subduction towards the west (Ricchetti et al., 1988; Doglioni et al., 1996). On the west side, in the satellite basin of S. Arcangelo, evidence has been recorded of sharp variations of the stress field around a regional fault (Pieri et al., 1997). At present, the thrust front is buried under the deposits of the Bradanic trough, as this unit is progressively uplifted from NW to SE.

A wide part of the Bradanic region exhibits the evidence of wide Pleistocene tectonics, marked by intense faulting, up to now interpreted as diffuse erosional phenomena, proof of a widespread extensional or trans-tensional tectonics. This tectonic activity is somewhat linked to the intense faulting of the Mesozoic basement, as reconstructed by Sella et al. (1988).

The morphology of the lower part of the Bradanic trough is characterised by a number of marine terraces, which develop parallel to the Ionian coastline (Figure 2). The Tyrrhenian terrace of 125 Ky BP is found at elevations varying from 80 m a.s.l., close to the Sinni River and the Apennine margin, to about 45 m a.s.l., near the Lato river, close to the Apulian platform (Dai Pra and Hearthy, 1988). The difference in elevation is shown on the terraces of lower and greater order, going from the left (where the sediments have the maximum depth, of several hundreds meters and overlay different tongues of the buried front of the Apennine chain) to the right side, where terraces stay a few hundreds or dozens of metres on rigid calcarenites or on the Mesozoic limestones of the Apulian platform.

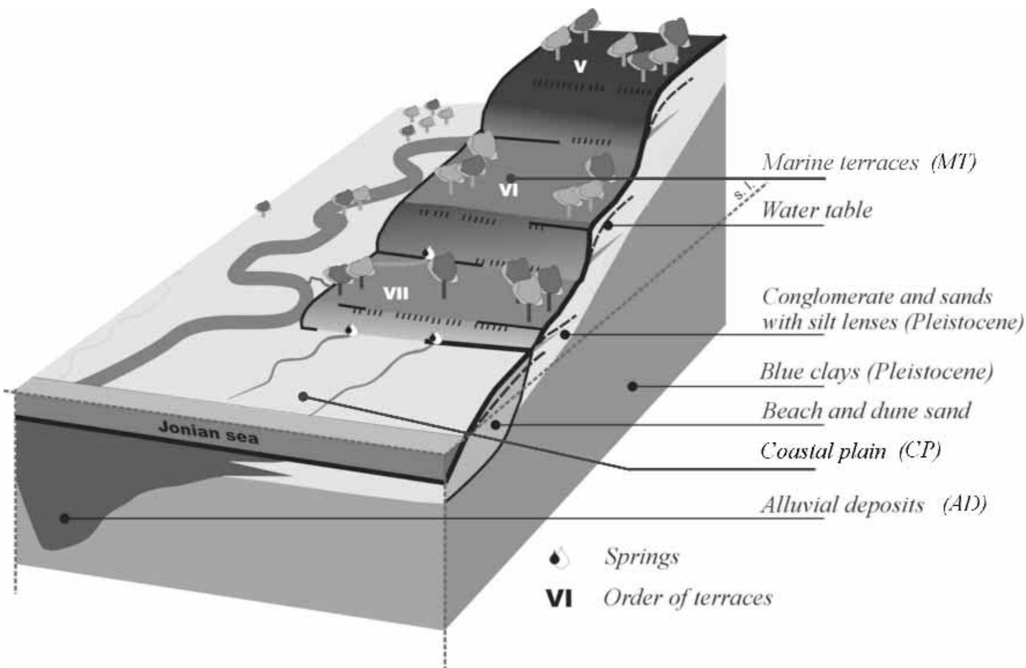

Figure 2. 3D schematic section of the hydrogeological system (from Spilotro, 2004a, modified).

The elevation of terraces above the sea level is totally attributed, in literature, to continental uplift, irrespective of the very different conditions in the deep border, which leans on three different structures: the eastern side of the chain, the trough and the western part of the foreland, as noted also by Bordoni and Valensise (1998). Parea (1986) notes a quite similar number of terraces (ranging from 11 to 14 and to the elevation of 355 m a.s.l.) in three areas of comparable tectonic setting to the external margin of the Apennine chain.

