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A GEO-ELECTRIC AND GRAVIMETRIC SURVEY IN THE DELTA OF THE RIVERS FLUVIA AND MUGA (GERONA), SPAIN

BY

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ABSTRACT

In the delta of the rivers Fluvia and Muga, the Quaternary is hydrogeologically the most important deposit. It is underlain by Pliocene marls and clays. From geo-electrical soundings and bore-hole data a map with depth contours of the Quaternary-Pliocene boundary plane was constructed.

Near the coast the Quaternary consists of two aquifers. One of the restrictions of the resistivity method is that the second aquifer is too thin in respect to its depth. Therefore only the formation resistivities of the complete Quaternary were calculated. By comparing the map of formation resistivities with maps of the clay percentage and the water resistivities in the Quaternary, prospective areas for water-winning can be delineated.

To the north of the delta, Silurian granites and schists crop out. A gravimetric survey over the contact shows a gently sloping boundary of the granite and schist with the Eocene-Pliocene of ca. 15°. From geo-electrical data a comparable inclination of 10° was found.

The pre-Eocene topography here is thought to have been formed under tectonic control but the inclination of the Eocene-Pliocene to granite/schist would seem to be too shallow to correspond to a normal fault plane.

INTRODUCTION

In cooperation with the Department of Geology of the Spanish Ministry of Public Works (MOP), geophysical investigations were carried out during summer 1972 in the delta of the rivers Fluvia and Muga in the province of Gerona.

The following students of Leiden, Utrecht and Amsterdam (VU) universities participated in the field work: C. J. M. v. d. Boog, R. I. Conens, G. K. Brouwer, E. Sixma, A. Zuidema, T. L. Rosenkranz, D. J. Feenstra and the student assistant G. H. T. C. Hoogervorst.

The purpose of this study was to gather information about the hydrogeology of the Quaternary. The methods used were resistivity prospecting and gravimetric surveying, the latter mainly to locate the presumed fault, cutting off the granite and Silurian schists in the north of the delta. Bore-hole data and water resistivities were taken from the hydrogeological report of MOP (1971).

In 1971 a resistivity survey of 150 soundings with a maximum electrode spacing $L/2 = 150$ m was done by the MOP. To supplement these data a program of 35 soundings of the Schlumberger configuration with long electrode spacings (up to $L/2 = 1000$ m) was carried out by the Department of Geophysics and Hydrogeology of Leiden University. The equipment used consisted of a 3000 VA outfit and a 500 VA outfit, both built by the department.

GEOLOGY AND HYDROGEOLOGY

In the north the delta is bordered by the Massif of Rosas, a mountainous area consisting of Silurian schists and of granites. In the south, around La Escala Cretaceous limestone is found. West of these limestones, Eocene, Pliocene and Plio-Quaternary deposits crop out. The Eocene, as well as the Pliocene, consists of marls, conglomerates, clays and sands. The Pliocene outcrops form the western margin of the delta. The Plio-Quaternary, consisting mainly of conglomerates is only found on the southern side of the delta (see Fig. 1).

The Eocene was deposited in marginal basins along the axis of the Pyrenees. During the Oligocene folding phase the Cretaceous was partly overthrusted upon the Eocene. The Pliocene with a horizontal bedding lies uncomformably upon the Eocene. In borings west of the studied area thicknesses of the Pliocene of over 450 m were found.

On most geological maps the contact of the Pliocene and granite/schist is assumed to be a fault. Results from this survey, however, point to a gently sloping boundary plane.

The Quaternary is, for water-winning purposes, the most important deposit. In the central part of the delta it is underlain by the Pliocene and can reach a thickness of 50 m. Near the coast a sharp increase in thickness occurs. It is not known if the sharp drop in the top of the Pliocene sediments was caused by faulting in the Pliocene, or due to pre-Quaternary erosion.

The upper part of the Quaternary is formed by a clayey layer varying in thickness from 1 to 15 m.

In the west the Quaternary consists mainly of coarse sands. From a line roughly over La Escala-Armentera-Fortia a clay layer is found in the sands which increases in thickness in the direction of the coast. This clay layer which can reach a thickness of 20 m divides the Quaternary into two aquifers with thicknesses of 10 to 20 m

