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KARSTIC AQUIFERS OCCURRENCE IN THE KYPARISSIA FIELD (MEGALOPOLIS BASIN, PELOPONNESE)

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ABSTRACT

The study of the karstic groundwater occurrence in the highly karstified limestone bedrock of the Kyparissia field is of fundemental importance for the possible exploitation of this field, due to the fact that the hydraulic head of the karstic aquifer is 60-70 m above the working floor of the future open lignite.

The distribution of fine individual karstic aquifers each with a different hydrogeological regime occurring in the limestone bedrock of the Kyparissia area was based on the study of the area's geology and hydrogeology (ie hydraulic head distribution and pattern of groundwater level fluctuations) and also on the results of the hydrochemical investigation.

ΣΥΝΟΨΗ

Η μελέτη της καρστικής υδροφορίας η οποία αναπτύσσεται στους έντονα καρστικοποιημένους ασβεστολίθους του υποβάθρου του λιγνιτικού πεδίου των Κυπαρισσίων είναι θεμελιώδους σημασίας για τη πιθανή εκμετάλλευση του πεδίου αυτού καθόσον, η πιεζομετρική επιφάνεια του καρστικού υδροφορέα ευρίσκεται 60-70μ. υψηλότερα από το επεχειρησιακό δάπεδο του μελλοντικού ανοιχτού ορυχείου λιγνίτη.

Ο διαχωρισμός πέντε ανεξάρτητων καρστικών υδροφόρων οριζόντων που ο καθένας έχει διαφορετικό υδρογεωλογικό καθεστώς και οι οποίοι αναπτύσσονται από ασβεστολιθικό υπόβαθρο της περιοχής Κυπαρισσίων βασίστηκε στην μελέτη της γεωλογίας και της υδρογεωλογίας της περιοχής (π.χ. της κατανομής στο χώρο της πιεζομετρικής στάθμης και του μοντέλου διακύμανσης της στάθμης του υπόγειου νερού και επίσης στα αποτελέσματα της υδροχημικής έρευνας.

1. ΕΙΣΑΓΩΓΗ-INTRODUCTION

From the early stages of the investigation it was realised that, in addition to the usual hydrogeological problems associated with mining from an open pit, major problems also arise from the presence of a karstic body developed in the

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Kyparissia field with a piezometric surface or a water table lying at an elevation of 330-340 m. Since, over most of the area, there is no dense horizon of impermeable strata between the limestone bedrock/aquifer and the lignite-the operational floor in a few places lies between 270 and 280 m above sea level-it was pointed out that, in order to guarantee safe mining in the district of the so - called Sikalia ridge and the area around it, it would be necessary to lower the karstic groundwater level by a total of 60-70 m below the present groundwater level.

The basin fill of the Kyparissia field consists mainly of sediments of the Apiditsa stage and the lignite-bearing Marathousa beds and partly of the Megalopolis beds. The lignite occurs here in the form of a thick horizon in which the interbedded clay, silt and marly layers are not of significant thickness. In places, it comes into contact with or lies directly on top of the limestones. A large part of the Kyparissia field is covered by the terrace gravel-bodies of the Alfios river.

The subsurface bedrock topography, as determined by the boreholes sunk in this area, is of relatively high relief. The Sikalia ridge, which forms part of a range of buried hills extending in a general SW-NE direction, together with the Lapatou and Lagada sub-basins, are the main topographical features of the bedrock of the Kyparissia field.

The nature and the structure of the bedrock of the Kyparissia field was interpreted partly from the reports of the boreholes extending down into the bed - rock and partly from the results of the geophysical investigation carried out in 1985. The bedrock is made up of formations of the Pindos zone, partly of first flysch and mostly of Upper Cretaceous limestones. The western and northern parts of the bedrock are built up from a series of elongated, irregularly repeated first flysch and Upper Cretaceous limestone bands, which are parts of the imbricate thrust-slice structure occurring here. The eastern and north-eastern parts of the bedrock, on the other hand, are built up of strongly folded Upper Cretaceous limestones extending over a long distance to the eastern side of the Kyparissia field as extensive outcrops, partially covered by the basin sediments.

Three types of aquifers are developed in the vinicity of the Kyparissia field, as follows :

1. The terrace gravel-bodies of the Alfios river are, generally, highly permeable, although a lower degree of permeability must be assigned to the Thoknia and especially the Potamia terraces, due to the higher proportion of clay in their composition. Based on their lithology, parts of higher permeability must be present within them in the form of channels or lenses.
   They form a single aquifer which is in close hydraulic relationship with the surface water system (eg Alfios river and minor tributaries) and also in places (eg around and to the north of the Kyparissia bridge over the Alfios river and at the Aghios Georgios gorge) with the kar - stic aquifers developed in the vicinity of the Kyparissia field.
2. A few aquifers of small extent and thickness are developed in the permeable parts of the unconsolidated basin sediments filling the Kyparissia field. These aquifers must occur as separate groundwater bodies, as different groundwater levels were recorded in a few of them. A few are, furthermore, under artesian (confined) conditions. The lignite beds are, in places (ie Sikalia ridge, Lapatou sub-basin), fragmentary (usually within their upper 20 metres) and relatively permeable. Finally, in the Sikalia ridge, where they lie directly on the limestone, the aquifer developed within them is in hydraulic continuity with the kar - stic aquifers.
3. Finally and most importantly, karstic aquifers are developed in the Upper Cretaceous limestones of the bedrock beneath the basin sediments. Their occurrence will be discussed, thoroughly, in the subsequent sections.