The hydrogeological researches of the LABIA group led, by means of the reconstruction of the clay basement of the region, to a very relevant result concerning the recent rate of evolution of the area (Spilotro, 2004a). In fact, the depth of the clay basement in correspondence of the river mouth of the five rivers flowing into the Ionian sea fits very well with the position of sea level at the Last Glacial Maximum (LGM), as predicted for the area by Lambeck et al. (2004). Therefore, from the age of the 10 m a.s.l. terrace until the LGM, both tectonic components acting in the area (the continental uplift and the differential uplift) seem to become irrelevant and of uncertain sign, relative sea level changes being due almost exclusively to eustatism and isostatic associate adjustment.

On the basis of the reconstruction of the lower limit the aquifer assumes the more correct appearance of an aquifer system. Indeed, the incision depth of the fluvial valleys of the five main rivers flowing into the Ionian Sea defines an alternant arrangement of hydrogeological environments along the coast: the estuarine type is present five times and alternates four times with the coastal type.

Hydrogeological setting

A meaningful contribution to the understanding of hydrodynamics of the Ionian coastal plain and of the related hydrogeochemical processes came from hydrogeological surveys carried out by the LABIA starting from 1999 (LABIA, 2000).

The hydrogeology of the plain has been defined on the basis of the analysis of geomorphological and geophysical surveys, and stratigraphic data coming from about 1,500 irrigation wells and boreholes distributed in the area. A number of boreholes has been purposely drilled and cased to perform specific analyses and samplings.

The coastal aquifer system is defined by a sequence of five alluvial estuarine riverbeds, which deepen as far as 120 m, which alternate four times with terraced alluvial and coastal sediments, transgressive over the blue clay basement, well delimited inland by the same blue clays and vanishing seaward under sea level. Moreover, inland, the coarse sediments of the higher elevation terraces constitute four distinct aquifers, confined in their lower part by the blue clays (figures 2 and 3).

The hydrogeological boundaries of the alluvial estuarine aquifers (first kind of aquifer) are the sea at coastline, the aquifers of second kind laterally and the river alluvial sediments on their back. Because of the presence of laminar widespread clay sediments, water flow can be partitioned and confined and/or artesian in some partitions. The second kind of aquifer has boundary conditions defined at coastline by the sea and laterally by the aquifers of the first kind: it is characterized by a water flow mainly under phreatic condition. The third kind of aquifer is unconfined on three sides and water flows under phreatic conditions. For all types of aquifer, the blue clay basement constitutes the lower boundary.

