# HYDROGEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS FOR EVALUATING SALT INTRUSION PHENOMENA IN SARDINIA

G. Barbieri

G. Barrocu

G. Ranieri

Faculty of Engineering, University of Cagliari, Italy

Abstract

In the region of Muravera, south-east coast of Sardinia, the trend of salt intrusion phenomena has been studied for more than two years through systematic hydrogeological, hydrochemical and geophysical investigations. Water level and chlorinity measurements have been compared with the results of resistivity and induced polarization (I.P.) vertical soundings. In particular a close relationship has been established between salinity, resistivity and chargeability and as a result the extension and depth of the fresh, brackish and salt water bodies have been defined in detail.

## 1. Introduction

A systematic geophysical investigation has been carried out involving resistivity and chargeability soundings in order to verify the evolution of sea intrusion phenomena already studied in the delta plain of the River Flumendosa on the SE coast of Sardinia (Barbieri et al., 1984). The object of the investigation was to integrate existing information on the coastal plain of the River Flumendosa, with particular regard to stratigraphy.

The geophysical survey was designed to check the reliability of geoelectrical methods used in studying salt intrusion phenomena by comparing results with data obtained from hydrogeological observations.

## 2. Geology

The geological formations of the coastal plain, shown in Figure 1, are, from top to bottom:

- aeolic deposits and coastal dunes
- recent alluvium, mostly sandy with layers of gravel, silt and clay (Olocene)
- terraced alluvial deposits well cemented with Paleozoic silty sandy gravels and ancient alluvial fans, now inactive, bordering the slopes of the Paleozoic schist and granite hills to the West of the plain (Pliocene-Pleistocene)
- granite and schisty sandstone bedrock (Paleozoic).

No wells have been drilled down to the bedrock. The thickness of the overlying alluvium is presumed to be more than 100 m at least in the central plain.

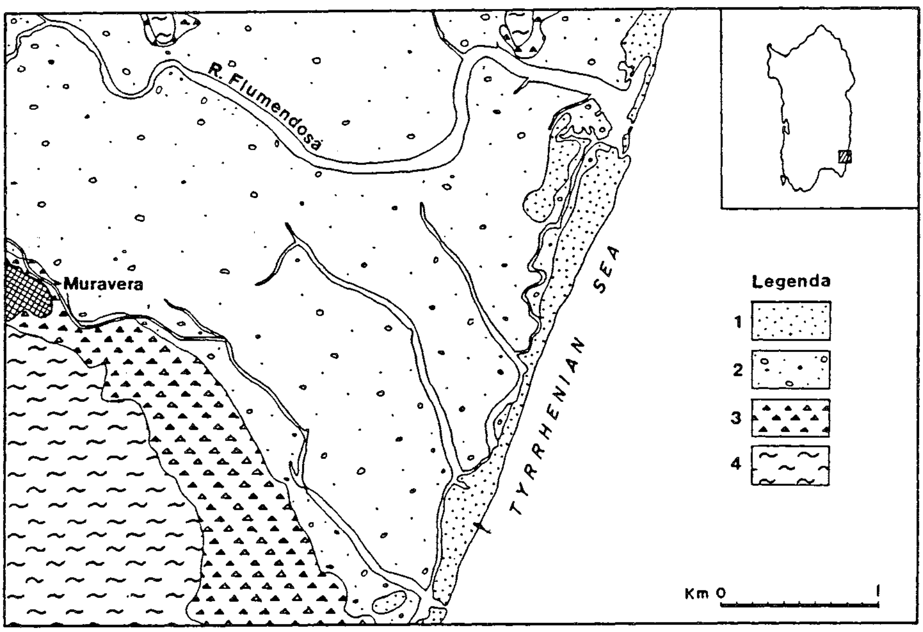


Figure 1. Geological sketch map of the delta plain of the River Flumendosa. Olocene: 1. sands; 2. loose alluvium; Pliocene, Pleistocene: 3. cemented alluvium; Paleozoic: 4. schisty sandstones

## 3. Hydrogeology

The plain is crossed by the River Flumendosa and its former outlets, now inactive. Up to a few years ago, before the river was dammed upstream, these outlets drained a surface aquifer recharged by frequent devastating floods.

