Proccedings of the

# IV Meeting of the

# Environmental and Engineering Geophysical Society (European Section)

September 14-17, 1998

Barcelona (Spain)

Environmental
and Engineering
Geophysical Society
European Section

# THE GEOPHYSICAL ELECTROMAGNETIC PROSPECTION IN THE SPATIAL LOCATION OF THE TRAVERTINE DEPOSITS OF THE BANYOLES DEPRESSION (GIRONA). GEOLOGICAL AND HYDROLOGICAL IMPLICATIONS.

**D. Brusi*, L. Palli*, C. Roqué*, I. Capellà*, A. Pujadas*, M. Vehi***

Area of Geodynamics. Department of Environmental Science. University of Girona. Montilivi Campus. 17071 (Girona). Spain.

ABSTRACT

The results of the application of the geophysical electromagnetic prospection methods in the resolution of the problems of the spatial location of the travertine quaternary formations of the Banyoles depression are presented.

KEY WORDS: Banyoles, Geophysical electromagnetic prospection, Travertine.

## 1. INTRODUCTION

The travertine deposits of the Banyoles (Girona, Spain) depression constitute a deposit of complex geometry derived from the carbonic sedimentation processes associated with the resurgent zones of lowest altitude of the Lake System of Banyoles.

In this sector, the geometry of the travertine formations are characterized by having a flat, slightly inclined surface with rapid lateral variations (Brusi et al., 1997a). The impossibility of measuring with the desired precision, the volume of the deposits based on the surface data and the existing mechanical soundings, leads to the use of the geophysical prospection methods as a means of clarification. The geophysical electromagnetic prospection has been presented as a method of great usefulness and its results provide very valuable information that can be processed in the studies of regional geology, sedimentology and., especially, in the analysis of the proportions and characteristics of the aquiferous system that drains the subterranean lake zone of Banyoles.

## 2. GEOLOGICAL AND GEOMORPHOLOGICAL FRAMEWORK

The resurgent zone of the Banyoles Depression can be placed in a relatively simple geological context: quaternary materials related to the presence of the lake accumulated on eocene or neogene formations that act as a substrate.

This summarized description should not overshadow the absolute subordination of the resurgent activity of the peculiar dynamics of the aquiferous system that feeds it. The hydro-geological system of Banvoles-La Garrotxa (Sanz, 1985) shares, in its area of resurgence, the hydro-chemical characteristics and travertinizational systems of many other karstic systems. However, it is important to highlight that, from a geomorphological point of view and from a travertinization study perspective, the phenomenon of the sinking of the topographic surface caused by the dissolution of the eocenic chalk subjacent to the zone (Brusi et al., 1987) and the disposition of the paleo-relief that contains the deposits are enormously influential.

In this context, the travertine formations that we have attempted to study belong to the quaternary, and their origin must be set in a period between middle Pleistocene to the present time (Brusi et al., 1997b).

## 3. METHODOLOGY

Among the numerous methods of geophysical exploration available, the equipment of electromagnetic (EM) prospection of low induction has proven to be the most adequate for our purpose. Seismic prospection was ruled out as a result of the interference produced by the "'background noise" of the urban surroundings. The conventional electrical prospection of symmetrical Schlumberger devices was rejected, since it requires very extensive emission lines.

As it is known, and generally speaking, the electromagnetic methods of geophysical prospection are based on the generation of a primary magnetic field by an emitting antenna situated near the surface of the terrain. This primary magnetic field induces a secondary magnetic field situated underground. A reception antenna situated at a certain distance from the emitting one registers the measure of the relation between both, allowing for the evaluation of the electrical conductivity of the different geological masses of the subsoil (McNeil, 1980).

The equipment that was used for our study was the EM34-XL from Geonics. To operate this piece of equipment requires two operators with two antennas situated in different, preselected locations with alternating orientations (vertical and horizontal), allowing for information to be obtained of apparent conductivity of different depths of the subsoil.

