The contribution of the Passega method and the use of the sedimentological indicators (Folk and Ward), as an evaluation tool of the Holocene depositional environment of Kifissos river, Athens, Greece.

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Abstract

This research concerns the evaluation of the depositional environment in Kifissos river, in N. faliro area (Greece). In order to retrieve the depositional history ten sampling boreholes (P1-P10) are made in the area of Piraeus-N. Faliro in 2005 from the coordination of EFA (École Française d' Athènes), CNRS (Centre National de Recherche Scientifique), SHS (Institut de Sciences Humaines et Sociales) and the director of the ARTEMIS-SHS. Only two boreholes (P2-P4) were selected for further sedimentological analysis as the most representative. After the description of its stratigraphic units, sampling had been followed. Forty samples were collected and they were sedimentologically and granulometrically studied through the laser granulometer Mastersizser 2000 of the Malvern Company. The available obtained data were statistically analysed through the program "Gradistat" to collect the appropriate results for the Passega method and the sedimentological indicators method (Folk and Ward).

The results of these sedimentological methods showed that the depositional environment was a combination of a low energy fluvial environment with the contribution of a coastal-lagoonal environment.

Keywords: *Sampling boreholes, Granulometric analysis, Statistic analysis, Passega method, Sedimentological indicators method*

Introduction

In order to determine the depositional environment of the study area, ten sampling boreholes (P1-P10) were made around the peninsula of Piraeus in 2005 by the coordination of EFA (École Française d' Athènes), CNRS (Centre National de Recherche Scientifique), SHS (Institut de Sciences Humaines et Sociales) and the director of the ARTEMIS-SHS. This area is very interesting from archaeological point of view as it was the main harbors of the Athenian city-state during the classical period.

These boreholes were described, sampled and analyzed extensively in order to collect and select the most representatives boreholes-samples for the granulometric analysis and radiocarbon dating. In this research two statistic methods were used to help identify the depositional environment and therefore the processes that dominated the area in this period, the Passega Method and the Sedimentological indicators Method (Folk and Ward). The reason of use of these two different methods is to combine and correlate the results in order to have the most accurate results.

From the combination and the correlation of the results of these two methods, the palaeogeography of the study area can be concluded. These methods show the dynamic of the deposition in this specific part where the borehole was made and they can give information about the palaeolandscape of the study area.

Methodology

For this study a series of sampling boreholes were used from the area of Piraeus (Figure 1), which were described, analyzed and sampled for dating. Also twenty samples were taken from boreholes P2 and P4 for granulometry analysis to obtain the data needed for grain analysis method "Passega" and the Sedimentological indicators (Folk and Ward) method, as the most representatives cause they are situated at the probable channels of Kifissos river and the interaction of the Holocene transgression.

The granulometry analysis (Laser) is made in the laboratory L.R.G.E. of the university Lyon 2. The Mastersizer 2000, laser granulometer, is used in order to make the granulometrical analysis and obtain the required results.

The results from Mastersizer 2000 were further analyzed with the use of "Gradistat". These results and the C_{14} datings, from the organic material that we collected from the

boreholes P_2,P_4 (Goiran et al 2011), are necessary for the Passega method in order to determine the environment of the deposition.

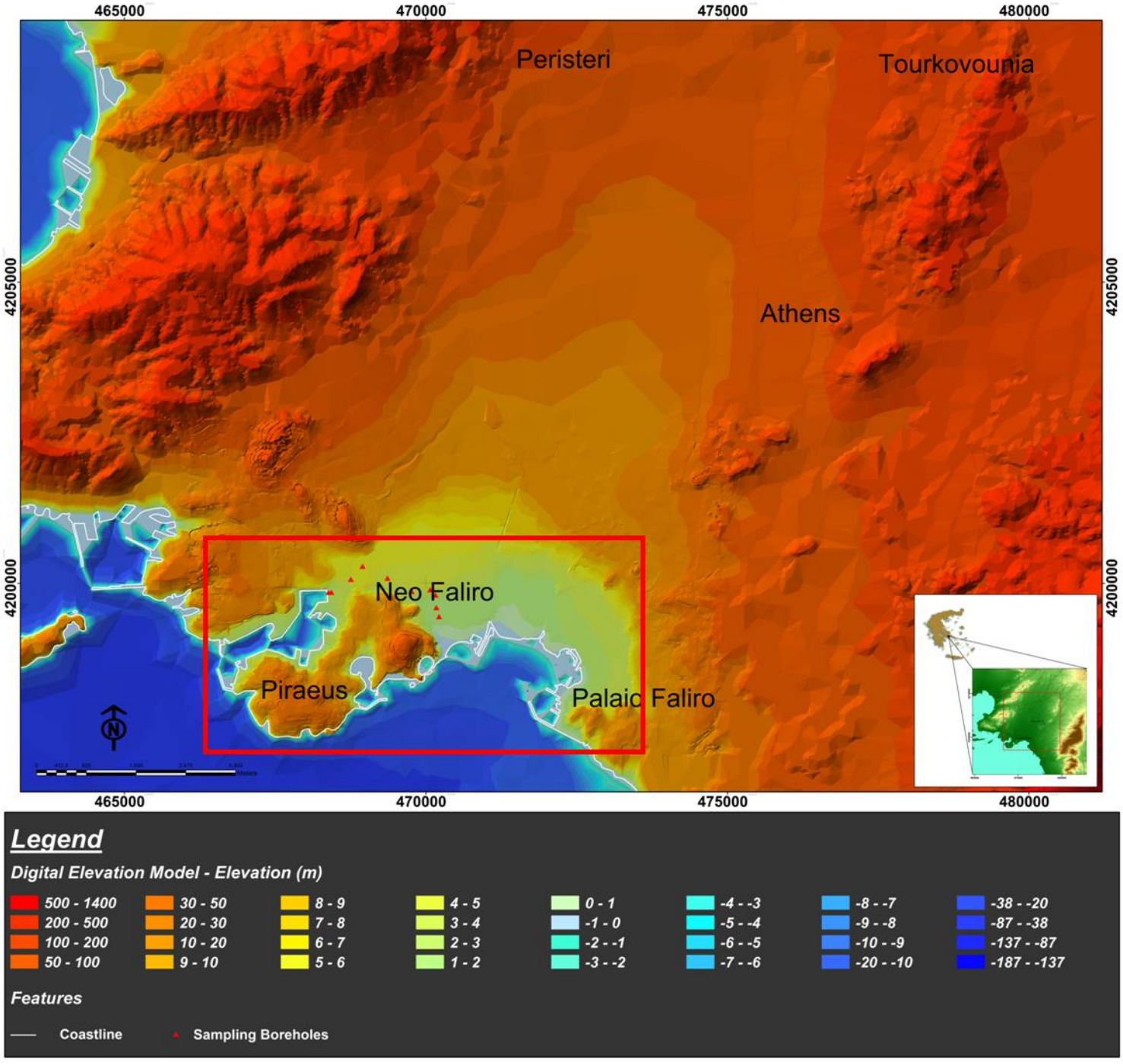


Figure 1: Area and position of the boreholes.