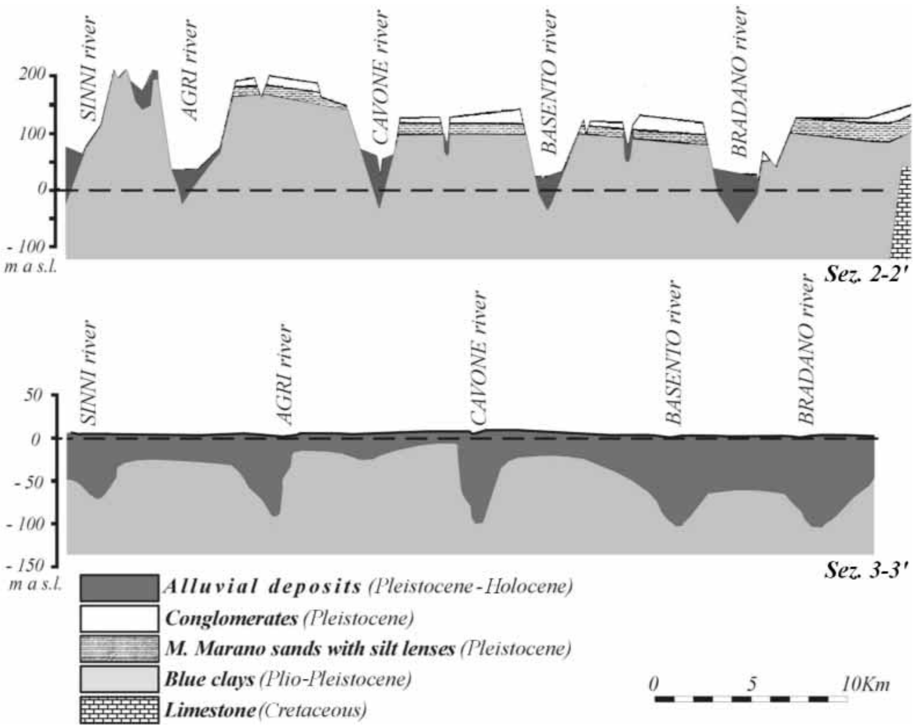

Figure 3. Geological sections reconstructed almost parallel to the coastline at an average distance from it of about 14 km (sect 2-2') and 3 km (sect 3-3'). Traces of the sections are in Figure 1 (from Spilotro, 2004a, modified).

The impermeable basement is strongly eroded at the coastline as far as 120 m under the present mean sea level in correspondence of riverbeds and it exceeds the sea level in correspondence of the marine terraced aquifer. In correspondence of the Cavone river mouth, it is so faulted that it has favoured the trapping of evaporite formations (Spilotro, 2004b).

The seasonal alternation of considerable irrigation and over-exploitation of groundwaters in the area conditions the energetic state of the aquifers, favouring or limiting the salinisation of the hydrogeological system. Due to the uncertainty in the evaluation of both irrigation and exploitation, the hydrogeological budget of the system is of difficult determination. The area is characterized by an average amount of precipitation of about 565 mm/y, which is among the lowest of the entire region. This, coupled with the semi-arid conditions characterizing the area, leads to an annual average infiltration of only 72 mm/y.

Approximately 150 Mm^3/y of fresh water, derived from reservoirs and destined to irrigation of the plain and of marine terraces must be considered in the hydrological balance and added to the amount of natural infiltration. Forty Mm^3/y, drained from the seaside of the coastal plain through the channels, built in the past for the reclamation of the area, almost entirely reach the sea; anyway sometime they, after being drained, are re-used for irrigation.

More difficult is the evaluation of the draft from wells. Ten Mm^3/y is the estimated amount of groundwater pumped from the wells drilled by the Consortium of Reclamation of Bradano and Metaponto, while the groundwater volumes drawn massively and irregularly from the coastal aquifer system through private and illegal wells, especially during dry seasons (ever more frequent in the last few decades) represent an output term almost impossible to quantify.

Salinisation sources and processes

Numerous processes can be at the origin of the salinisation of ground waters of the Ionian coastal aquifer system. The first, the classic seawater intrusion where seawater is a boundary condition, is due to the exploitation of fresh water that results in the decrease of hydraulic heads. Luckily, confined flow in the aquifers of first kind and large amount of irrigation in the aquifers of second type make this saltwater intrusion not common.

Seawater can mix with fresh water by means of other mechanisms. Brackish waters have been revealed some kilometres upstream of the river mouths due to combined effects of tides and southern winds; this water is commonly used for irrigation. Seawater can enter also in the ponds behind the dune belt. In both cases salt from seawater accumulates in the soil cover and reaches groundwater, due to the mainly sandy composition of the soils of the plain. The large amount of water coming from irrigation is responsible for the enrichment of salt in the cover soils, only in part removed from the run-off.

One case of salinisation, well documented in the next paragraph, comes from an anthropic salt source constituted by some artificial ponds for fish breeding, fed by seawater subject to evaporation.

The last two phenomena that are responsible of the presence of salts in groundwater, come from the interaction between marine clays and groundwater: the first is due mainly to ionic diffusion at the base of the aquifer of second and third type, while the second occurs mainly along soil fractures due to both dispersion and diffusion. The phenomena are very common whenever groundwater flows near a surface of marine blue clay or through a fracture in such clays.