## 4. RESULTS

The different campaigns of geophysical electromagnetic prospection carried out to date, have allowed for 265 soundings, structured in 27 profiles (Fig 1), in priorly selected zones.

From the analyzed data a set of conductivity values which characterize each of the geoelectrical units have been calculated:

1) Travertine materials: between 1 and 5 mmho/m
2) Eocene, loamy substrate: between 10 and 15 mmho/m
3) Eocene, sandy substrate: below 1 mmho/m
4) Pliocene, clay substrate: between 25 and 50 mmho/m
5) Edafic covering material: between 20 and 75 mmho/m

The important contrasts between the conductivity of the travertine materials of the area and the geological formations that constitute its substrate, have been determined by obtaining useful, interpretive results. It is also important to note that these values do not take into consideration the high conductivity which is characteristic of water with high levels of mineralization of subterranean aquifers. The geoelectrical levels of very high conductivity have been analyzed as aquifer groups.

With the information obtained from the analyzed soundings, 22 levels of geoelectrical correlation have been identified (Fig 1). It is commonly found that travertine formations derived from resurgent activity present a flood roof and a channelized base, with an average depth of nearly 20 m. In the zone near Lake Banyoles, the depth can, in some areas, reach more than 70 m, coinciding with the mud fillings of old basins.

The carbonic deposits, oriented in a southeasterly direction, originate in the resurgent zone in the basin of Lake Banyoles, and gradually disappear in the area of Cornellà del Terri because of the progressively dominant terrigenous materials.

The travertine zone rests, preferably, on a clay substrate, and in its basal sector, behaves as a free aquifer receiving contributions of lake water and that also receives water coming from streams that feed superficially into the lake.

## 5. ACKNOWLEDGMENTS

This research has been supported by a CICYT HID96-1321 research grant: The Application and optimization of the geophysical electromagnetic prospection in the characterization of the geometry and dynamics of the aquifer of aquiferous system 69.

## 6. REFERENCES

BRUSI, D.; PALLI, L. and SANZ, M. (1987) Characterization of the gravitational instability of the Banyoles area (Girona). Minutes of the III National Meeting of Environmental Geology and Territorial Organization, II, Valencia, pp. 1.021-1.034.

BRUSI, D; PALLI, L. ànd-TRILLA, J. (1997a) Depositional Model of the travertine formation of the Banyoles depression, Etudes of Geographie Physique, travaux 1997, supl. XXVI, pp 67-70.