Passega method

This method is used to provide the most accurate information for the environment of transportation and deposition of the fluvial sediments. For this reason in this method logarithmical diagrams were constructed where the samples taken form as a “cloud”. These diagrams are called “CM diagrams”.

The C is the percentile, which represents the most coarse sediment and measuring the ability of the current. The M represents the median or average size of grains of the sample and deposition.

The M refers to the abscissa and C at the ordinate in a logarithmic diagram, where a sample is represented by a point. The 20 and 30 points representing the range of sediments placed in position by a means of transportation, creating a cloud or a standard CM repository. These points are sufficient to describe “the granulation image”.

Sedimentological indicators Method (Folk and Ward)

The Sedimentological Indicators Method (Folk and Ward) is based mainly in four characteristics, Mean, Skewness, Sorting and Kurtosis.

The "Mean" shows the average value of the sample (Folk et al., 1957, Briggs, 1977). The "Skewness" shows the non-normal distribution of the sample (Folk et al., 1957). Generally the positive value of Skewness shows that the sample is consisted of fine sediments. The negative skewness shows that the sample is consisted of coarse sediments

The "Sorting" is the value, which demonstrate the distribution of the grains in the sample. Too fine or too coarse sediments are "poorly sorted", sediments like sand are characterized as "well sorted" (Folk et al., 1957).

The "Kurtosis" is more brief value than "Sorting" and it counts the peakedness of the distribution (Folk, 1966).

The combination of these values can lead to the appropriate and accurate results, in order to be compared and combined.

Results

Stratigraphy of the boreholes P2, P4

Borehole P2 (Figures 2,3): The stratigraphy of this borehole shows that the dominant sediment is the sand which stopped abruptly by more finely sediments like silt and clay. Sand appears almost in all depths either fine or coarse. This is an indication of the

influence of the sea in this core. Then the presence of silt and clay declares a low energy area with seasonal standing water, like a lagoon. In the last meters of the borehole are dominated by the clay with shell fragments (-13m to -17m) and organic material where the presence of sand is minimal.

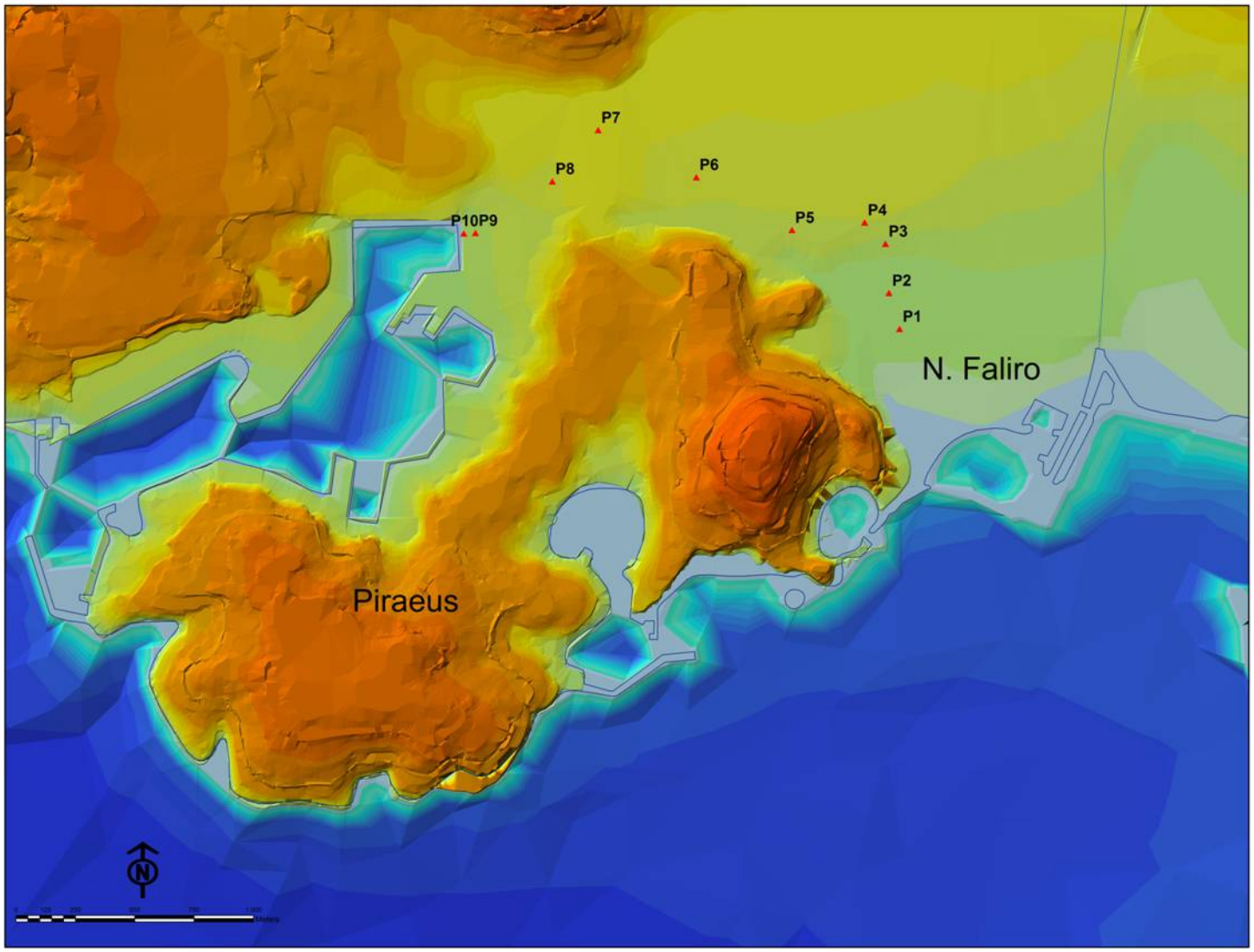


Figure 2: The position of the boreholes P2-P4.

Borehole P4 (Figures 2,4): The stratigraphy of this borehole shows to be dominated by clays. Clays make their appearance also at all depths, as pure layer or as a layer containing clay, sand and pebbles. In parallel there is a shell or fragments of these in almost all the depths of the core (-1,5m to -12,5m). Above appears that at this point where the core was a lagoonal-marshy environment with a direct effect of the sea because the presence of sand and shells.

From the description of the two cores, concluded that the P2 presents an environment with a strong presence of the sea because the presence of sand (coarse, fine). In core P4 which most closely approximates the area of the port of Piraeus presents a low energy environment and more terrestrial because we have the presence of mainly fine-grained sediment (clay), but with many shell fragments which shows the direct relationship with the sea.