An enhanced phenomena of this kind is present in groundwater along the lower part of the Cavone river, where the ionic diffusion can derive from deep buried evaporites. To ascertain and recognize the source and the extent of salinisation, the hydrogeological survey involved 14 wells formerly drilled with the aim of updating the profile of the blue clay basement in the areas of river estuaries (Spilotro et al., 2002). The wells are located along the coast and intercept the main groundwater bodies of the coastal system, but mainly they are concentrated in the estuarine aquifers.

Temperature and conductivity logs have been carried out in above wells in March and May 2004, and 17 water samples have been collected (in static conditions) for chemical analysis from 10 out of the 14 wells in between the execution of logs. Other chemical data are provided from the analyses of samples from pumping wells, but the discussion will focus primarily on the samples taken in the well net.

Discussion

Temperature and conductivity sections

The usefulness of temperature and conductivity profiles in the recognition of flow systems, preferential groundwater pathways and salinisation origin, has been discussed especially with reference to highly anisotropic systems (Tulipano, 1986; Tulipano and Fidelibus, 1989). The interpretation of data from logs is carried out by reconstructing the trend of the isotherms along meaningful vertical (and horizontal) sections.

For the present study, the logs were used for the reconstruction of the thermal and conductivity trends along a section parallel to the coastline, which intercept the wells drilled at the five river mouths. Figure 4 and Figure 5 show temperature and conductivity sections for March and May 2004.

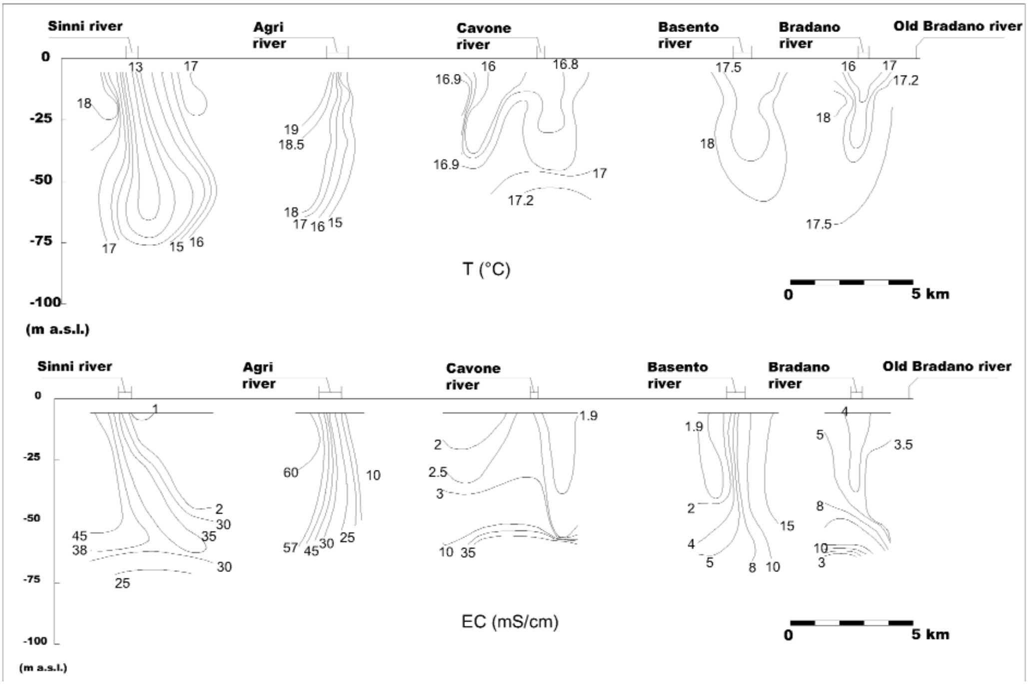

Figure 4. Temperature (°C) and conductivity (mS/cm) vertical sections (March 2004) intercepting the five alluvial aquifers of the Ionian coastal plain (Basilicata Region).