2. KARSTIC AQUIFERS

2.1. Introduction

2.1.1. Results of the previous investigations

A relatively thorough hydrogeological investigation was carried out by the firm of O.GOLD (1963), as part of the explorary work for the exploitation of the lignite. The results were reported in Volumes 8 and 9, hydrology and annexes respectively, and also in Volume 10 of the additional hydrological investigations.

From the evaluation of the data on the karstic springs in the area (situation, flow, water temperature and quality), from the records of the drilling operations and also from the results of the pumping tests obtained, it was concluded that the limestone is saturated with groundwater to the surface level of the basin of the Kyparissia field. The karstic water underneath the basin filling must be considered to be large and possibly far-reaching with relatively uniform pressure conditions prevailing.

It was concluded, based on the geological map (1:25,000) prepared by LÜTTIG and VINKEN in 1960 (included in the Gold Report, 1963), that the karstic body developed in the Kyparissia field was delimited as follows :

1. in the south, by a deeply eroded gully filled with basin sediments,
2. in the west, by an extended flysch zone-referred to as first flysch in the present study-stretching from SSW to NNE and outcropping on this side of the basin.
3. in the north, by the water divide bordering the Lousios river which limits the extent of the karstic water body.
4. in the east, the limit of the more or less uniform karstic aquifer was not clearly defined. Thus, an additional geological map (to a scale of 1 :25,000) was produced in spring 1963. Based on this, it was claimed that is delimited to the east, between the villages of Stemnitsa and Vangos.

Based on the geological mapping and the interpreted limits of the karstic body forming a hydrogeological unit, it was calculated that a limestone surface of an area of about 70 km² is exposed to infiltration following precipitation, estimated at 1000mm/year for this area. Based on a coefficient of effective infiltration of 50%, the quantity of water infiltrating was calculated to be in the region of 30 X 10^6 m³/year. After considering the method of dewatering (pumping, construction of a gallery) to be employed and making a few assumptions regarding the new shape that the karstic water table would adopt as a result of these new conditions, the quantity of permanent water which would have to be removed was estimated to be between 85 and 210 X 10^6m³.

LÜTTIG and THIELE (1968), in their report on potential sources of water supply to the power station (units I and II) and referring to the hydrological conditions of the karstic aquifer developed in the Kyparissia field, reported results the same as those contained in the GOLD Report (1963) in which the investigations (carried out during 1962 and 1963) at the karstic springs, in the boreholes and via pumping tests, showed that

1. the limestone contains groundwater up to the level of the top surface of the Kyparissia basin,
2. the karstic groundwater storage can be considered large and the karstic body of great extent with more or less uniform pressure conditions, and
3. the northern part of the basin represents the recharge area of the aquifer.

A detailed and comprehensive investigation of the groundwater surface water budget of the Megalopolis basin and the Alfios catchment in general was carried out by KARKULIAS (1975). His main conclusions are as follows :

Two types of aquifers are developed within the Megalopolis basin occurring in

a. the unconsolidated basin fill, and
b. the karstified limestone beneath and at the margins of the basin.

.GEORGEN (1978) also considered that the karstic body developed beneath the Kyparissia field had a catchment extending far beyond the field to the east and north.

Based on these assumptions and calculations, GEORGEN proposed a detailed time-schedule concerning the construction and start of operation of a step by step dewatering of the karstic body through the 25 years of the mining period. According to this, the lowering of the water table of 60 to 70 m could be achieved by a total of 22 wells arranged in 3 or 4 batteries.

2.1.2. Present interpretation

A completely different interpretation of the hydrological extent and occurrence of the karstic aquifers developed in the Kyparissia field is proposed in the present study.

The bedrock of the Kyparissia field consists of formations of the Pindos zone. The central and western parts of the bedrock of the Kyparissia field are built up of imbricate thrust-slices, this structure being present along the whole western side of the Megalopolis basin. The presence of this type of structure beneath parts of the Kyparissia field suggests the occurrence of a number of separate limestone subcrops in these parts and this, under certain conditions, would in turn lead to the formation of individual hydrogeologically isolated aquifers.

From a hydrogeological point of view, the problem arising here, therefore, is to establish to what extent the proposed structure and distribution of the first flysch-limestone subcrops, based on the geological mapping, correspond to the actual situation and, further, to what extent the separate limestone subcrops are in fact hydrogeologically isolated (ie form individual aquifers).