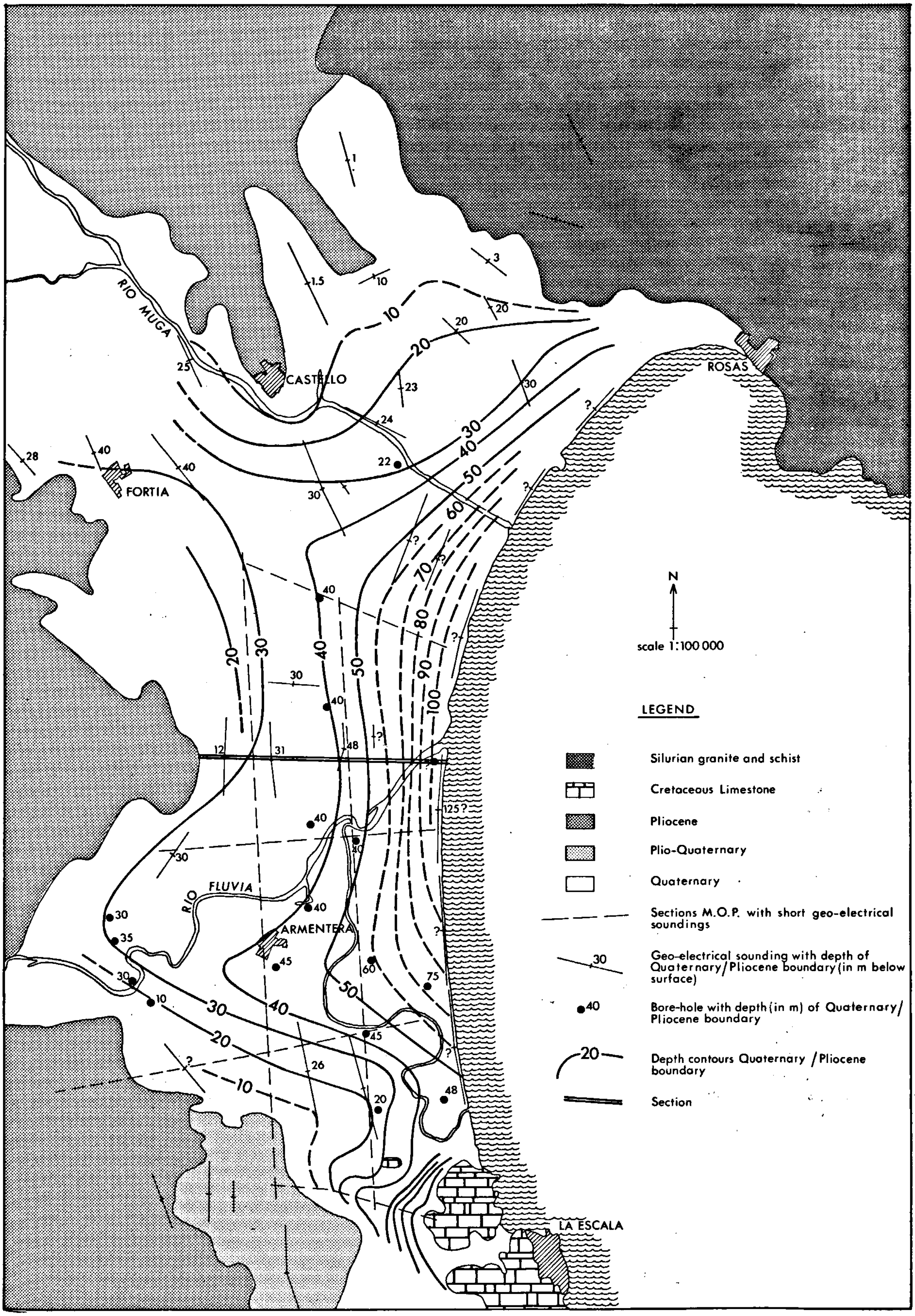

Fig. 1. Depth contours of the Quaternary/Pliocene boundary.