Two main aquifers have been identified in the delta plain. A phreatic aquifer, with a water table a few meters deep below the surface level, has been studied with direct observations throughout a network of 30 productive wells excavated down to a depth of 4-5 m. They are representative of more than 300 wells surveyed throughout the plain.

The contour lines in Figure 2a represent the water table in March 1984, after recharging by winter rainfall and before overpumping for irrigation began.

The contour lines in Figure 2b clearly show the water table draw-down below sea level in areas of citrus groves in July 1984, when the natural recharge was nil and water demand for irrigation at its peak. At that time, as indicated by the flow lines, wells were draining water from the beds of the River Flumendosa and its former outlets, in direct communication with the sea.

The recent alluvium is highly permeable. Transmissivity and storativity have been calculated, using the Theis, Jacob and Chow methods, as $2.4 \times 10^{-4} - 4.2 \times 10^{-3}$ $m^2/s$ and $S = 0.13$ respectively. Yields are strongly affected by well characteristics, and range from as little as 3 up to 200 l/sec.

Hydrochemical analysis of water samples from the wells revealed the salt content in the surface ground water in the coastal zone. Isochlore contour lines in Figures 3a and 3b indicate the trend of salt intrusion from June 1983 to October 1985.

The underlying confined aquifer is exploited only by a few bore holes drilled upstream from the plain down to depths of 50 m for drinking water supply. A maximum yield of 30 l/sec has been measured with transmissivity $T = 1.3 \times 10^{-2}$ $m^2/sec$ and storativity $S = 0.48$.

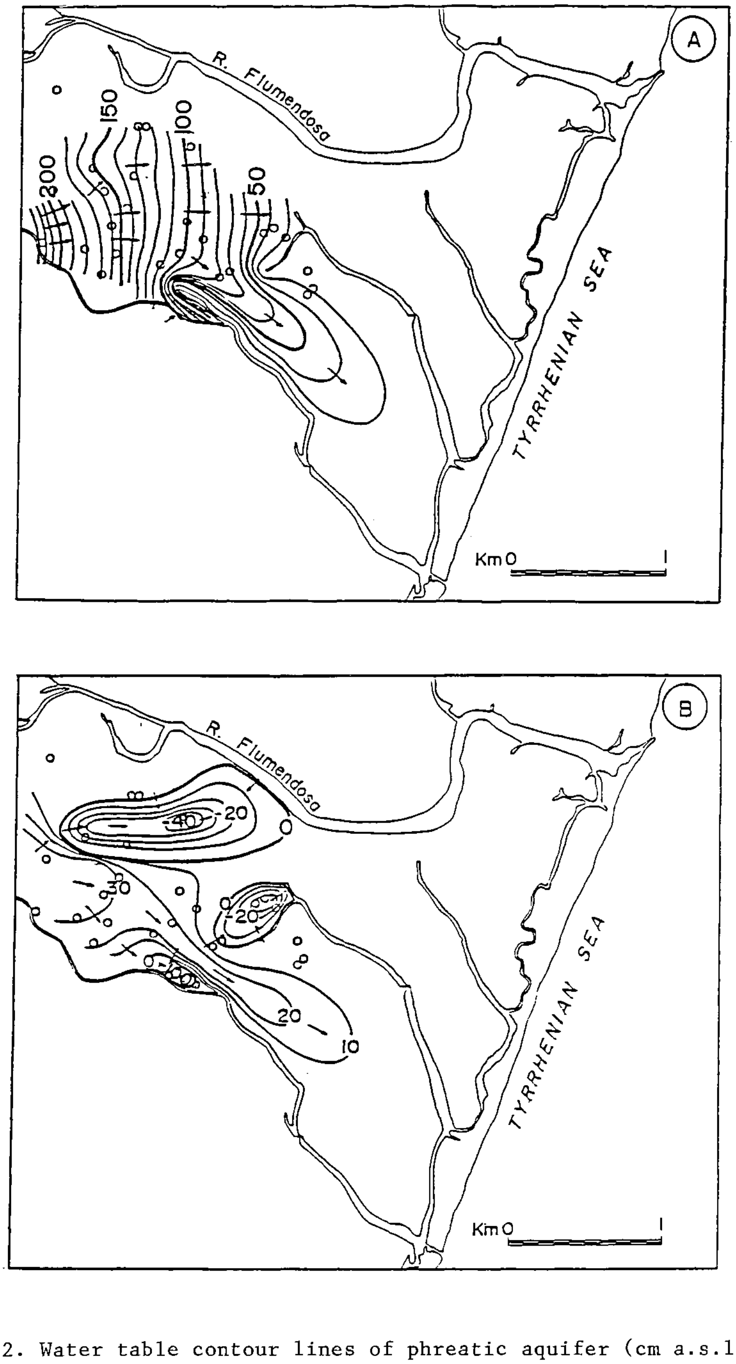


Figure 2. Water table contour lines of phreatic aquifer (cm a.s.l.).
a) March 1984; b) July 1984. Observation wells ( o )