The temperature ranges in both periods from 16 to 19 °C, while conductivity varies between 1 and 60 mS/cm. The areas of the sections influenced by fresh water flow are clearly indicated by the contemporaneous presence of the lowest conductivities and temperatures, being characterised by both low temperature and conductivity gradients; these areas more or less coincide with the sandy and gravel horizons. The isotherm trends are mostly concave upward, indicating an active recharge to the system, which is moving downward from the Sinni, Cavone, Basento and Bradano riverbeds in both periods. The recharge to the coastal plain turns out more meaningful in May (Figure 5) than in March (Figure 4), showing a large time lag between high discharge and maximum infiltration period.

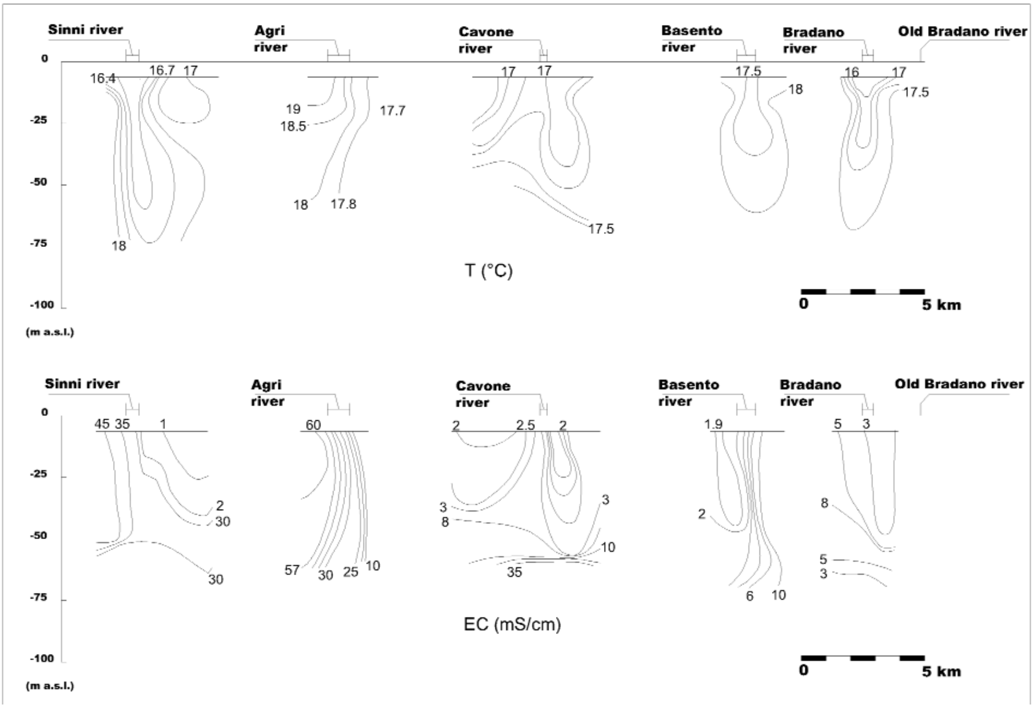

Figure 5. Temperature (°C) and conductivity (mS/cm) vertical sections (May 2004) intercepting the five alluvial aquifers of the Ionian coastal plain (Basilicata Region).

The Sinni section shows a very low temperature in May (12 °C), which apparently originates from a cold flow from the surface; however, the low temperature could be only related to the presence of permeable layers confined by clay layers, without any link with surface recharge. To this point, it has to be underlined that the system shows a very high heterogeneity, as usual in estuarine deposits: they, due to the presence of coarse and fine sediments and interbedded clay layers, show normally a complex stratigraphy. In the case under study, the lateral extension of gravel and silt lenses can be very limited. The temperature and conductivity trends are closely related to the heterogeneity of the system and the consequent permeability distribution: in this way, present interpolation of temperature and conductivity data suffer, in some places, from the lack of detailed stratigraphic information, however maintaining a general usefulness.