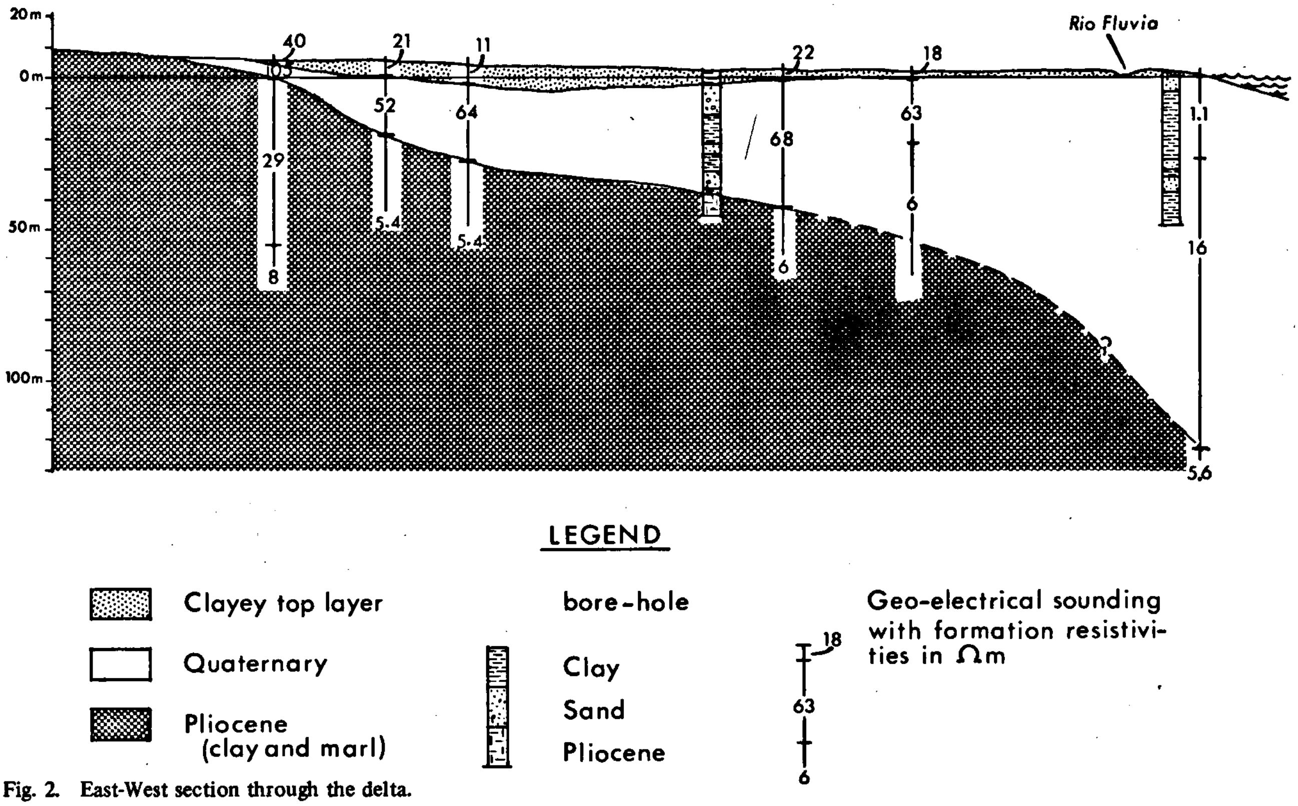

Fig. 2. East-West section through the delta.

for the upper aquifer and of ca. 10 m for the lower. Near the coast the lower aquifer bifurcates into two aquifers of ca. 10 m thickness. From a few borings it is known that along the coast at depths greater than 60 m the old Quaternary consists mainly of clay. In Fig. 2 a cross-section through the Quaternary is presented.

In the delta only few bore-holes and chemical analyses are available. Near the coast the upper aquifer with a phreatic water table contains salt water. As the lower aquifers have a high hydrostatic pressure no salt water intrusion takes place. Only one bore-hole along the coast near the mouth of the Fluvia contains salt water.

GEO-ELECTRICAL SURVEY

The geo-electrical soundings were interpreted with a set of three-layer standard graphs (Rijkswaterstaat, 1967). The resistivities found for the Pliocene vary from 30 Ωm in the west of the delta to ca. 6 Ωm near the coast. There is generally a good resistivity contrast with the Quaternary.

Resistivities of the fresh-water-containing Quaternary vary from 100 Ωm inland to ca. 30 Ωm near the coast. The thickness of the Quaternary can thus be found, the accuracy depending mainly on the difference of the resistivity values in horizontal and vertical directions (anisotropy). In only 4 places a bore-hole could be compared with a resistivity sounding. An anisotropy of 10 % was assumed for the southern part and of 20 % for the northern part of the delta where the resistivities are generally lower too. In the area where the intermediary clay layer occurs, the depths found for the Pliocene were accordingly corrected. In Fig. 1 depth contours of the Quaternary-Pliocene boundary are presented.

The geo-electrical soundings located near the granite and schist outcrops in the north, tend to rise for long electrode separations. This rise is due to the presence of granite and schist with a high resistivity, under the Pliocene. The depth contours of this boundary plane are indicated in Fig. 3.

One of the restrictions of the resistivity method in the coastal area is that the second aquifer is too thin in respect to its depth. Also where the first aquifer contains salt water the resistivity contrast with the underlying clayey layers is too small to allow a distinction to be made between them. Those restrictions are the more important because only few bore-holes and chemical groundwater analyses were available. Therefore only resistivities of the Quaternary excluding the top layer are presented (Fig. 4).