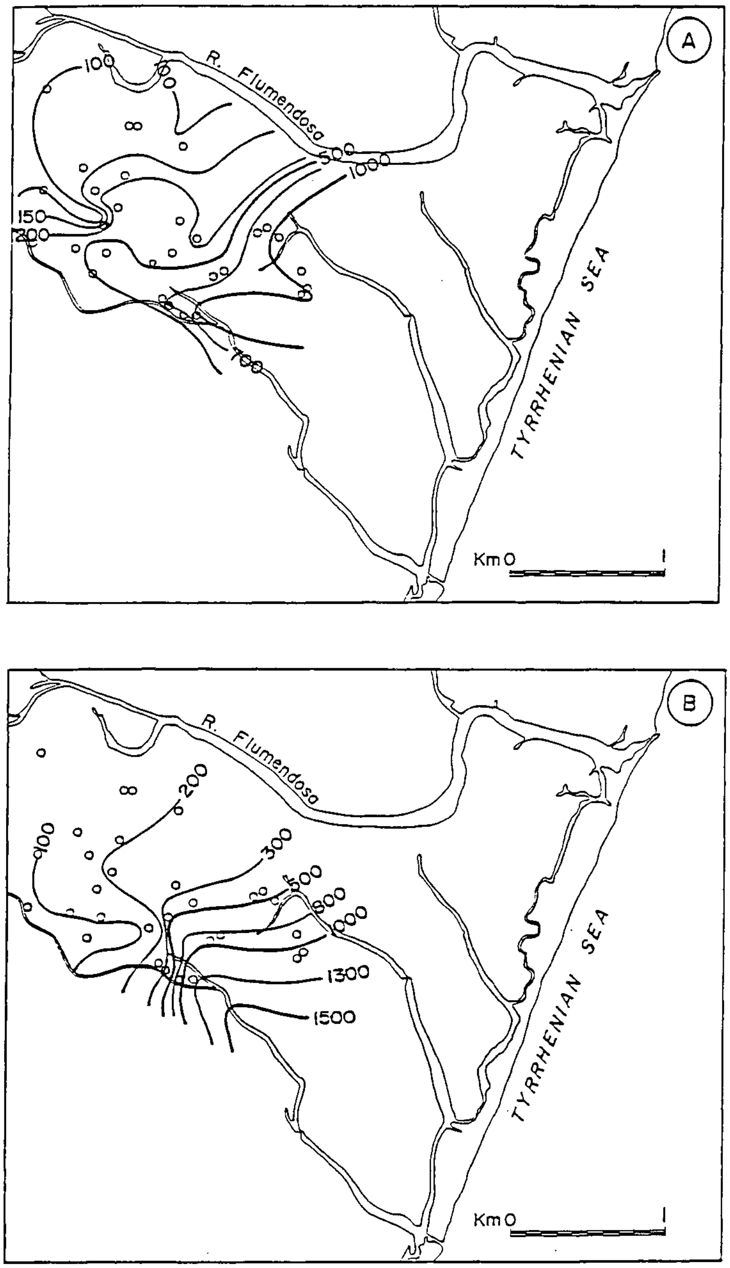


Figure 3. Isochlore contour lines of phreatic aquifer ($Cl^-$ mg/l).
a) June 1983; b) October 1985. Observation wells ( o )

## 4. Geophysical investigations

For the purpose of defining the shape and size of the salt intrusion wedge, a resistivity and IP survey was carried out via 26 Schlumberger soundings using an Austral Y842 transmitter, a Scintrex IPR 10 receiver and an 8 Hp generator for the field survey. Steel stakes and copper-copper sulphate porous pots were used as current and potential electrodes respectively and the charging-discharging time was fixed at 4 seconds.