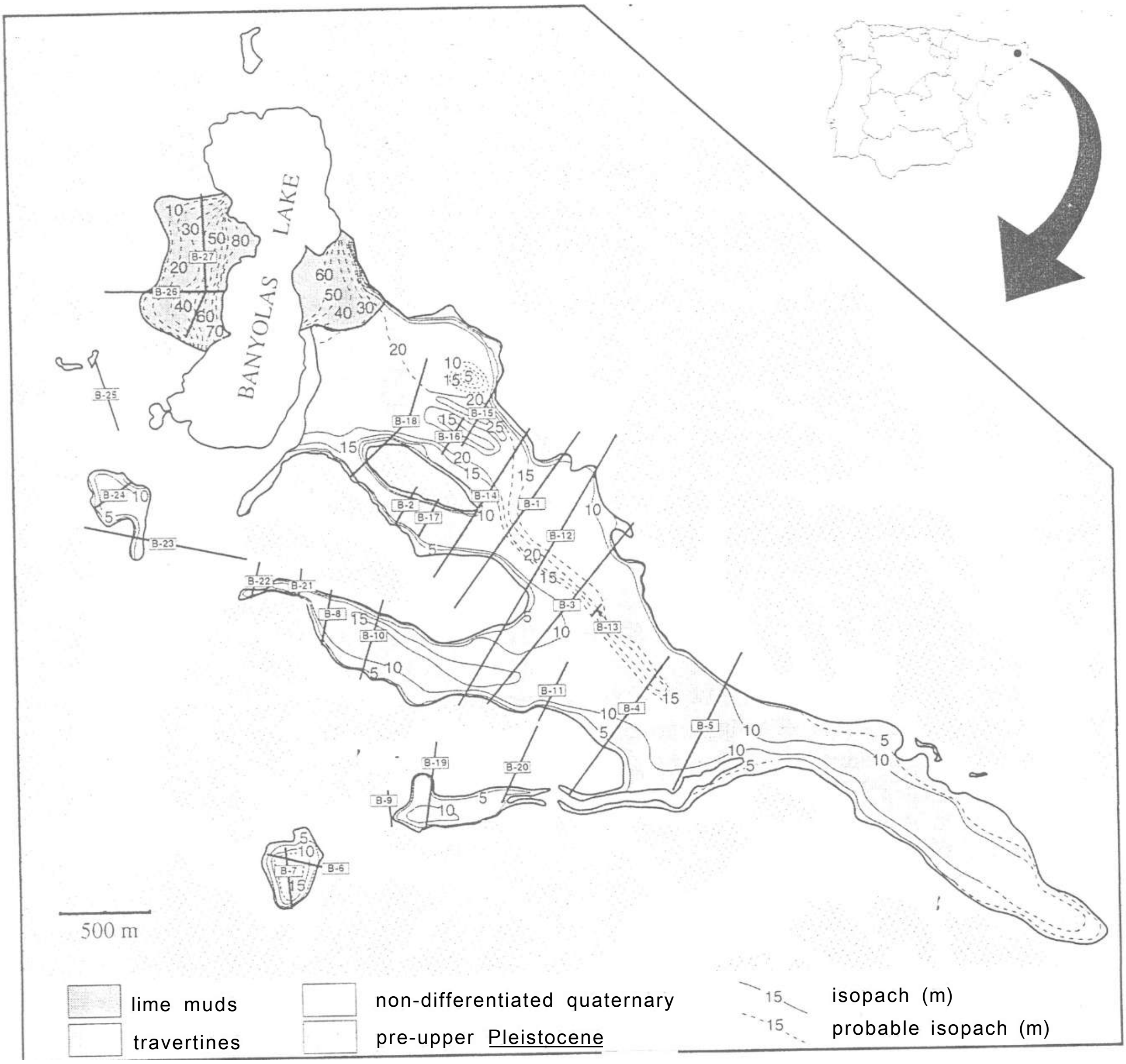
BRUSI, D.; PALLI, L. and ROQUE, C. (1997b) Application of the geophysical electromagnetic prospection in the delimitation of the travertine deposits of the Banyoles depression, Etudes of Geographie Physique, travaux 1997, supl. XXVI, pp 67-70.

SANZ-PARERA, M. (1985) Hydrological study of the Banyoles-La Garrotxa region, Quaderns del Centre d'Estudis Comarcals de Banyoles, 1980-1984, Banyoles, pp. 171-250.