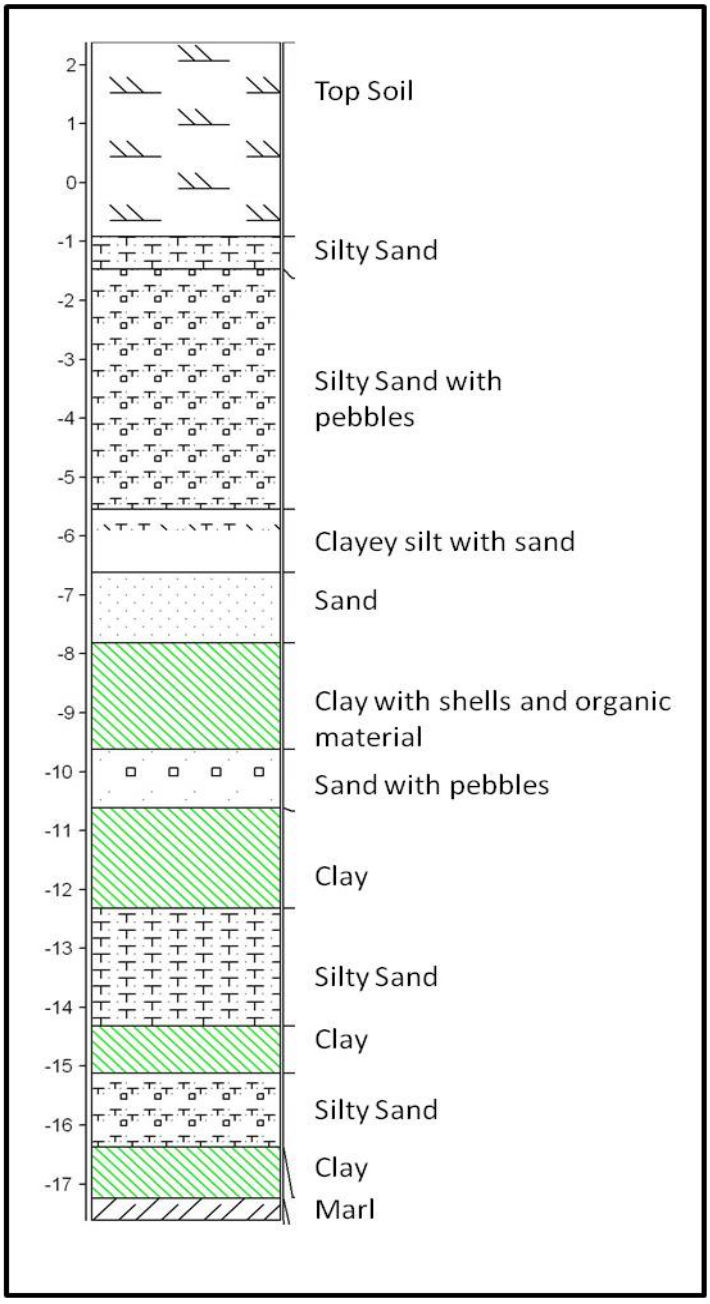


Figure 3: Borehole P2

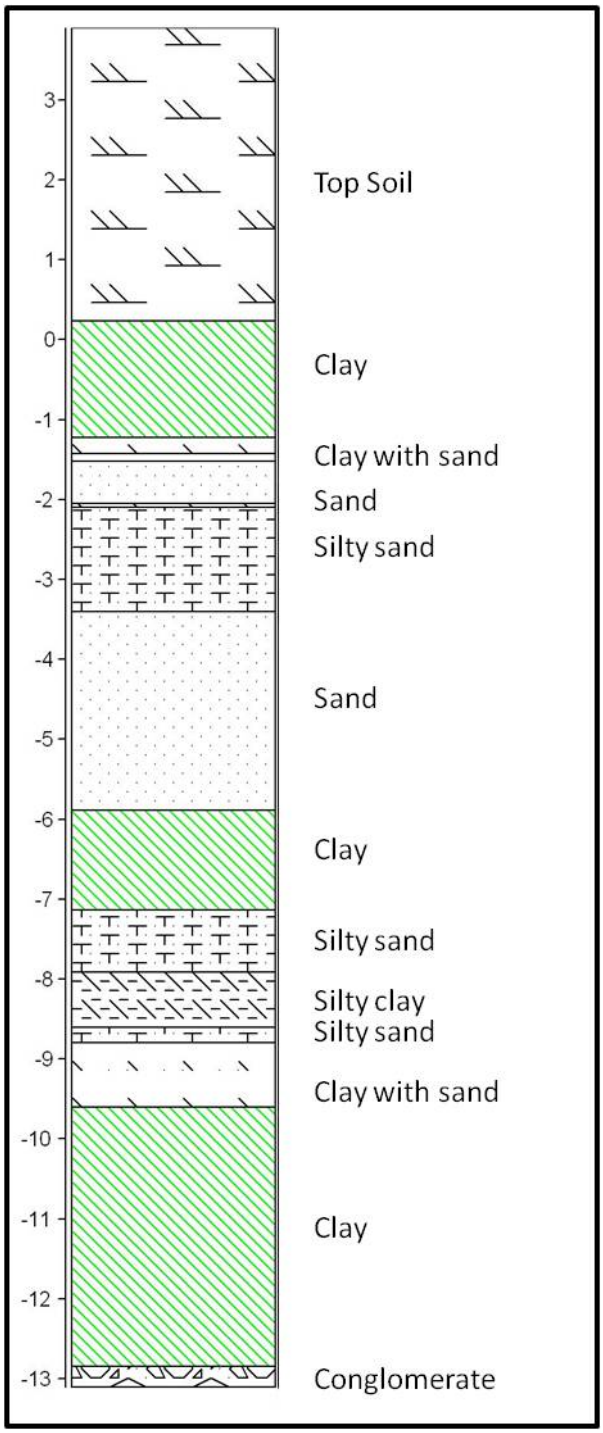


Figure 4: Borehole P4

Results from Gradistat

The program Gradistat (4th edition), is implemented by Simon Blott in 2000, who holds the copyright, and he is based in the University of London, in the geology department. With this software, the data collected from the grain analysis of the samples of the boreholes of Piraeus (P2 and P4), can be analyzed further.

Firstly these samples have been separated by sieve in fractional array and collect the amount that is suitable for further study of the particle size Laser scanner "Mastersizer 2000", the quantity of grains with a diameter less than 2mm (Trautmann et al., 2000a, b)

Afterwards the results (moyenne) derived by the software of "Mastersizer 2000" processed quantitatively and qualitatively with the software "Gradistat". From the results, the average (M or D50) and C (D90) in «mm» were used in order to draw a logarithmic diagram of CM Passega, which provides information (data) according to the transportation and the deposition of the sediments in fluvial systems and plenty of information of the Palaeogeographical study (Bravard & Peirry., 1999).