Measurements were repeated in June 1983 and October 1985, before and after heavy rainfall, in order to study the relationship between phreatic groundwater and resistivity or chargeability.

A true resistivity map of the water table at 3 m below the surface for 1983 is given in Figure 4a. Low resistivity values (<2 Ωm) have been observed near the mouth of the River Flumendosa. Furthermore, a marked introflexion of the isoresistivity lines along the former outlets of the River Flumendosa delineate critical areas where brackish water intrusion had been detected with direct hydrogeological observations.

The trend of sea water intrusion in October 1985 is shown in Figure 4b. The area delineated by the 5 Ωm resistivity line protrudes even further inland along the former outlets.

I.P. methods have been used for a long time in ground water investigations as reported, among others, by Vacquier et al. (1957), Bodmer et al. (1968), Ogilivy and Kuzmina (1972) and Patella (1973). According to Roy and Elliot (1980), salt and fresh water may be distinguished through combined chargeability and resistivity measures.

In the Flumendosa delta plain resistivity vertical soundings have been integrated with chargeability measurements repeated in June 1983 and October 1985. Figures 5 and 6 show the apparent chargeability map for AB/2 = 5 m and AB/2 = 45 m. These values may be referred to the phreatic and the confined aquifer respectively.

The relationship between true resistivity calculated at 3 m below the surface and the salinity of water samples collected at the same depth is shown in Figure 7a. The relationship is linear up to resistivity of 50 Ωm and negative exponential for higher values. The maximum permissible salt content for drinking and citrus grove irrigation water are also indicated in order that the resistivity maps might provide pointers

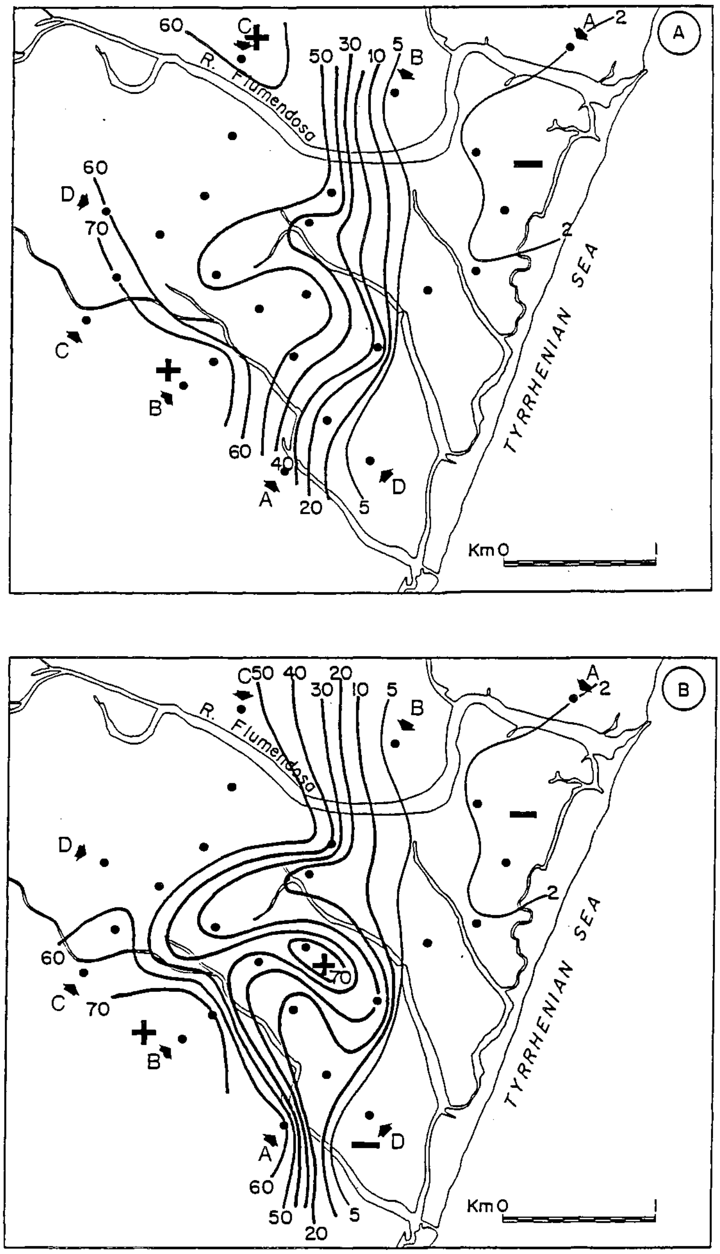


Figure 4. True resistivity map at depth of 3m ($\Omega$ m). V.E.S. centers (•).
a) June 1983; b) October 1985