Regarding the Cavone River section, two main fresh plumes are clearly recognized, which could have relation with the natural riverbed diversions the river undergoes during the year; anyhow, temperature and conductivity show that the diversion does not prevent the maintenance of different active riverbeds.

The highest temperatures accompany the highest electrical conductivities, as in the right hand (left side in the figures 4 and 5) and at the bottom of the alluvial bed of Sinni River, at the right hand of Agri River and at the bottom of the section for Cavone River. The lateral and bottom influences are characterized by high gradients of temperature and conductivity, which indicate a very high permeability anisotropy of the concerned parts of the sections: at the bottom, in a few decimetres, conductivity suddenly varies from 1–2 mS/cm to 35 mS/cm, while laterally the passage from 10 to 45 or 60 mS/cm occurs in hundreds or thousands of meters.

In the case of Sinni River, the influence of the saline water spreads along the section, suggesting both saline lateral influence and salinisation from the underlying clays. At Agri River, the very high conductivity overcomes that of seawater and the trend of the isotherms and the conductivity contour lines indicate an origin of the salt plume from the surface. In this case, the high salinity seems to originate from the presence of artificial pools used for fish breeding: they are fed with seawater, which concentrates due to evaporation.

The conductivity sections confirm the considerations deduced from the thermal profiles: the coastal plain is abundantly washed by waters coming from the riverbeds, while salinisation shows an irregular pattern, with salinity plumes coming laterally, from the surface or from the bottom of the alluvial deposits. On the base of temperature and conductivity sections, the salinisation of groundwater in the studied alluvial deposits seems to originate mainly from salinity of the sediments and from human activities.

Groundwater chemical composition

The recognition of the different salinisation mechanisms affecting the coastal system is anyhow of difficult determination, just because there is not a single source and more processes can concur to the same effect. Useful information for the recognition of the origin of salinisation has been collected by analysing the chemical composition of ground waters sampled in the coastal plain, both in static and pumping conditions.

The analyses concern only major constituents. The available set of data allows only advancing first hypotheses on the salinisation origin and the main water-rock interaction processes, which groundwaters undergo. Cross plots of major ion concentrations vs. chloride concentration for all available samples show that ion concentration deviates from the theoric conservative mixing lines, which can be calculated between the freshest water sample (chosen among the analysed fresh samples as the fresh water end-member, FW) and the present seawater (Ionian Sea, salt end-member, SW). Figure 6 and Figure 7 show respectively magnesium and sulphate concentrations, and calcium and sodium concentrations, vs. chloride concentrations: data refer to water samples collected both in static and pumping conditions from the net of 14 wells and from private wells in the plain, and are shown in comparison with related FW-SW conservative mixing lines. Using a simple stoichiometric approach, the deviation of each measured concentration from the theoric value determined by conservative mixing can be easily calculated. Therefore, the calculated deviations of each ion reflect the compositional changes connected to diagenetic processes acting at the sediment/water interface.

The deviations (excesses or deficits) for calcium, magnesium, sodium, and sulphates, related to samples collected in static conditions only, are shown in Figure 8 with respect to the depth of sampling, together with bicarbonate concentrations. Data are grouped from SW to NE according to their location, and

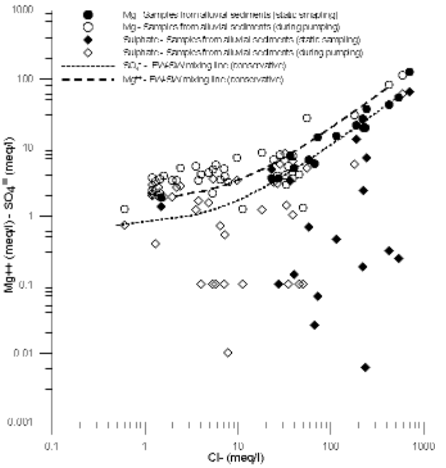

Figure 6. Magnesium and sulphate concentrations (meq/L) vs. chloride concentrations: data refer to water samples collected both in static and pumping conditions from the net of 14 wells, which intercept the five alluvial aquifers of the plain, and from private wells in the coastal plain. The FW-SW lines represent the related conservative mixing.