The solution to this major hydrogeological problem was found from the study of the form of the piezometric surface or, in places, of the water table of the karstic aquifers developed in the Kyparissia field and the pattern of the fluctuations of the groundwater levels in these aquifers which were recorded by means of a great number (62) of observation wells (piezometers) sunk for this purpose

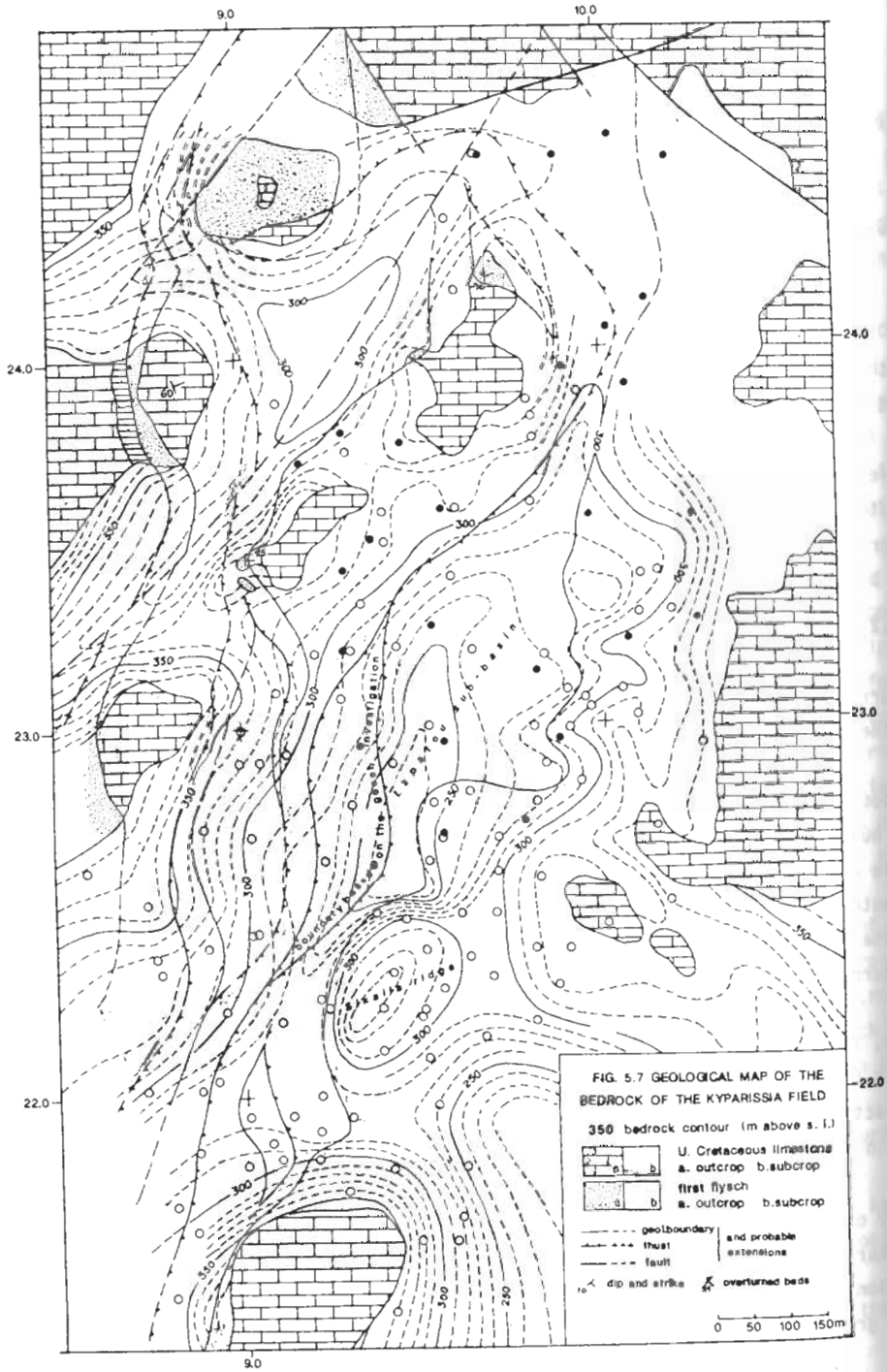


Fig. 1 Geological map of the bedrock of the Kyparissia field.

Σχ. 1 Γεωλογικός χάρτης του υποβάθρου του πεδίου των Κυπαρισσίων.

throughout the Kyparissia field and also by a detailed hydrochemical investigation.

2.2. Geological and geophysical determination of the extent of the karstic aquifers

It is pointed out that the type of structure shown by the Pindos zone within the study area is of fundamental importance for the determination of the hydrogeology of the various parts of the area, as it controls the movement of the groundwater within the Upper Cretaceous limestones.

The Pindos zone exhibits a different structure and development on opposite sides of the Megalopolis basin, resulting in different hydrogeological regimes. Thus, on the western side of the basin, the Pindos zone presents a structure of imbricate thrust-slices of first flysch and Upper Cretaceous limestones, irregular both in thickness and extent. The limestone outcrops mostly form individual aquifers with the groundwater moving roughly in a N-S direction and discharging through a great number of springs. On the eastern side of the basin, however, the Pindic nappe consists almost exclusively of strongly folded Upper Cretaceous limestones. Where the Upper Cretaceous limestones are overthrust onto the carbonate rocks of the Tripolis zone, the groundwater percolates downwards to a deeper aquifer system while , in places where these limestones are overthrust onto the flysch of the Tripolis zone, it discharges through contact springs.