The soundings of the western part of the delta are of the three-layer type, the values of the second layer were plotted. In the coastal areas the soundings are more complicated and average transversal resistivities were calculated according to:

$$\rho t = \frac{\rho 1 d1 + \rho 2 d2}{d1 + d2}$$

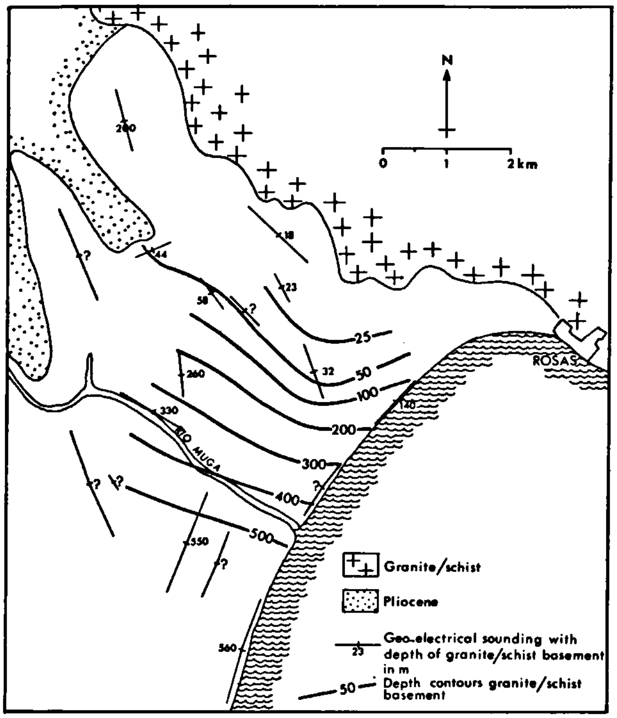

Fig. 3. Depth contours of the granite/schist basement.

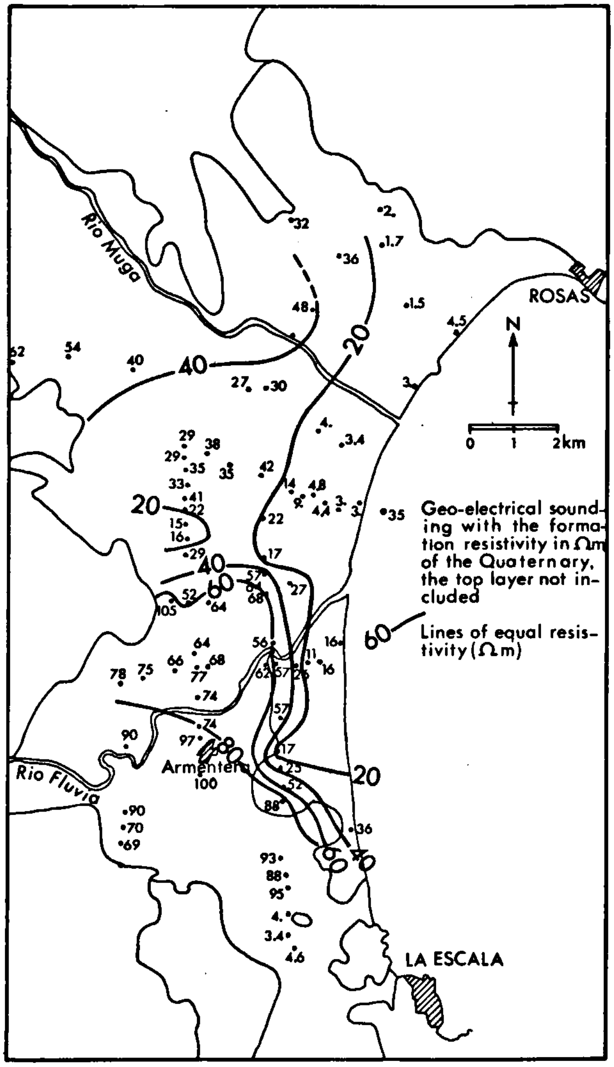

Fig. 4. Formation resistivities of the Quaternary, the top layer not included (see also Fig. 3).

Where the Quaternary-Pliocene boundary dips steeply, the total thickness of the Quaternary for calculation of the transversal resistivities was assumed to be 70 m.

For comparison with the resistivity data, the clay percentage of the Quaternary, excluding the top layer, calculated from the bore-holes is presented in Fig. 5. The water resistivities of the first aquifer are also given (Fig. 6).

Conclusion

The low formation resistivities in the north near the coast are due to low water resistivities and to a large clay percentage of the Quaternary. This area is not suited for groundwater withdrawal.

Near the limestone outcrops in the south low formation- and water-resistivities occur while the Quaternary consists mainly of sand. This area with low resistivities corresponds with the old course of the river Ter, which now debouches south of the limestone outcrops. It is interesting to note that salt water was intruded farthest inland just on the borders of the delta.

The area which offers the best possibilities of groundwater withdrawal is found around Armentera. Here the formation resistivities are greater than 60 Ωm, while the thickness of the Quaternary – the top layer not included – varies between 25 and 35 m.