Thereafter, in order to design the diagrams for the Sedimentological Indicators Method (Folk and Ward) the Mean, Skewness, Sorting and Kurtosis were used.

From these results the CM Passega diagram can be drawn (Passega, 1965) which as mentioned above can provide information for the environment of transportation and deposition of sediments and the palaeoenvironment of the study area.

The C-M diagram is divided into three main sections according to the diameter of the grain and the middle of the transport. These sections are OP-QR-RS, etc. (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).

Different transport mechanisms are represented by different parts of matrix CM:

1) The section QR of the diagram represents the deposition of sediments carried by graded suspension.

2) The section PQ represents the deposition of sediment of rolling grains and graded suspension. When the concentration of grains in deposits increased rolling resistance represented by the section OP when scrolling flood sediments in almost all the deposit represented by the section NO.

3) The Section O, P, Q, of the diagram, which form the «step», refers to different means of transport either by rolling or graded suspension.

4) The Section RS represents the deposition of sediments transported by uniform suspension.

5) This section T represents the silty clay, who is been transported by the “pelagic” suspension.

6) This section NO represents rolling sediments.

Passega diagrams

Through Passega Method, the evolution of the study area will be analyzed, noting the difference of the distribution through time compared with the depths depends on the (T, RS, RQ) of the samples analyzed and described by this method.

For this reason, the diagrams of the boreholes P2 and P4 were divided into sections, according (Diagrams 1,2) to specific characteristics, in order to show the advance or retreat of the sea and when it was finally stabilized (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).

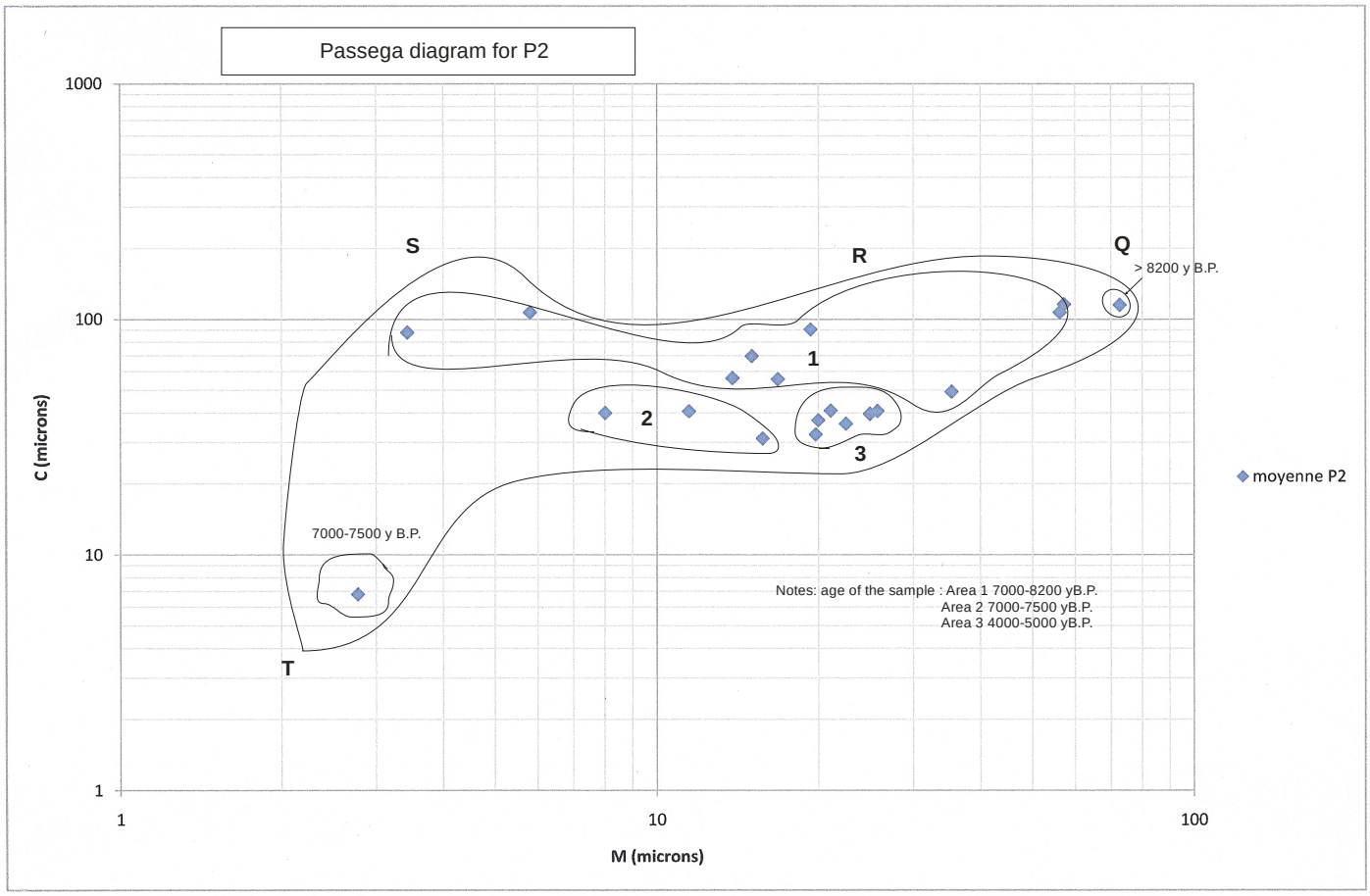


Diagram 1: Categorization of the samples of P2.

In this diagram (Diagram 1) there are four samples with different or the same age but with varying depth and sometimes other material deposition indicating different Palaeoenvironment.

Specifically, in Section 1, the ages of the samples, ranging from 7000 years BP to 8200 years B.P. this part of the P2 presents a lagoonal area, which enriching with seawater periodically. (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).

In Section 2, the ages range between 7000 years BP to 7500 years B.P. this part of the sample P2 shows a region which was in direct contact with the sea that once covered and once again appeared as dry (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).

In Section 3, the ages range from 4000 years BP 5000 years BP in this section of the samples shows that the area of P2 was underwater (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).