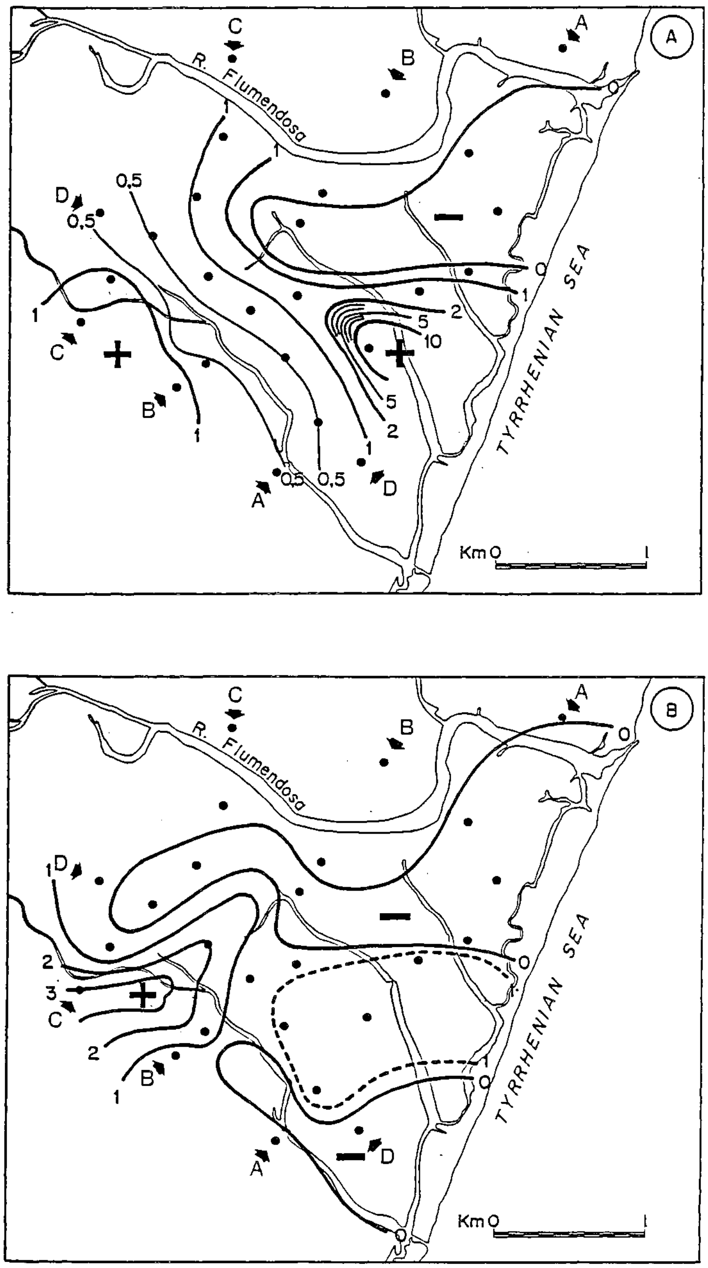


Figure 5. Apparent chargeability map AB/2 = 5 m (mV.s/V) V.E.S. centers (•).
a) June 1983; b) October 1985