GRAVIMETRIC SURVEY

A gravimetric pilot survey was carried out over the presumed fault, cutting off the granite and Silurian schists of the Rosas Massif. Three sections were measured (Fig. 7); section 2 was chosen along a stretch of the railroad and section 3 along the beach because of the ease of height determination. The elevations of section 1 were partly derived from detailed maps of irrigation projects, partly determined by the Ministry of Public Works. The accuracies of the topographic heights were within 0.01, 2 m and 0.50 m for the respective sections 1, 2 and 3 (see Figs. 8 and 9).

The gravimeter stations are 500 m apart on sections 1 and 3, and 200 m apart for section 2. A base station was chosen near Castello and station gravities calculated relative to this base.

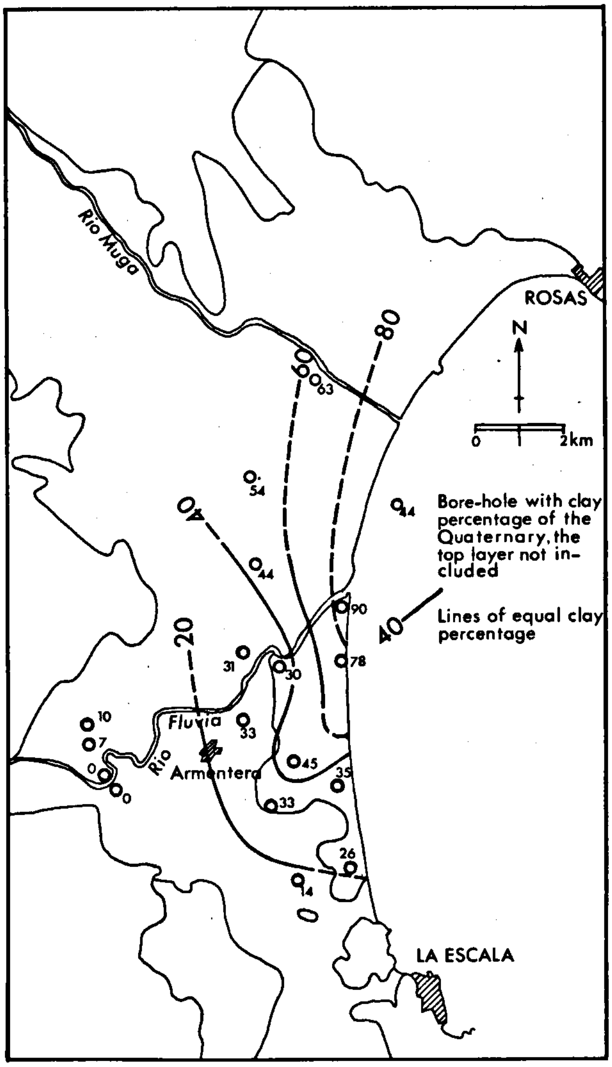

Fig. 5. Clay percentages of the Quaternary, the top layer not included.

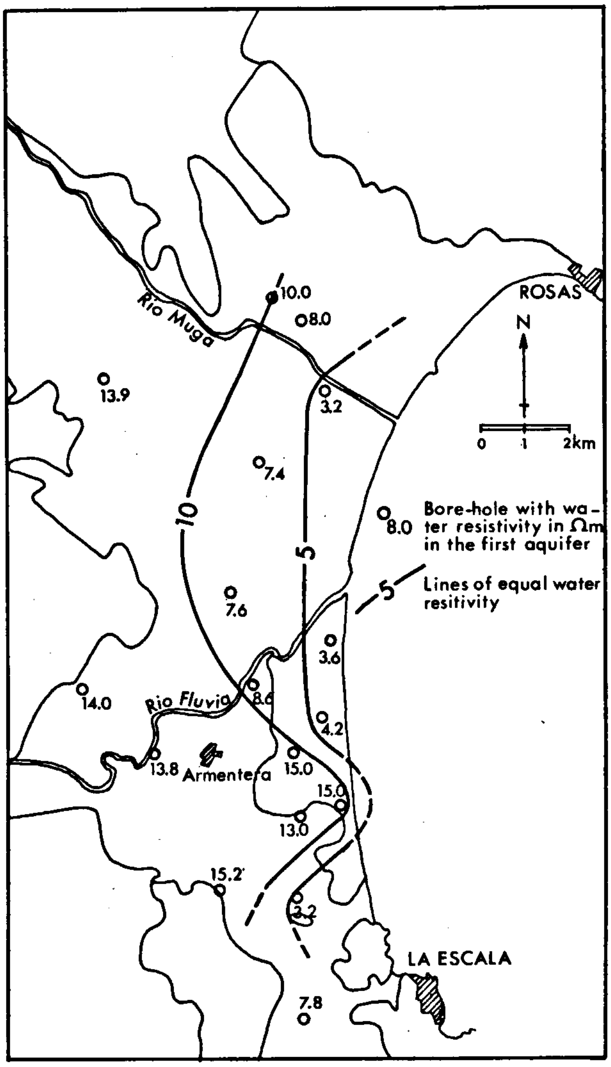

Fig. 6. Water resistivities in the first aquifer.