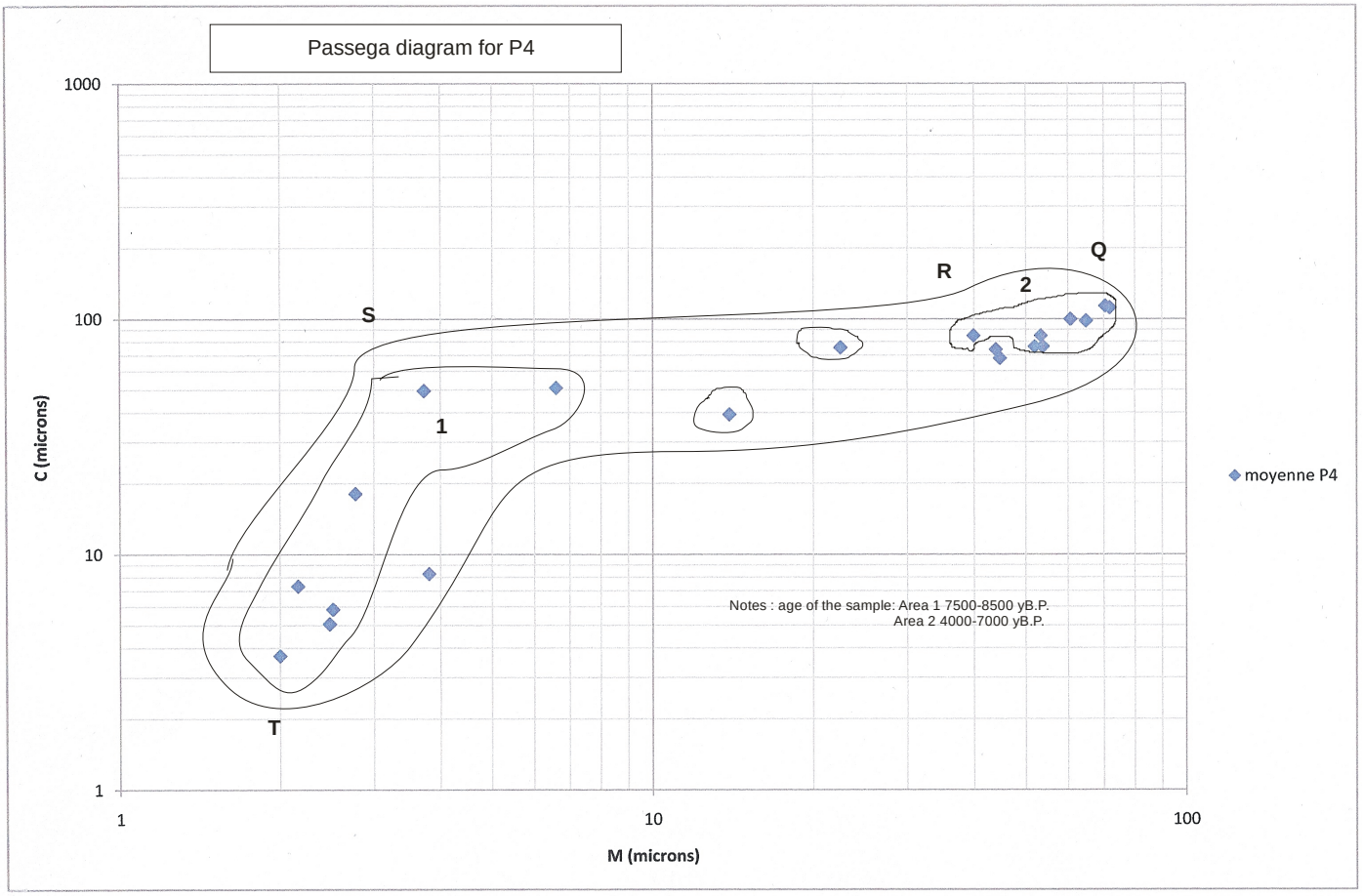
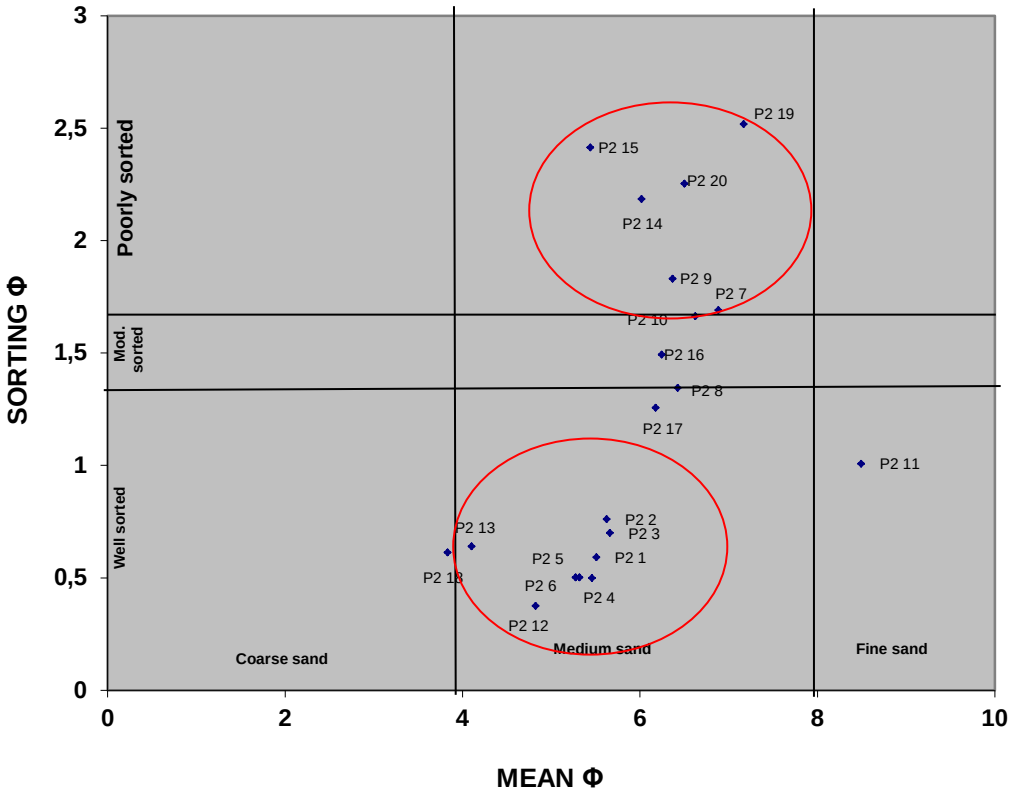