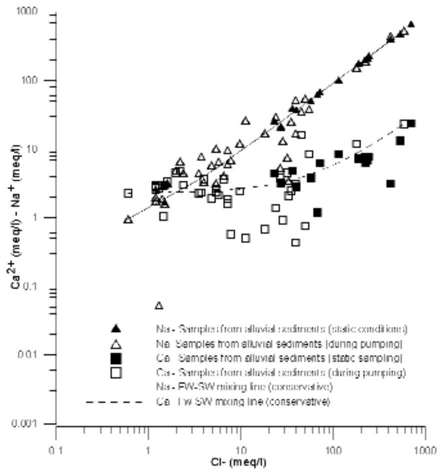

Figure 7. Calcium and sodium concentrations (meq/L) vs. chloride concentrations: data refer to water samples collected both in static and pumping conditions from the net of 14 wells, which intercept the five alluvial aquifers of the plain, and from private wells in the coastal plain. The FW-SW lines represent the related conservative mixing.

ordered, within each group, according to increasing sulphate depletion. The last two river deltas (pertaining to Basento and Bradano River) are gathered in the last group, due to the closeness of the related samples.

Figure 8 makes straightforward the whole behaviour of the major chemical constituents with sampling depth (except K, which is not represented due to its very low concentrations). Sulphates are always depleted with respect to conservative mixing and magnesium depletion clearly accompanies that of sulphates. Calcium and sodium show a general depletion as well, even if not so clearly variable with depth. Bicarbonate concentration increases with depth: its concentration reaches even 12 meq/L.

Sulphate depletion indicates the action of a removal process such as sulphate reduction: the depth at which this reaction first occurs can mark within each

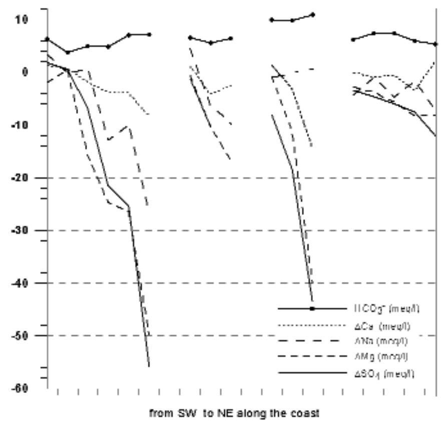

Figure 8. Deviations (excesses or deficits) for calcium, magnesium, sodium, and sulphates, and bicarbonate concentration (related to samples collected in static conditions only) vs. the depth of sampling. Data are grouped from SW to NE according to their location, and ordered, within each group, according to increasing sulphate depletion.

context the passage from oxic to anoxic conditions. This boundary should correspond to a substantial availability of organic matter in an environment with limited oxygen supply. In the vicinity of such a boundary, the redox potential approaches the transition between oxidised and reduced conditions and involves the dissolution of solid Fe(III)-oxyhydroxides; above (oxidized part) and below (reduced part) the iron forms insoluble compounds. In fact, below the boundary Fe(III) reduces to Fe(II) and forms iron sulphides, which thus precipitate in the anoxic part of the profile (Burdige, 1993; Berner, 1984).

When these main reactions occur, groundwaters show also an increase of ammonium concentration and carbonate alkalinity with increasing depth. The increasing carbonate alkalinity is often observed in the euxinic part of sediment profiles of both lakes and seas (Murrey et al., 1978, Gaillard et al., 1987). The bicarbonate concentrations of analysed waters show close correlation with depletion of sulphates, thus indicating that sulphate reduction is the main source of carbonate alkalinity.