The accuracy of the station gravities depends mainly on the assumed surface density, on the elevation, on the topographic correction for the influence of the Massif of Rosas, and on the isostatic correction.

For section 1 the error will be within 0.15 mgal for a density taken between 1.8 and 2.5 g/cm³. In the north the error is about 0.5 mgal due to the topographic correction. For sections 2 and 3 the topographic correction was omitted, as these sections end further away from the mountains which are also lower. The error thus introduced is estimated to be smaller than 1.5 mgal. The height correction and the error in the density will introduce an error of ca. 0.15 mgal for section 3, and 1.5 mgal for section 2. This is also the absolute error in respect to section 1.

The isostatic correction was derived from a published map (Lit., 1964), scale 1 : 5,000,000. In a NW-SE direction the correction is 0.6 mgal/km. Due to the scale of the map this value is inaccurate and possible local influences of the Massif of Rosas cannot be seen. Apart from local influences a difference of 0.1 mgal/km in the correction factor will result in a difference of 1 mgal for the S part of section 1, and 0.5 mgal between sections 2 and 3 in respect to section 1. The three sections each show a gravity effect of more than 20 mgal. The error for most stations therefore is less than 5 % of this effect. Only in section 3 the error can amount to 7.5 % of the effect.

Interpretation of the gravity data

The corrected station gravity values (i.e. Bouguer anomalies) are plotted on the isogal map of Fig. 7 and on the sections 1 to 3. In order to arrive at a possible interpretation, the gravity effect of different types of geological models was calculated and compared with the gravity anomalies found on sections 1 and 3. Both sections are similar: composed of two S-formed parts which can each be assumed to represent the gravity

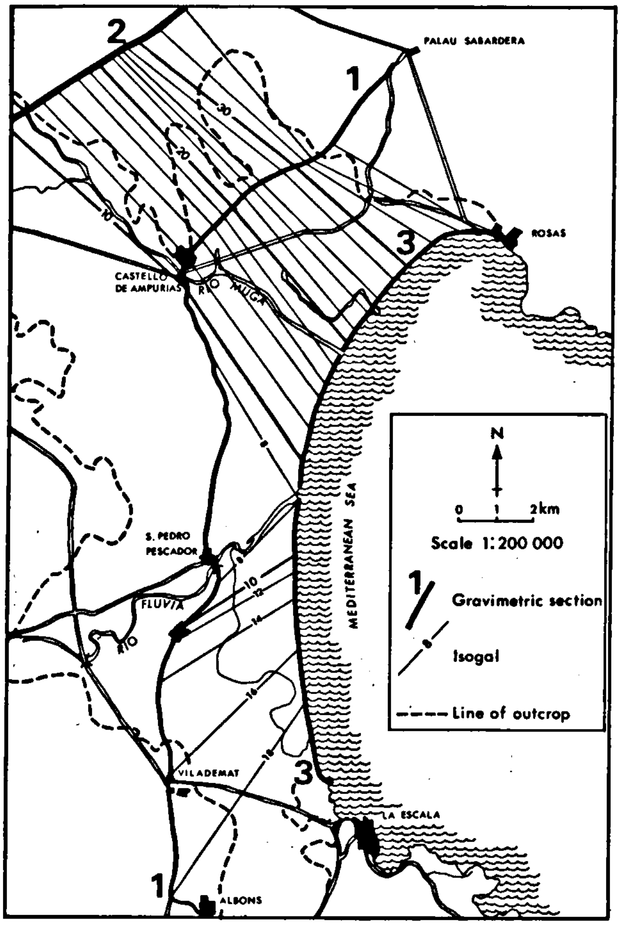

Fig. 7. Isogal map.

effect of a horizontal layer divided into two parts of different specific gravity by an inclined plane. From the difference in magnitude between the asymptotic values of an S-curve, the thickness-times-density contrast can be calculated. As the densities of the different rock types in the area are unknown, geological models with different thicknesses will fit the same curve. We have assumed a probably rather high density contrast between the granite comprising the Silurian schists and the Eocene, and also between the Limestone and Eocene: respectively 0.5 and 0.25 g/cm^3.