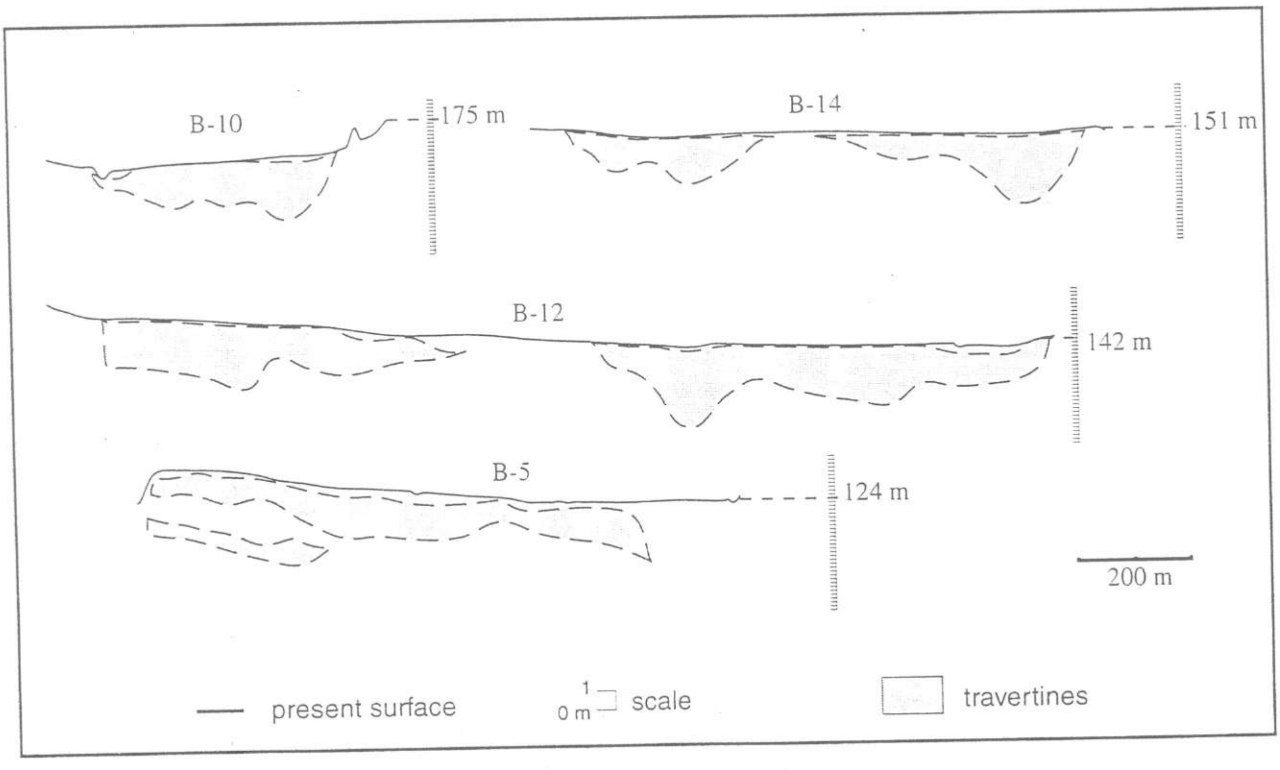
MCNEIL (1980) Electromagnetic terrain conductivity measurement at low induction numbers, Geonic Ltd., Canada, 15 pp.

FOOTNOTES

Figure 1. Situation of the studied zone with indications of the geophysical profiles and of the isopach lines of the deposits.



BANYOLAS LAKE
500 m
lime muds
travertines
non-differentiated quaternary
pre-upper Pleistocene
isopach (m)
probable isopach (m)

B-10
175 m
B-14
151 m
B-12
142 m
B-5
124 m
200 m
present surface
scale
travertines

# THE GEOPHYSICAL ELECTROMAGNETIC PROSPECTION IN THE SPATIAL LOCATION OF THE TRAVERTINE DEPOSITS OF THE BANYOLES DEPRESSION (GIRONA). GEOLOGICAL AND HYDROLOGICAL IMPLICATIONS

D. Brusi, L. Pallí, C. Roqué, I. Canellà, A. Pujadas, M. Vehí

Àrea de Geodinàmica. Departament de Ciències Ambientals. Universitat de Girona. Campus Montilivi. 17071 (Girona)
e-mail: cadbb@fc.udg.es

## NTRODUCTION

The travertine deposits of the Banyoles (Girona, Spain) depression onstitute a deposit of complex geometry lerived from the carbonic sedimentation rocesses associated with the resurgent ones of lowest altitude of the Lake ystem of Banyoles (Fig 1).

In this sector, the geometry of the ravertine formations are characterized y having a flat, slightly inclined surface vith rapid lateral variations (Brusi et al., 997a). The impossibility of measuring vith the desired precision, the volume f the deposits based on the surface data nd the existing mechanical soundings, eads to the use of the geophysical rospection methods as a means of larification. The geophysical lectromagnetic prospection has been resented as a method of great usefulness nd its results provide very valuable nformation that can be processed in the tudies of regional geology, edimentology and, especially, in the analysis of the proportions and characteristics of the aquiferous system that drains the subterranean lake zone of Banyoles.