The geological mapping of the narrow area around the Kyparissia field revealed that the type of structure and development of the Pindic nappe present over the whole western side of the Megalopolis basin also occurs on the western and northern sides of the Kyparissia field. The presence of thrust-slices in the north of the Kyparissia field, together with the fact that the thrust traces follow a roughly N-S direction, led to the conclusion that this type of structure must extend southwards, beneath the Kyparissia field. In the eastern and north-eastern parts of the Kyparissia field, on the other hand, the bedrock is made up exclusively of Upper Cretaceous limestones, as concluded from the type of structure the Pindic nappe presents on the eastern side of the Kyparissia field (ie the same as that occurring on the whole eastern side of the Megalopolis basin).

The presence of the first flysch bedrock beneath the Kyparissia field was detected by a few boreholes deep enough to reach the bedrock and sunk during the investigative stage (1960-1963) in the central-western part of the field. According to the type of structure deduced to be present in these parts of the bedrock, these points of the first flysch must represent parts of elongated subcrops, extending roughly in a N-S direction.

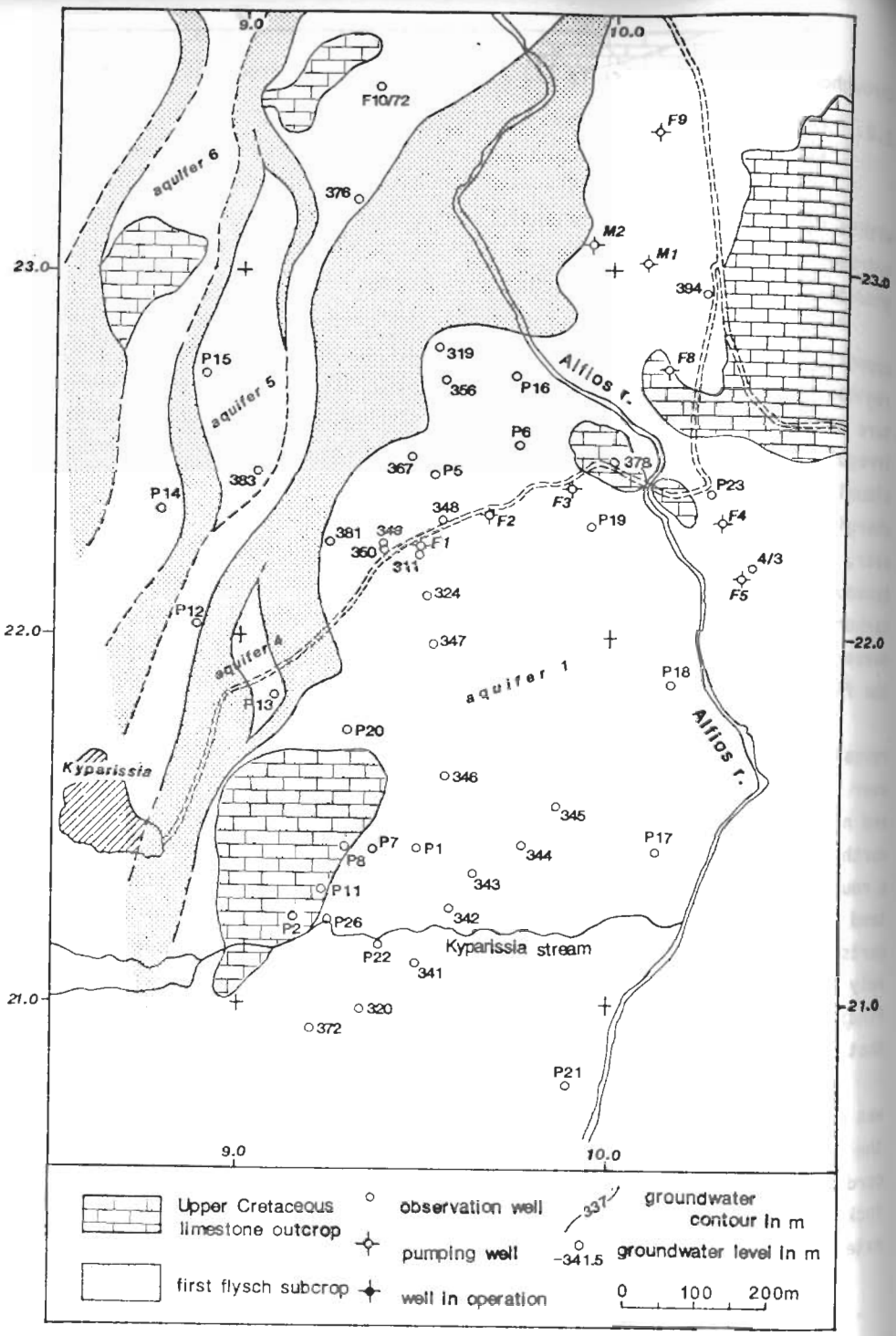


Fig. 2 Location of the observation and production wells sunk in the karstic aquifers developed in the Kyparissia area.