Section 1. – The geological model which fits section 1 (Fig. 8) reasonably well, has a gently sloping (15°) boundary between the granite and the Eocene, and a similar slope between the Eocene and a somewhat heavier substratum, probably the Cretaceous Limestones. For this model we find a minimum depth of the Eocene of 1500 m. Below this plane it was assumed that the Palaeozoic is present with no lateral density variations. It is obviously impossible to take into account any lateral density variation below the depth of this plane.

Section 2. – As the gravity anomaly of this section does not form an S-curve, a direct interpretation is not possible. However, its slope is comparable to the slope on section 1 so that a similar interpretation could apply.

Section 3. – For section 3 the same slopes of the boundaries between the granite and schist/Eocene, and the Eocene/Cretaceous and older were used (Fig. 9). A reasonably fitting model shows a depth of the Eocene of 2200 m, in the centre of the valley. For deeper strata the same assumptions as in section 1 were made. From both sections and also from the isogal map it appears that the pre-Eocene valley narrows in the direction of the sea. This is probably due to the tectonic origin of the pre-Eocene valley.

Conclusions

The main reasons for the large uncertainties when trying to interprete the gravity results are, as usual, the lack of geological information of the deeper strata and the lack of accurate density values. The interpretations presented can be considered as the simplest possible solutions with plane interfaces.

As the density contrasts chosen are probably rather high, the sections give a minimum thickness of the Eocene plus Pliocene.

The two main conclusions are that the inclined planes are probably not steep enough to be fault planes and that the Eocene basin is probably at least 1500 m deep.

The inclination of the granite/schist plane of 15° is comparable to the inclination of 10° determined from the geo-electrical soundings (Fig. 3).