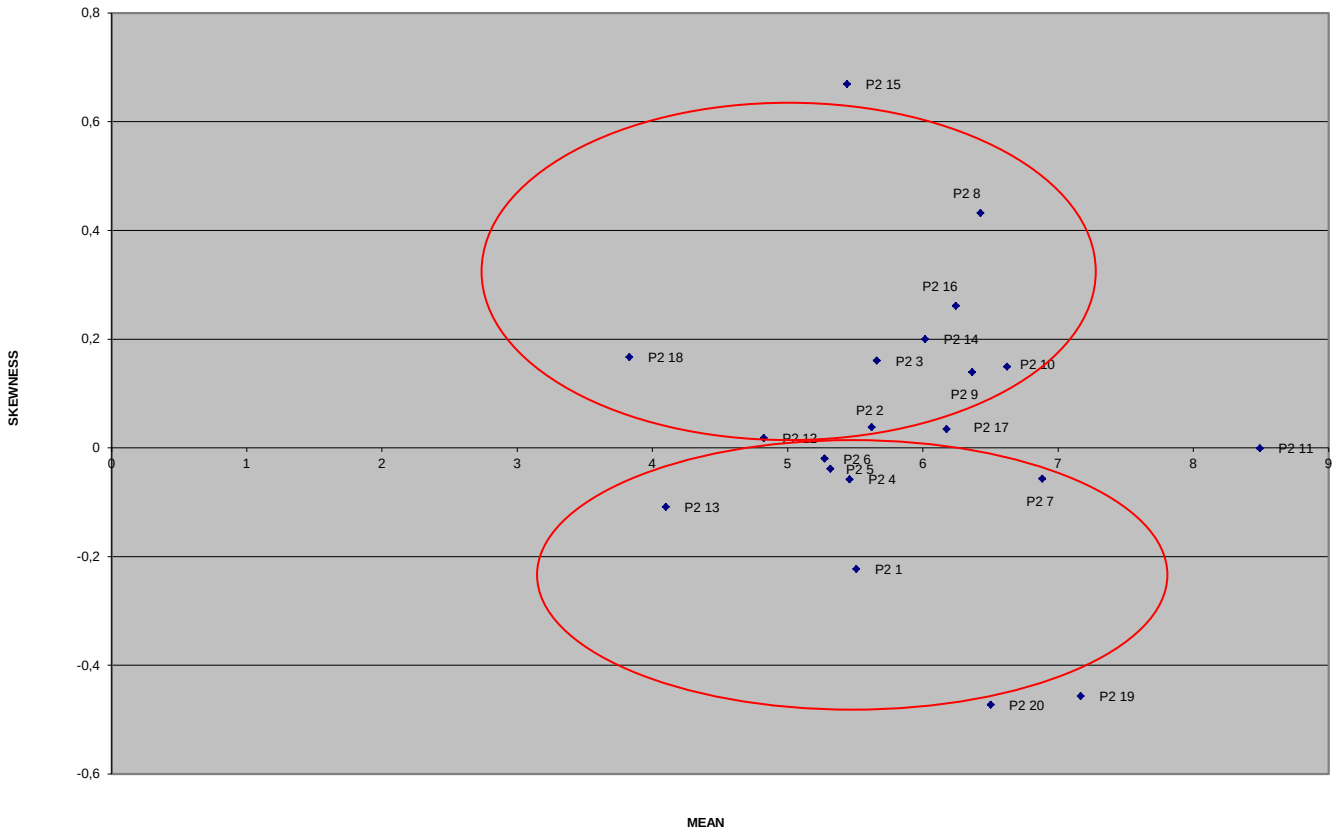
Diagram 2: Categorization of the samples of P4

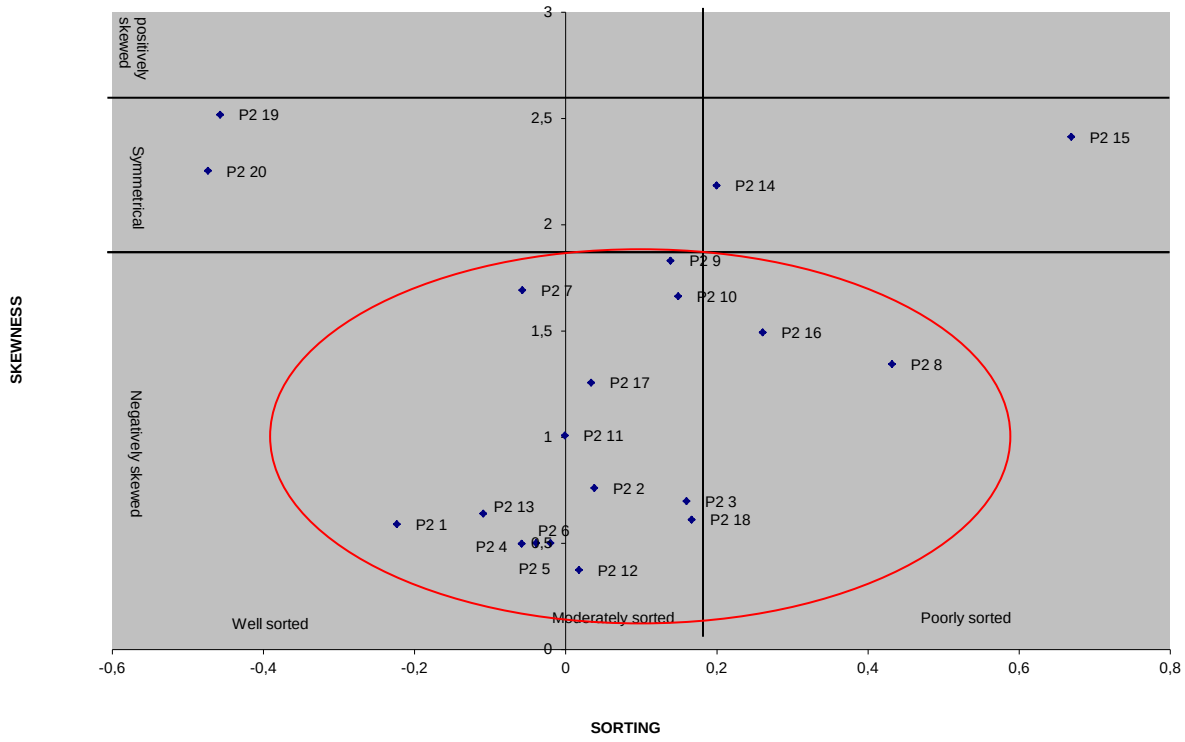
In this diagram (Diagram 2) there are two areas with different or same age but with varying depth and sometimes other material deposition indicating different Palaeoenvironment (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999). More specific, in Section 1 the ages of the samples ranging from 7500 years BP to 8500 years B.P. this part of the P4 presents lagoonal area, which enriching with seawater periodically (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).
In Section 2, the age is around 5000 years BP this part of the samples of P4 shows a region covered by the sea (Passega 1957, Passsega 1965, Passega 1977, Bravard & Peiry, 1999).
Generally in this diagram for P4 (Figure 8) there is a more terrestrial sediment distribution in relation to the diagram for P2. The environment is becoming more and more terrestrial. But this shows that the area of Piraeus peninsula by 4000-8500 years before was an island with shallow waters which sedimented from the KIfissos river.

Sedimentological Indicators Diagrams (Folk and Ward)

After the suitable interpretation of the results from "Gradistat" four diagrams of each borehole were designed. In these diagrams the Mean, the Sorting, the Skewness and the Kurtosis were combined and correlated in order to obtain the appropriate information about the palaeogeography of the study area.
Generally these diagrams show the transgression of the sea against the continent and the combination of the fluvialand the marine processes.