Σχήμα 2 Θέση των πιεζομέτρων και των παραγωγικών γεωτρήσεων που έχουν ανορυχθεί στους καρστικούς υδροφόρους ορίζοντες, οι οποίοι αναπτύσσονται στο πεδίο των Κυπαρισσίων.

A geophysical/geoelectrical investigation was proposed and was carried out for further investigation into the structure and the nature of the bedrock (ie distribution of the limestone and first flysch subcrops). The geophysical investigation confirmed the thrust-slice type of structure to be present in at least part of the bedrock of the Kyparissia field.

The most probable structure of the bedrock, together with the probable distribution of the first flysch and the limestone subcrops, is shown on the map in Figure 1.

2.3. Hydrogeological extent of the karstic aquifers

2.3.1. Introduction

The existence of a small number of karstic aquifers developed in the Kyparissia field was assumed as a basic premise in the first stages of the geological and geophysical investigations and was later confirmed.

The findings concerning the extent of these karstic aquifers were based on the study of the form of piezometric surface or, in places, of the water table within the Kyparissia field and also on the study of the type of fluctuations presented by the groundwater level in each of the observations wells.

More than sixty boreholes/observation wells (Fig. 2), spread across the future mine area of the Kyparissia field and also to the north and east, were used to obtain information about the groundwater levels. Observation wells were chosen from those boreholes which penetrated the unconsolidated basin sediments and intercepted the limestone bedrock. They were cased in such a way (bling pipe down to the limestone surface) that the measurements taken referred only to the groundwater levels of the karstic aquifers. The existing production wells sunk in the area (F1 to F9) and also the wells F8/72 and F10/72 were also used as observation wells.

A few other wells, sunk mainly in the south-eastern part of the field, were cased in such a way as to give information on the piezometric surface or the water table of the aquifers developed in the loose basin sediments, the Marathousa beds. Unfortunately, these data are unavailable.

In a few of the wells, the recording of the groundwater level was started more than 25 years ago (in 1960), but valid and continuous data are only available for the period 1975-1983. The measurements of the groundwater level, which were provided by the Electricity Board, were taken on a weekly basis (every Sunday morning) up to 1981 and every two weeks for the period 1981-1983. The depth of the groundwater level was measured using electric tape dippers.