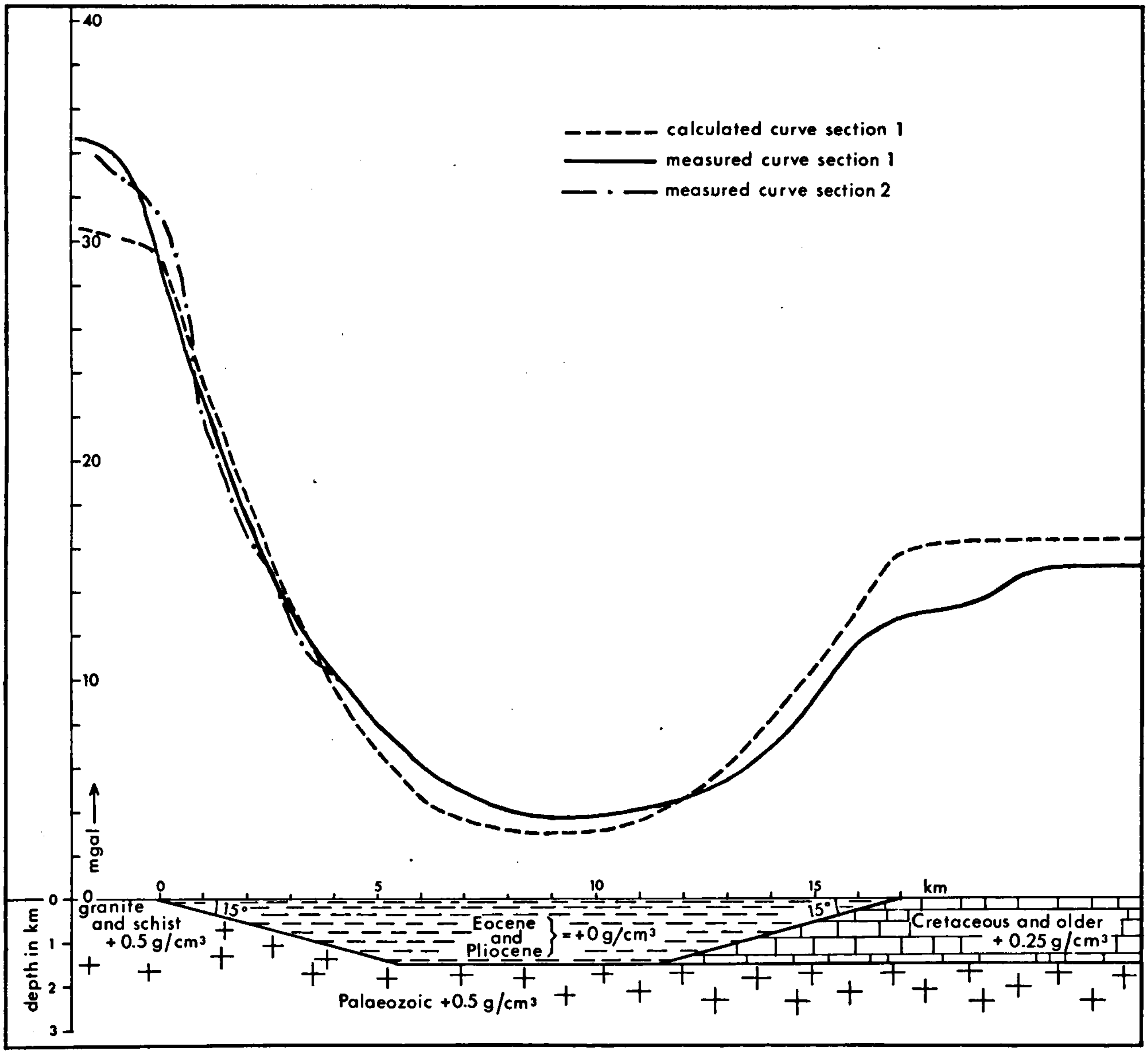

Fig. 8. Gravimetric sections 1 and 2.

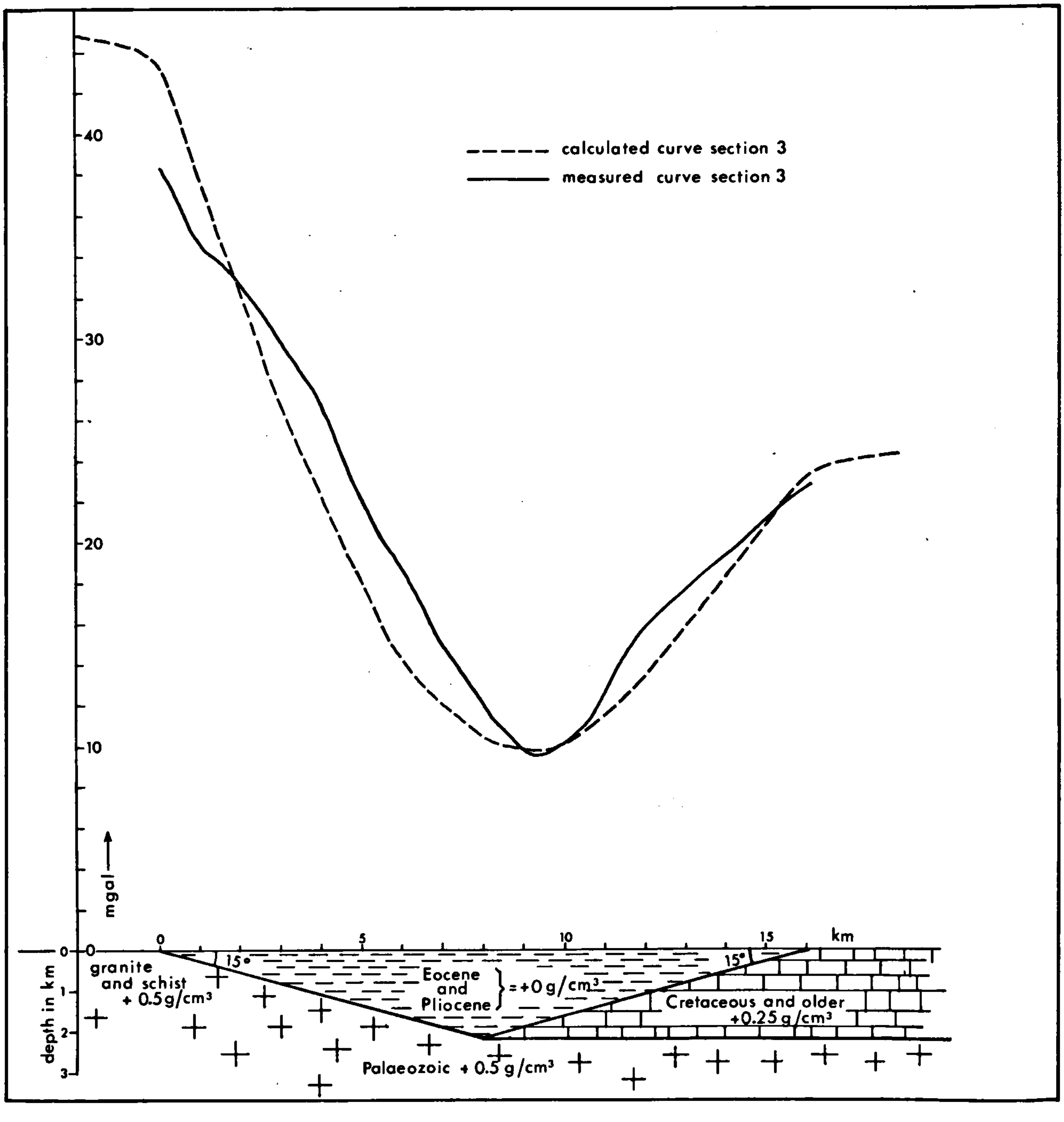

Fig. 9. Gravimetric section 3.

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