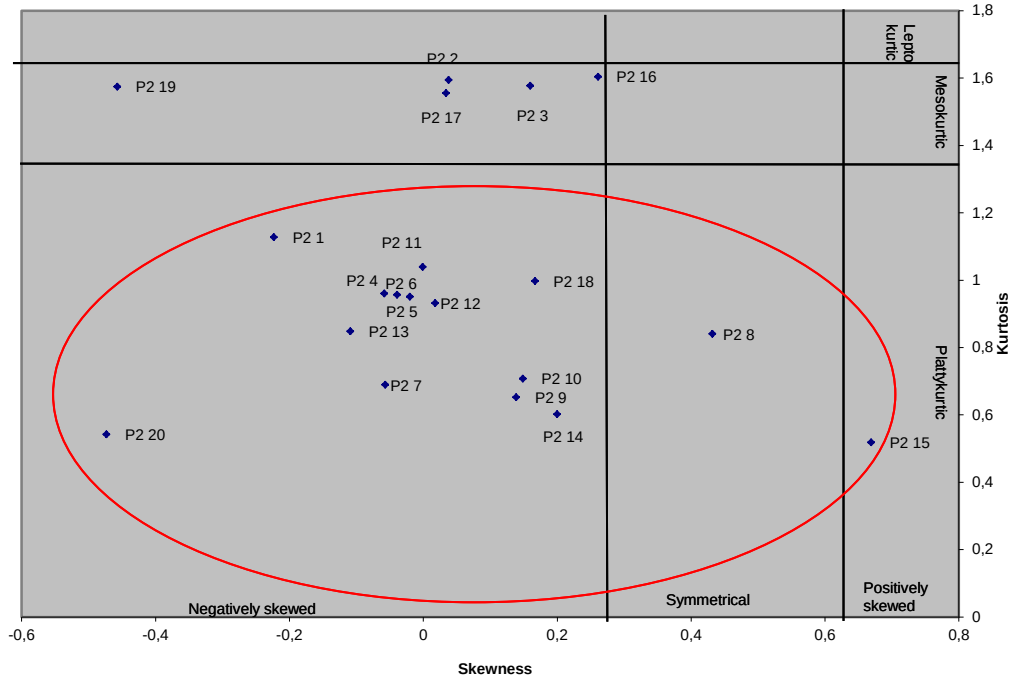
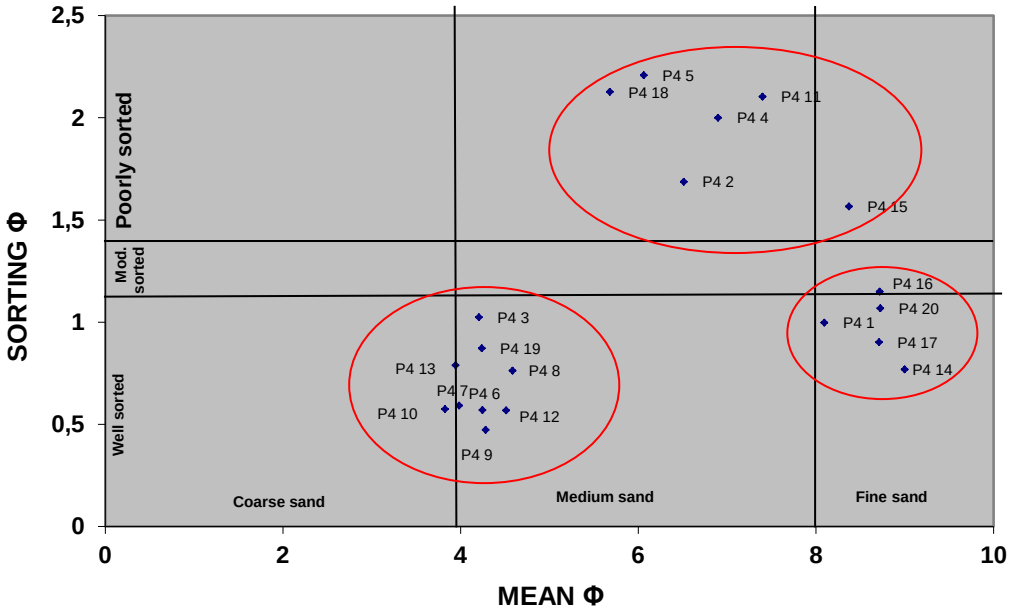
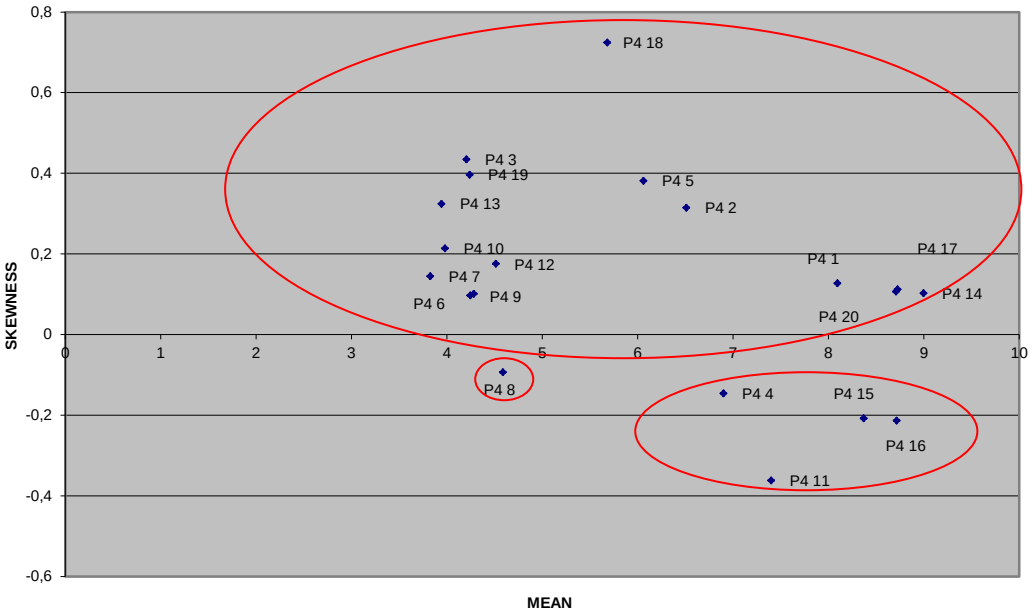


Figure 5: Diagrams with the combination of the sedimentological indicators for the results of the samples from borehole P2.

Observing these diagrams from borehole P2 (fig. 5), is obvious that the most of the samples are "well sorted", indicating the marine origin. But there are also six samples poorly sorted which indicate that there are two processes (fluvial and marine) fighting each other. In the diagram of Skewness-Mean twelve samples have positive Skewness (marine processes) and eight samples have negative Skewness (fluvial processes). In the diagram Skewness-Sorting the most of the samples have negative Skewness which indicates marine sand and they are well sorted (marine processes).