The depletion of magnesium, calcium, and sodium is not so immediate to explain. Depletion of magnesium has been already observed in sediment profiles with increasing depth when the environment is in reduced conditions (Sholkovitz, 1973; Sayles, 1981; Pigott and Land, 1986); the mechanism of depletion should involve the removal of iron oxides from clays and the following uptake of magnesium in previously occupied sites. The same should be for sodium (Sayles and Manheim, 1975), but its depletion, together with that of calcium, is not correlated with magnesium and sulphate depletion in a clear way.

As a matter of fact, the behaviour of the major cations is actually controlled by more than one process. Sodium and calcium, and subordinately magnesium and potassium, are subject to ionic exchange both in fresh and salinised environments. Many times their mutual variations have been recognised in coastal aquifers subject to salinisation (inverse exchange) and during refreshing (direct exchange) (Fidelibus et al., 1992; Gimenez et al., 1995; Fidelibus and Tulipano, 1996). Many competing processes, in particular, control calcium concentration, as solution-precipitation of calcite or carbonate minerals, ionic exchange and gypsum solution (Barbieri et al., 1994, Barrocu et al., 1994).

In order to explain the modifications of the characteristics of groundwaters in the plain with respect to those expected from conservative mixing with present seawater, all the above data indicate that a number of water-rock interaction processes may exist and act during the mixing processes in the euxinic environment.

Anyway, the same results are consistent with the superimposition on mixing of fresh waters with saltwater of marine origin already deeply diagenised (which could be represented by the original seawater trapped in the sediments during deposition and then modified during burial in an anoxic environment) of water-rock interactions brought about by mixing.

In any case, the observed chemical compositions indicate that waters are flowing in an anoxic saline environment with restricted relation with present seawater. Apart from the case of the salt waters coming from the pools for fish breeding, salinisation in the alluvial sediments of the plain seems to be connected with the flushing and dilution of salt pore waters preserved in the sediments of lower permeability.

Conclusions

The hydrogeological survey carried out in the Ionian coastal plain of Basilicata region evidenced a diffuse salinisation of groundwaters, involving, even if in different measure, the whole hydrogeological system. Many processes trigger salinisation (diversion and/or damming of the river courses with consequent regression of the coastline, variation of the elevation of the dune barriers, groundwater over-exploitation, re-use of waters drained from the reclamation canals, use of river waters in irrigation, decrease of the precipitation amount and contemporaneous increase of maximum temperatures in the last 15 years) in an area subject to different natural and human sources of salinisation (saline diagenised pore water in low permeability sediments, present seawater, evaporated seawater in artificial pools and natural evaporite salts).

The interpretation of temperature and conductivity profiles and related vertical sections indicated that the salinisation in the estuarine and alluvial sediments of the plain is mainly connected with flushing and dilution of salt pore waters preserved in the sediments of lowest permeability, while present lateral intrusion of seawater can be excluded. Profiles allow evidencing the recharge from rivers and the effects of artificial salt sources as the seawater evaporated ponds.

Chemical analyses helped in inferring the most probable water-rock interaction processes acting on waters of different salinity: reduction of sulphates and precipitation of metal sulphides occur according to the onset of anoxic conditions, while ionic exchange works on the whole range from oxic to anoxic conditions. Same effects on water chemistry can be obtained by mixing freshwaters with a salt end-member deeply diagenised; this means that diagenesis (due to the above water-rock interactions) occurred only in the past on seawater trapped in the sediments, resulting in an end-member different from present seawater. For discriminating between the two hypotheses it will be necessary to explore the aquifer for sampling the more saline waters present in the alluvial deposits and carry out more detailed chemical analyses.

New chemical analyses should focus on the completion of the spectrum of parameters needed for recognising the supposed reactions; moreover, isotopic analyses might give an insight in the age of more saline components. In addition, new drillings and water sampling should be located in the inter-estuary areas, with the aim of completing the knowledge of the whole coast stretch. New EC and T profiles should be carried out in the present well net in order to cover almost a complete hydrologic year and reconstruct new sections. The worse conditions as to salinisation are expected in the late summer after a long over-exploitation period.

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