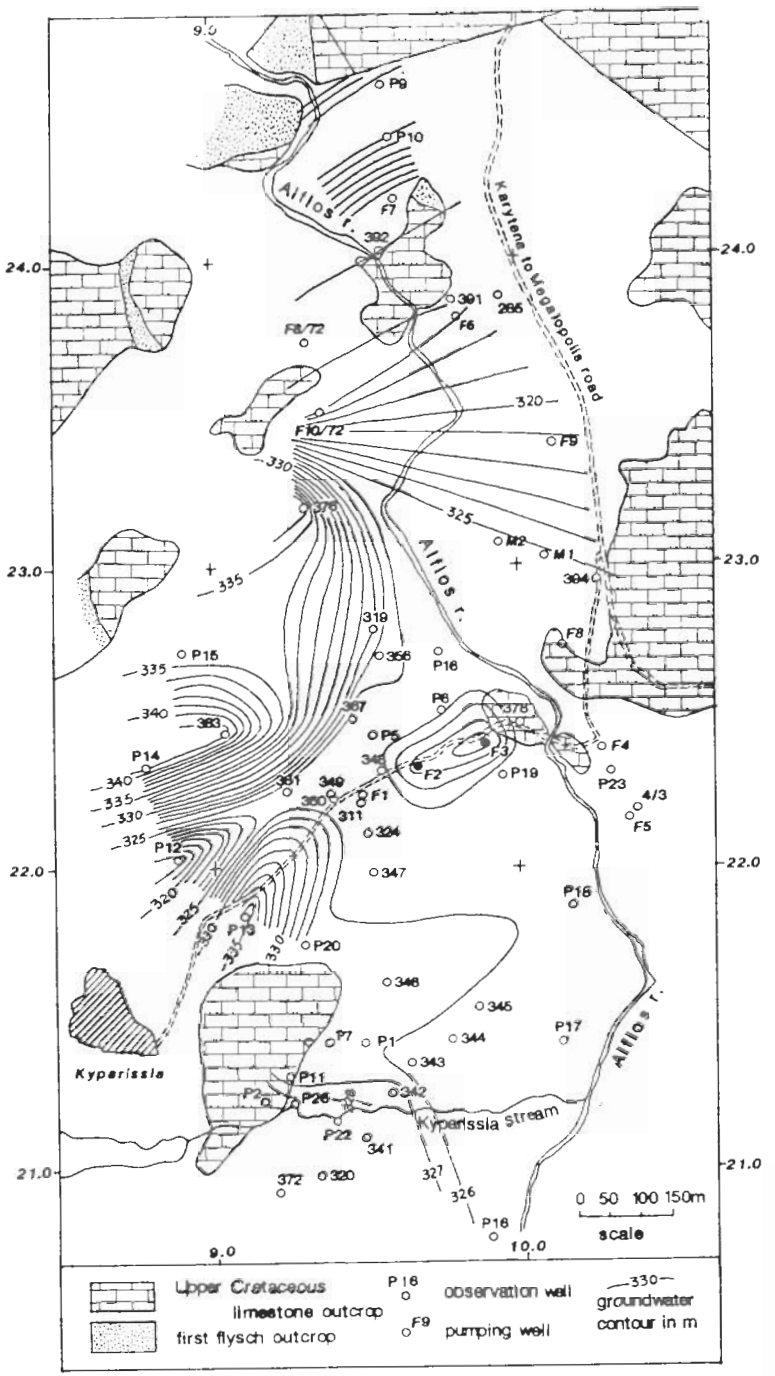


Fig. 3 Map of the hydraulic head distribution in the karstic aquifers developed in the Kyparissia area; Lower groundwater levels recorded on 13.11.77.

Σχ. 3 Χάρτης κατανομής της πιεζομετρίας στους καρστικούς υδροφόρους ορίζοντες, που αναπτύσσονται στο πεδίο των Κυπαρισσίων; Κατώτατη στάθμη που μετρήθηκε στις 13.11.77.

The data provided for the period 1975-1981 have been analysed and studied as part of the present investigation. The method of analysis used and the general conclusions drawn are presented in the subsequent Sections 2.3.2 and 2.3.3.

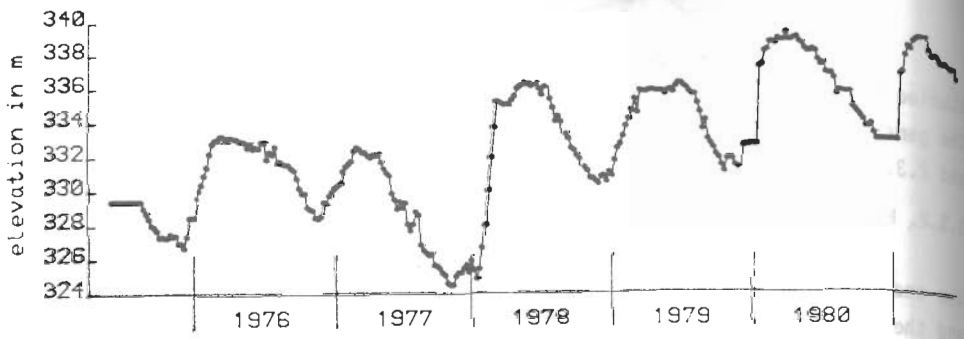
2.3.2. Form of the piezometric surface/water table

Contour - maps of the higher and the lower groundwater levels (ie at the end of the wet and the dry seasons, respectively) of the Kyparissia field and the area surrounding it were drawn for the period 1977-81 (an example of the maps drawn in given in Figure 3). The well hydrographs (see next Section) were used to obtain the dates when the piezometric surface/water table reached its highest or lowest levels. For the construction of these maps, the groundwater levels recorded at each well on those certain dates, as determined from the well hydrographs, were noted next to the wells shown on the map. Contour lines were then drawn by connecting the points of equal groundwater level. The drawdown caused by the production wells F1 to F9 when they were in operation (indicated by a black spot on the map) was not taken into account, for the drawdown caused by pumping is only of local extent and does not affect the groundwater level in the observation wells situated a few metres away from the production well (eq pumping well F1 and observation well 311).

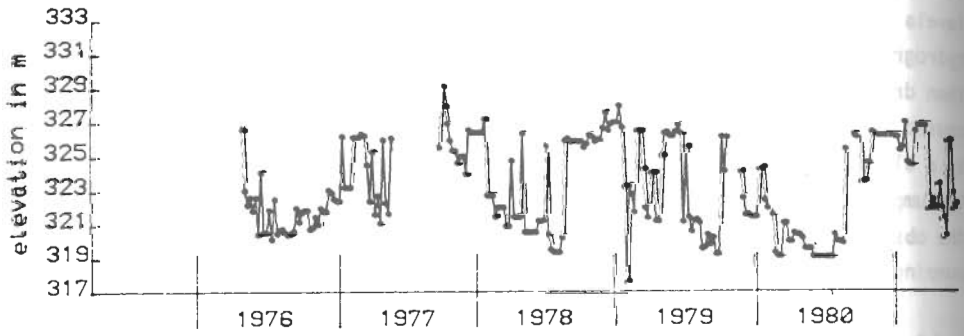
The shapes of the piezometric surface/water tables for the higher and lower groundwater levels revealed by the groundwater contour-maps for the period 1977-81 are characteristic of the hydrogeological regime of the area. They show alternating areas with planar and very steep groundwater levels. In places (ie 11 May 1980) a great difference of up to 32.7 m in the groundwater level existed between the adjacent wells P12 and P14, situated less than 300m away from each other.

According to Darcy's law, Q=Aik, where Q equals the quantity of water flowing between two points, i equals the hydraulic gradient existing between them and k represents the permeability coefficient of the porous medium. As only minimal groundwater movement takes place within the basin, those zones along which a steep slope of the groundwater levels occurs (ie along which a high hydraulic gradient (i-value) exists) must have a low k-value which shows the presence of low permeability/aquiclude rocks along these zones.