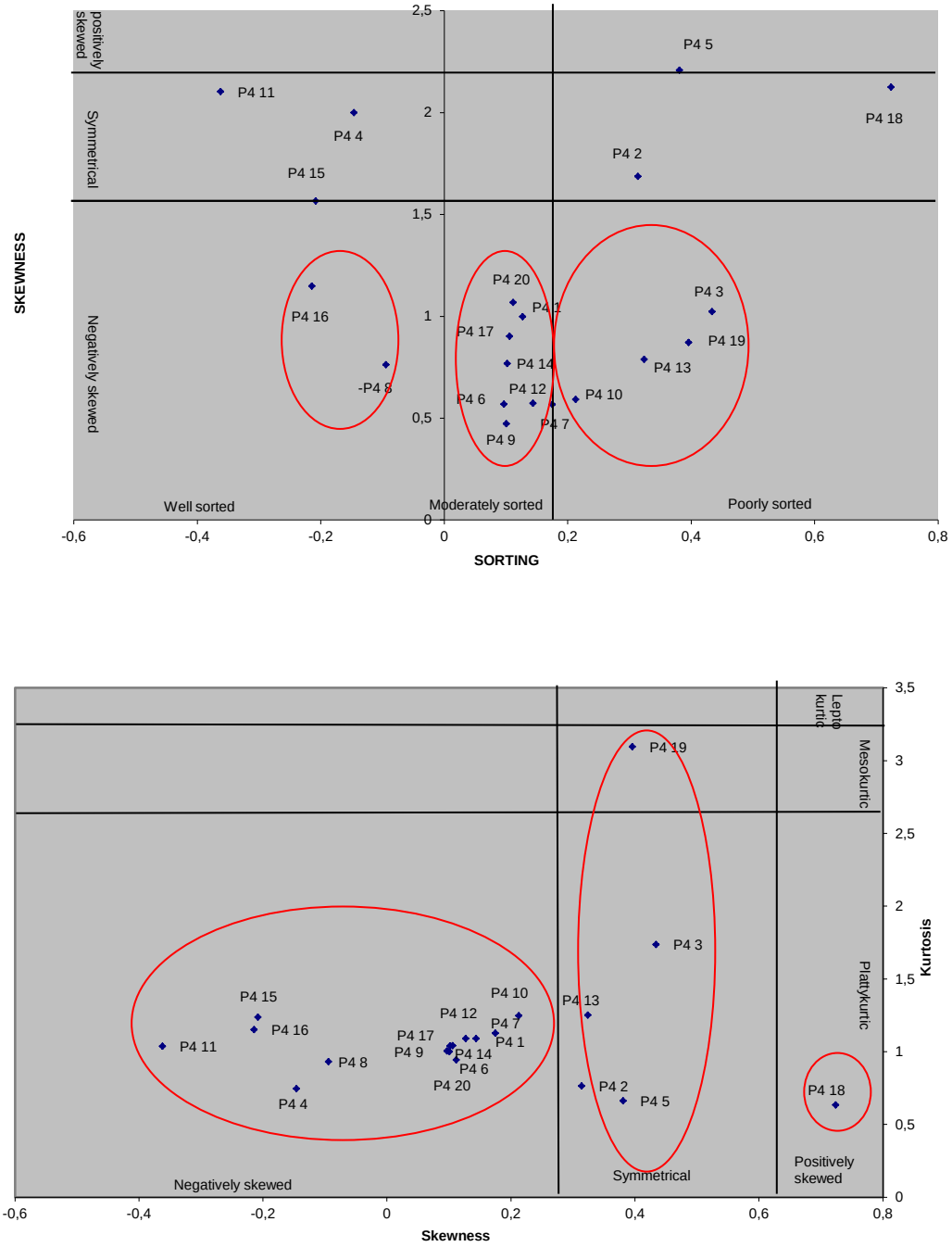


Figure 6: Diagrams with the combination of the sedimentological indicators for the results of the samples from borehole P4.

Observing these diagrams from borehole P4 (fig. 6), is obvious that the most of the samples are "well sorted" (more than P2), indicating the marine origin. But the present of fine sand indicates a depositional environment of low energy, such as lagoon-marsh. This fact shows a protected environment from marine dynamic marine processes (waves). The

diagram Skewness-Mean shows fluvial processes than marine. In the diagram Skewness-Sorting the most of the samples have negative Skewness which indicates marine sand and they are well sorted (marine processes).

Discussion-Conclusion

In conclusion all the diagrams show the combination of marine and fluvial processes, showing the changes of the deposition environment according to the period of the deposition. The presence of the "well sorted" and "poorly sorted" sediments with the "low energy" indication from the Passega diagrams lead to the conclusion that in this area two depositional environments are present, the marine along with the fluvial. In some places the low energy environment, help the development of a lagoonal-marshy environment in the area of borehole P4 (fig. 2). On the other hand, the area near the borehole P2 is directly affected from the marine processes.

From the datings (Goiran et al., 2011) of the samples gathered from the sampling boreholes and comparing the results with the information derived from the interpretation of the data through Passega Method and Sedimentological Indicators Method (Folk and Ward), four periods can be distinguished.

The first period around 8.000-4.500 yBP (Goiran et al., 2011) shows that the coastal area was dominated mainly by a large shallow lagoon protected from the marine processes as shown in the fine grained sediments (silt and clay) which define a low energy environment (Goiran et al., 2011; Vandarakis, 2013; Vandarakis et al., 2014).

At 4.500 yBP this lagoon started to be infilled with sediments from the drainage network of the area and it was separated in two parts (Goiran et al., 2011; Vandarakis, 2013; Vandarakis et al., 2014). This can be explained considering the climatic change and the maximun of the precipitation in eastern Mediterranean (Finne et al., 2011) and the low rate of Sea Level Rise during Holocene (RSL approximately -2m below present sea level (Lambeck et al., 2005, Baika, 2008, Kapsimalis et al., 2009, Pavlopoulos et al., 2011))

Subsequently in 2.500 yBP these two lagoonal parts started to be swampy (Goiran et al., 2011; Vandarakis, 2013; Vandarakis et al., 2014) as the references indicate, anthropogenic activity in this area in order to stabilize the structures from the subduction, due to the loose sediments and the swampy environment of the area.

Finally, the recent landscape of the study area is derived after the interference of the human activity. The coastal and the central part of the Athenian Basin have been extensively transformed in to habitation areas for the Athenians. The drainage networks of Kifissos and Ilissos rivers have been modified to cast out separately in the Phaleric coastal area.

Generally the Passega Method and the Sedimentological Indicators Method (Folk and Ward), help the identification of the palaeoenvironment and the palaeolandascape of the study area as shown in this research. Both of the methods can be used as a useful tool for the characterization of the depositional environment and the determination of the processes which dominated the area through time.

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