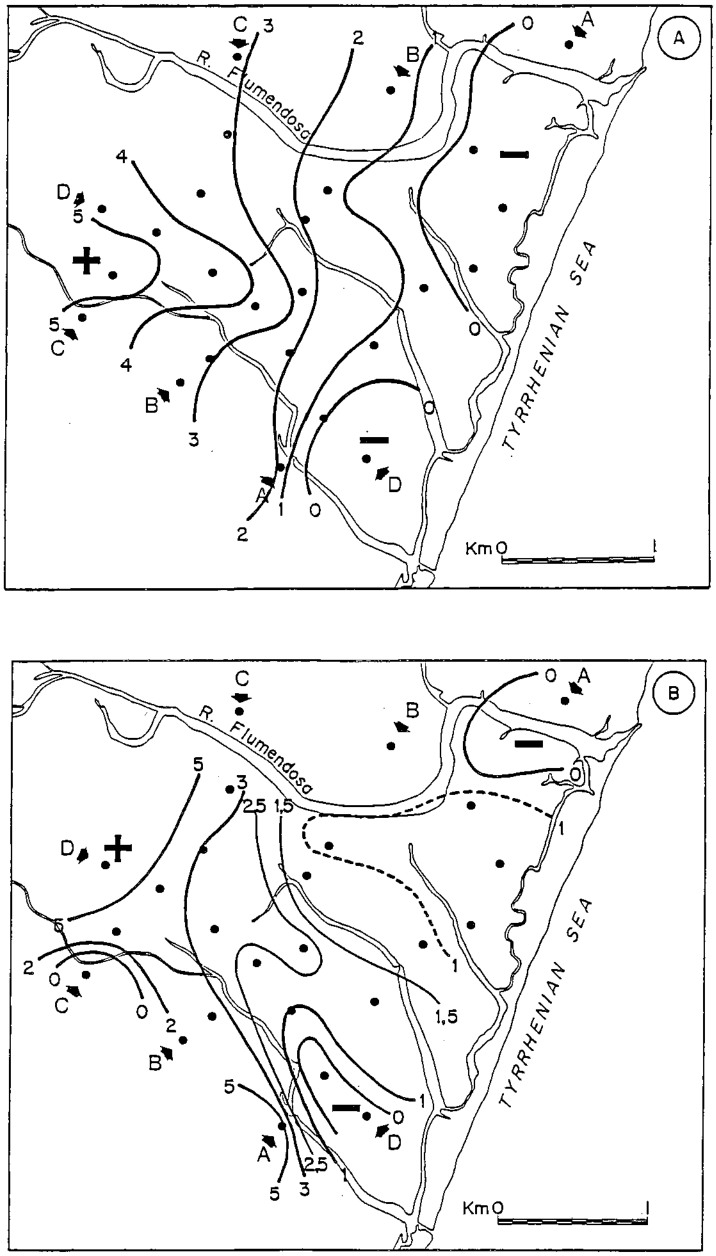


Figure 6. Apparent chargeability map AB/2 = 45 m (mV.s/V) V.E.S. centers (•).
a) June 1983; b) October 1985

for optimum development of soil and water resources. Peak resistivity was observed near a canal excavated to protect the town of Muravera from floods and drain the area.

A salinity-chargeability relationship has been obtained using the apparent chargeability values calculated with AB/2 = 5 m, that, in the case at hand is referred to a layer about 3 m deep. The relationship is non linear with negative values for $[Cl]^- > 1080$ mg/l and maximum values coincide with low concentrations (Figure 7b). A relative maximum is given for contents of $[Cl]^- = 500$-$1000$ mg/l.

This result does not appear to entirely agree with the findings of Roy and Elliot (1980) who claim that salty water zones are identified by a simultaneous decrease in resistivity and chargeability. In reality the discrepancy is only apparent and can probably be put down to the variability of the salinity-chargeability relationship which is strongly affected not only by ground water salt content but also by the lithology of the aquifer. The relationship found allows to distinguish zones with different salinity. Negative and positive zones show areas with salt and fresh water respectively.

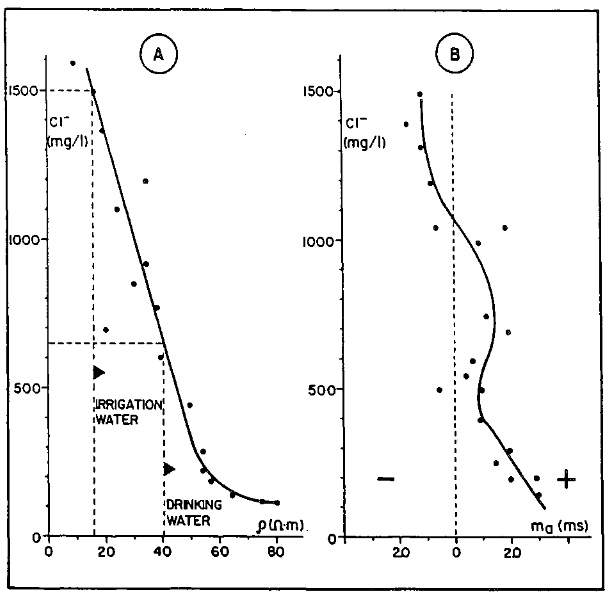


Figure 7. a) resistivity-chlorinity relationship

b) apparent chargeability-chlorinity relationship

The evolution of the salt intrusion phenomenon with time and depth is clearly evidenced in Figures 5 and 6.
The electrostratigraphic sections constructed from the resistivity data are given in Figure 8. Sections A, B and C are parallel and section D perpendicular to the coast line. Different layers have been interpreted by extrapolating to depth the relationships between chlorinity and resistivity or apparent chargeability.