**Fig. 1**:Setting of the studied area

## GEOLOGICAL AND GEOMORPHOLOGICAL FRAMEWORK

The resurgent zone of the Banyoles Depression can be placed in a relatively simple geological context: quaternary materials related to the presence of the lake accumulated on eocene or neogene formations that act as a substrate.

This summarized description should not overshadow the absolute subordination of the resurgent activity of the peculiar dynamics of the aquiferous system that feeds it. The hydro-geological system of Banyoles-La Garrotxa (Sanz, 1985) shares, in its area of resurgence, the hydro-chemical characteristics and travertinizational systems of many other karstic systems. However, it is important to highlight that, from a geomorphological point of view and from a travertinization study perspective, the phenomenon of the sinking of the topographic surface caused by the dissolution of the eocenic chalk subjacent to the zone (Brusi et al., 1987) and the disposition of the paleo-relief that contains the deposits are enormously influential.

In this context, the travertine formations that we have attempted to study belong to the quaternary, and their origin must be set in a period between middle Pleistocene to the present time (Brusi et al., 1997b).

## METHODOLOGY

Among the numerous methods of geophysical exploration available, the equipment of electromagnetic (EM) prospection of low induction has proven to be the most adequate for our purpose. Seismic prospection was ruled out as a result of the interference produced by the "background noise" of the urban surroundings. The conventional electrical prospection of symmetrical Schlumberger devices was rejected, since it requires very extensive emission lines.

As it is known, and generally speaking, the electromagnetic methods of geophysical prospection are based on the generation of a primary magnetic field by an emitting antenna situated near the surface of the terrain. This primary magnetic field induces a secondary magnetic field situated underground. A reception antenna situated at a certain distance from the emitting one registers the measure of the relation between both, allowing for the evaluation of the electrical conductivity of the different geological masses of the subsoil (McNeil, 1980).

The equipment that was used for our study was the EM34-XL from Geonics. To operate this piece of equipment requires two operators with two antennas situated in different, preselected locations with alternating orientations (vertical and horizontal), allowing for information to be obtained of apparent conductivity of different depths of the subsoil (Fig 2).

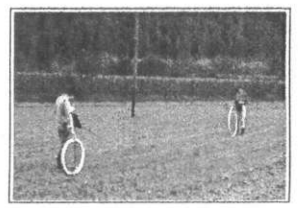
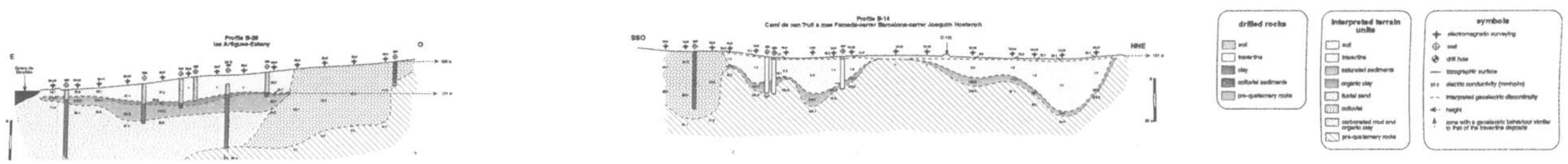