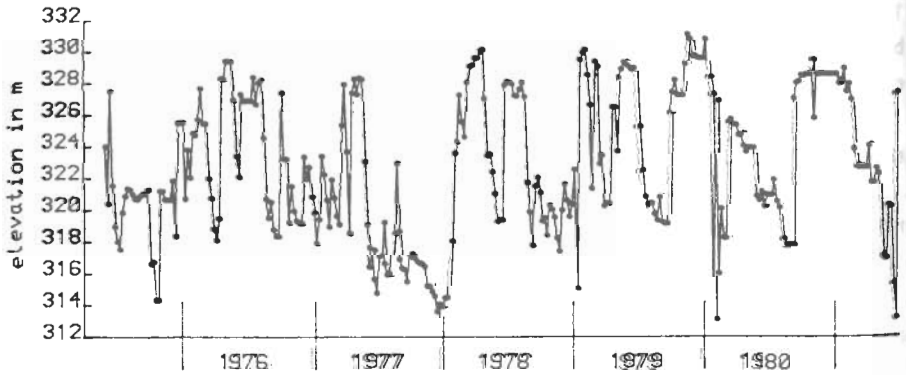
These hydrogeologically determined zones of impermeable rocks, which act as barriers to the groundwater movement, coincide with those zones of first flysch whose presence has been inferred both geologically and geophysically. In



a) Groundwater hydrograph of well 347, sunk in aquifer 1.



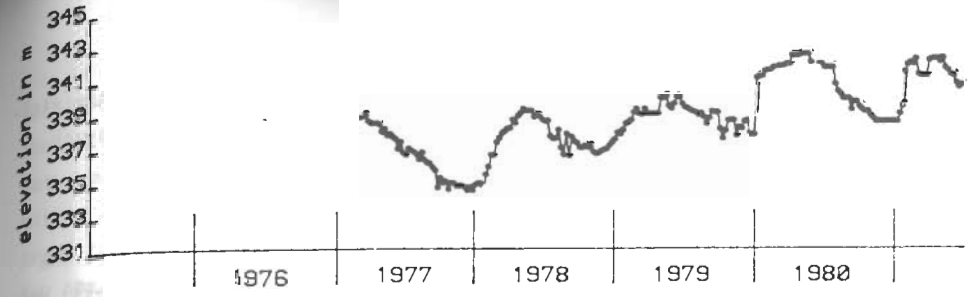
b) Groundwater hydrograph of well P10, sunk in aquifer 2/3.



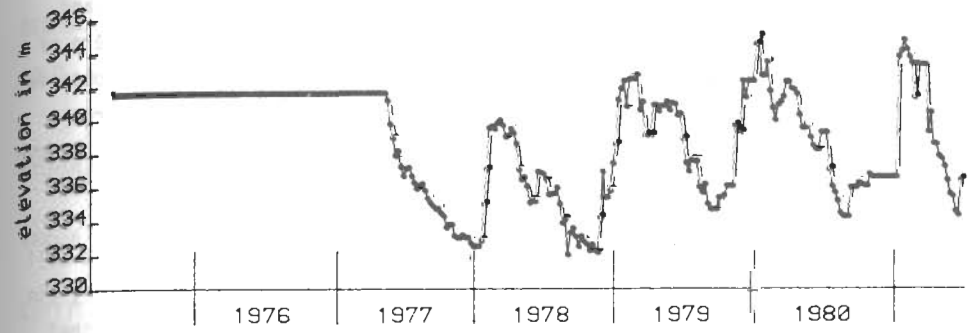
c) Groundwater hydrograph of well P10/72, sunk in aquifer 2/3.

Fig. 4 Representative groundwater hydrographs of the karstic aquifers 1 to 3 developed in the vicinity of the Kyparissia field.

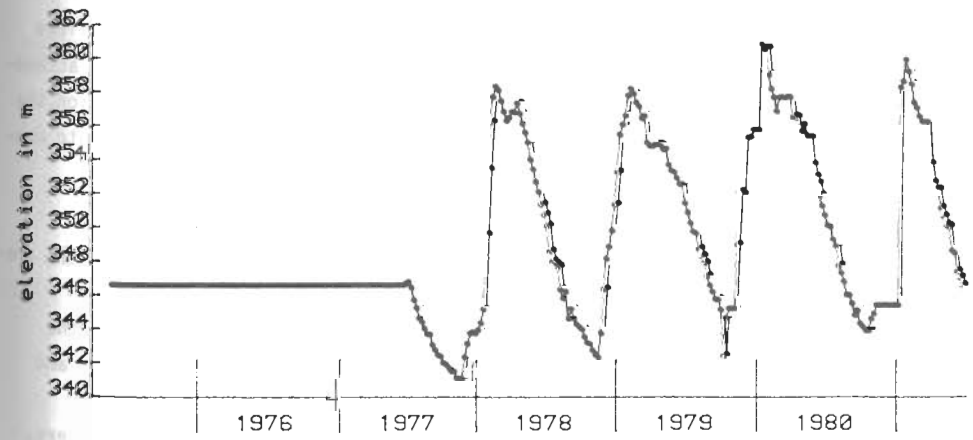
Σχήμα 4 Αντιπροσωπευτικά υδρογραφήματα των Καρστικών υδροφορέων 1 έως 3 οι οποίοι αναπτύσσονται στην περιοχή του πεδίου της Κυπαρισσίας.



a) Groundwater hydrograph of well P13, sunk in aquifer 4.



b) Groundwater hydrograph of well P15, sunk in aquifer 5.



c) Groundwater hydrograph of well P14, sunk in aquifer 6.