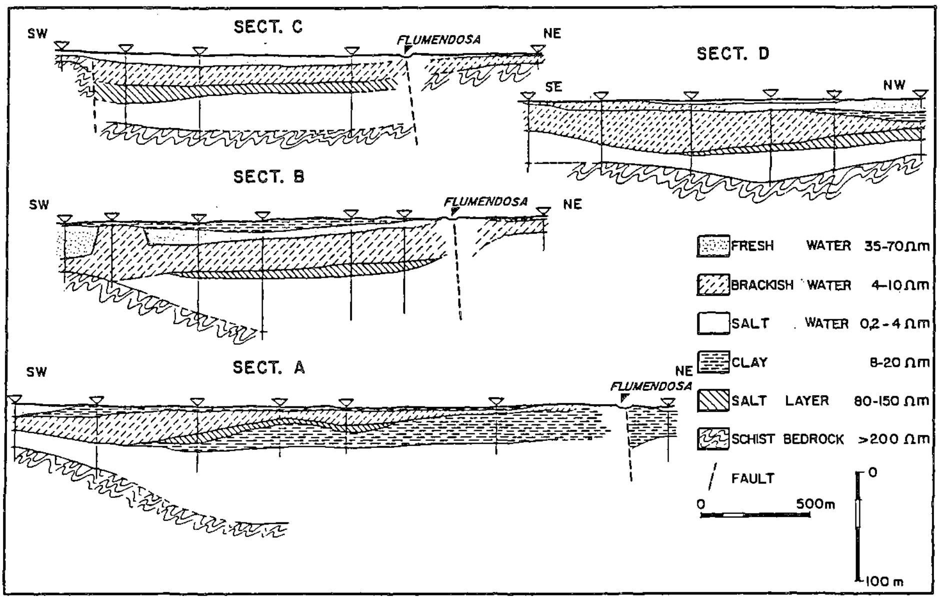


Figure 8. Electrostratigraphic and hydrogeological sections

## 5. Conclusions

The relationship between salinity and resistivity or chargeability has been studied on the basis of the results of hydrogeological and hydrochemical investigations. In the case under study the areas of higher salinity are characterized by low resistivity and negative I.P.
The correlation found for the phreatic aquifer has been extrapolated

to depth. In this way the stratigraphy of the region has been defined as well as the spatial and temporal development of sea water intrusion.

## References


Barbieri, G., Barrocu, G., Poledrini, C. and Uras, G. 1983. Salt intrusion phenomena in the south east coast of Sardinia. Geol. Appl. Idrogeol., XVIII, 315-323.

Barbieri, G. and Barrocu, G. 1984. Consequences of overexploiting coastal aquifers in areas of touristic development in south eastern Sardinia (Italy). 5th International Conference on Water Resources Planning and Management "Water in the Year 2000". 1-4 October, 1984. 1-12 preprints.

Bodmer, R., Ward, S.H. and Morrison, H.F. 1968. Induced electrical polarization and ground water. Geophys. 33(5), 805-821.

Ogilivy, A.A. and Kuzmina, E.N. 1972. Hydrogeologic and engineering-geologic possibilities for employing the method of induced potentials Geophys. 37(5), 839-861.

Patella, D. 1973. A new parameter for the interpretation of induced polarization field prospecting (time-domain). Geophys. Prosp. 21(2), 315-329.

Roy, K.K. and Elliott, H.M. 1980. Resistivity and I.P. survey for delineating saline water and fresh water zones. Geoexpl. 18, 145-162.

Vacquier, V., Holmes, C.R., Kintzinger, R.P. and Lavergne, M. 1957. Prospecting for ground water by induced electrical polarization. Geophys. 22(3), 660-687.