**Fig. 2**: Work field with the EM34-3XL equipment in horitzontal dipole mode.



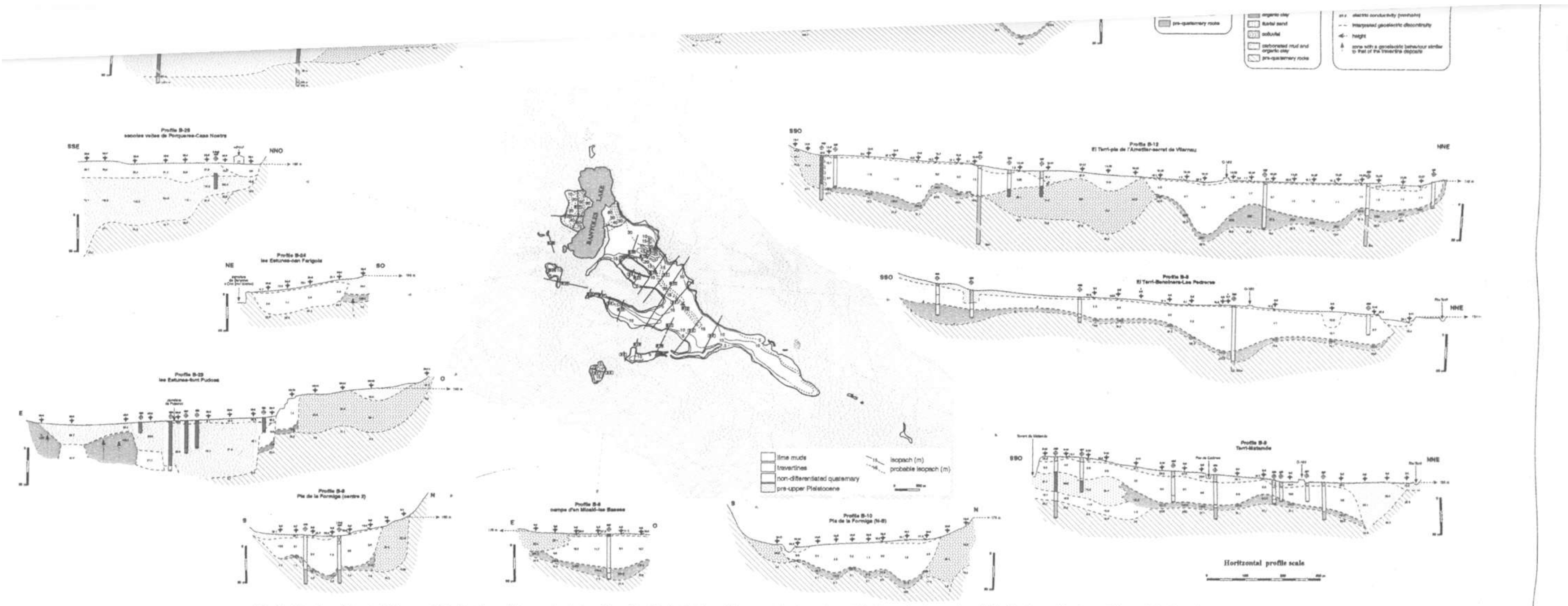



**Fig. 3**: Situation of the studied zone with indications of the geophysical profiles. Spatial distribution of the travertine formations of the Banyoles depression with indications of the isopach lines of the deposits.

## RESULTS

The different campaigns of geophysical electromagnetic prospection carried out to date, have allowed for 265 soundings, structured in 27 profiles (Fig 3), in priorly selected zones.

From the analyzed data a set of conductivity values which characterize each of the geoelectrical units have been calculated:

Travertine materials: between 1 and 5 mmho/m
Saturated materials: upper 100 mmho/m
Eocene, loamy substrate: between 10 and 15 mmho/m
Eocene, sandy substrate: below 1 mmho/m
Pliocene, clay substrate: between 25 and 50 mmho/m
Edafic covering material: between 20 and 75 mmho/m

The important contrasts between the conductivity of the travertine materials of the area and the geological formations that constitute its substrate, have been determined by obtaining useful, interpretive results. It is also important to note that these values do not take into consideration the high conductivity which is characteristic of water with high levels of mineralization of subterranean aquifers. The geoelectrical levels of very high conductivity have been analyzed as aquifer groups.

With the information obtained from the analyzed soundings, 22 profiles of geoelectrical correlation have been identified (Fig 3).

## REFERENCES

BRUSI, D. (1993) Les formacions travertíniques de la depressió de Banyoles, Ph.D. Thesis, Universitat Autònoma de Barcelona, pp. 477.