Fig 5 Representative groundwater hydrographs of the karstic aquifers 4 to 6 developed in the vicinity of the Kyparissia field.

Σχήμα 5 Αντιπροσωπευτικά υδρογραφήματα από τους καρστικούς υδροφόρους ορίζοντες 4 έως 6, οι οποίοι αναπτύσσονται στην περιοχή του πεδίου Κυπαρισσίων.

Figure 6, which shows the position of the karstic aquifers developed in the vicinity of the Kyparissia field, these zones are represented by the first flysch bands defining the extent of the individual karstic aquifers.

2.3.3. Fluctuations of the groundwater level with time

Well hydrographs were drawn for each of the observation wells. The groundwater level (in m above sea-level) was plotted against time (in weeks) using a computer.

The study of the well hydrographs led to their division into five groups, based on the type of fluctuations shown by the groundwater level and also on the mean value of the hydraulic head recorded. An identical pattern of fluctuation in the groundwater levels was seen throughout the period of observation in each of the observation wells within any one group. These five groups of wells must, therefore, represent a corresponding number of individual, hydrogeologically isolated karstic aquifers. A representative well hydrograph for each of the five aquifers/groups of wells is given in Figure 4 and 5.

It should be noted here that when the recorded values for each well were plotted, in several cases one or more adjacent values departed greatly (in the range of a few metres) from the next or previous values recorded for that well. In general, corresponding discrepancies were not reflected in the values recorded in the other wells of the group at the same time. These values were, therefore, considered to be erroneous and were, in a few cases, discarded.

The Kyparissia field and the area surrounding it were also divided into corresponding separate aquifers, their extent having been determined according to the distribution of each group of wells (Fig. 6). For this separation, the extent of the limestone subcrops in the Kyparissia field was also taken into consideration.

2.4. Hydrochemical extent of the karstic aquifers

A detailed hydrochemical investigation was carried out during the present study.

The chemical composition of the surface water (Alfios river), the water of the karstic springs emerging to the north of the Kyparissia field and the groundwater of aquifers 1 and 2 was studied.

The hydrochemical investigation established that these two aquifers, the main ones developed beneath the Kyparissia field, contain water of different chemical composition. Aquifer 1 contains water of Ca/Mg:HCO_3 type, while aquifer 2 contains water of Ca/Mg:HCO_3/SO_4 type. According to the existing hydraulic gradient between aquifers 1 and 2, water should move from the former to the latter. The difference in chemical composition of the water in these two aquifers could not, however, be explained as a natural process of evolution of the water chemistry and so the presence of these chemically different water types acts as proof that the two aquifers are not in hydraulic continuity but, rather, make up two separate hydrogeological units with different hydrogeological and hydrochemical regimes.

3. ΒΙΒΛΙΟΓΡΑΦΙΑ-REFERENCES

GEORGEN, H. (1978). Study for the extension of the Megalopolis lignite mine.(Vol. 3 Hydrogeology). *Internal Report, Electricity Board (DEH)*, Athens.

GOLD, O. (1963). Geological and hydrogeological investigations of the Megalopolis lignite mine (Vol.8 & 9:Hydrogeological investigations-vol.10:Additional hydrogeological investigations). *Internal Report, Electricity Board (DEH)*, Athens.

HYDROEREVNA LTD. (1975). Pumping tests of the wells for the Electricity Power-station (Unit III)-Megalopolis; Chemical analyses of samples obtained (in Greek). *Internal Report, Electricity Board (DEH)*, Athens.

KARKULIAS, V. (1975). Der Wasserhauschalt in Bereich des Beckens von Megalopolis. Grundwasser-Oberflachenwasser Dargebot-Nutzung-Bedarf-Bilanz. *Geol.Jb.*, C10, 1-116.

LÜTTIG, G. & THIELE, J. (1968). Expert opinion on the potentialities of water supply to the Megalopolis S.E.S. (Peloponnese). *Internal Report, Electricity Board (DEH)*, 1-21, Athens.

LÜTTIG, G. & WAGER, R. (1977). Final report on the pumping tests in the Megalopolis basin (in Greek). *Internal Report, Electricity Board (DEH)*, 1-22, Athens.

SPILIOTIS, G. (1978). Groundwater control in opencast mining of a lignite deposit in Southern Greece. *Internal Report, Electricity Board (DEH)*, 1-14, Athens.

TSIFTSIS, I. (1988). The geology of the Megalopolis basin Peloponnese 4th congress geol. Soc. Greece Athens.