BRUSI, D.; PALLI, L. and SANZ, M. (1987) Characterization of the gravitational instability of the Banyoles area (Girona). Minutes of the III National Meeting of Environmental Geology and Territorial Organization, II, Valencia, pp. 1.021-1.034.

BRUSI, D; PALLI, L. and TRILLA, J. (1997a) Depositional Model of the travertine formation of the Banyoles depression, Etudes of Geographie Physique, travaux 1997, supl. XXVI, pp 67-70.

BRUSI, D.; PALLI, L. and ROQUE, C. (1997b) Application of the geophysical electromagnetic prospection in the delimitation of the travertine deposits of the Banyoles depression, Etudes of Geographie Physique, travaux 1997, supl. XXVI, pp 67-70.

SANZ-PARERA, M. (1985) Hydrological study of the Banyoles-La Garrotxa region, Quaderns del Centre d'Estudis Comarcals de Banyoles, 1980-1984, Banyoles, pp. 171-250.

MCNEIL (1980) Electromagnetic terrain conductivity measurement at low induction numbers, Geonic Ltd., Canada, 15 pp.

## ACKNOWLEDGMENTS

This research has been supported by a CICYT HID96-1321 research grant: The Application and optimization of the geophysical electromagnetic prospection in the characterization of the geometry and dynamics of the aquifer of aquiferous system 69.

## CONCLUSIONS

It is commonly found that travertine formations derived from resurgent activity present a flood roof and a channelized base, with an average depth of nearly 20 m. In the zone near Lake Banyoles, the depth can, in some areas, reach more than 70 m, coinciding with the mud fillings of old basins.

The carbonic deposits, oriented in a southeasterly direction, originate in the resurgent zone in the basin of Lake Banyoles, and gradually disappear in the area of Cornellà del Terri because of the progressively dominant terrigenous materials (Fig. 4).

The travertine deposits close to the Banyoles lake depression are involved in gravitational collapses related to karstic subsidence events. Such collapses, as described by Brusi et al. (1987), appear to be very evident around the Banyoles lake. The rigid deposits are involved in collapses (as seen in the profile 23) or show tiltings related to fractures which make easy the underground water flow (Fig 5).

To the east of the Banyoles lake travertine deposits constitute an unconfined aquifer which allows to flow water coming from the artesian springs and those related to losses of the due toartificial dranaige system of the Banyoles lake. Geophysical detection of such deposits is easy because of the high mineral content and the conductivity of the water in the artesian springs. The disposition of the aquifer adapts to those the travertine deposits whose lower limit lies on clayey sediments and show a channel geometry. The flow is along the paleovalleys in which there are the travertine overspills (Fig 6).

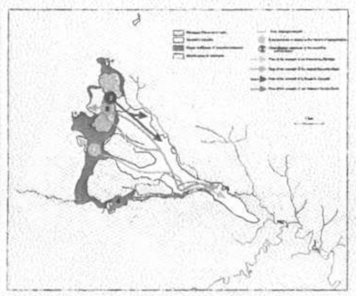


**Fig. 4**: Sequence of the main events of the travertine sedimentation in the Banyoles depression based on the geometry of the deposits and absolute dating of the carbonates (Brusi, 1993).

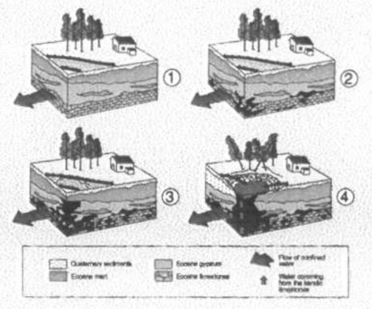


**Fig. 5**: Episodes in the development of a karstic lake (Brusi et al., 1987).

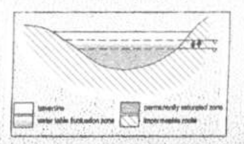



**Fig. 6**: Single cross-section of an unconfined aquifer in travertine rocks

The transmissivity of this carbonated deposits is very high the high porosity. The high velocity of the flow is in some occasions related to the karstification of the lower part of the carbonated deposits.