# POROSITY DENSITY AND OTHER PHYSICAL PROPERTIES OF DEEP-SEA SEDIMENTS FROM THE BLACK SEA

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**Abstract.** During the August 2004 cruise of ship Mare Nigrum, sediment cores with a maximum length of 4 meters were taken with a gravity corer from several sites in the Black Sea, at depths of 860 to 1414 meters. All cores were characterized by the presence of deep-sea sediments typical of the Black Sea, that is coccolith ooze, sapropel, grey and black clay. Measurements of porosity as well as of other physical properties (bulk saturated density, grain density, water content and shear strength) were performed on two cores. Porosity values are situated within normal limits for these types of sediments, ranging from 71 to 80%, with the exception of coccolith ooze and most notably sapropel, characterized by exceptionally high values exceeding 90%. Bulk saturated density and water content values are in proportion with porosity values. Grain density values are highly homogenous, ranging from 2.60 to 2.72 gr/cm³, with the exception of previously mentioned muds with exceptionally low values ranging from 2.41 to 2.51 gr/cm³. Shear strength measurements were performed on soft sediments and resulted into very low values ranging from 9 to 43 gr/cm³, which are too close to the equipment's accuracy to allow for them to be used beyond the purpose of information.

**Key words:** porosity, saturated bulk density, shear strength, gravity corer, coccolith ooze, sapropel, grey clay, Black Sea

## INTRODUCTION

Knowledge of the physical properties of deep-sea sediments is important both in order to characterize the sediments in the fullest details possible and to understand the sedimentation processes in this area. The lack of data regarding the physical properties of Black Sea sediments can be explained through the relatively small number of cruises in the course of which deep-sea cores were taken, as well as through the difficulty of bringing to the surface cores with an undamaged structure.

The August 2004 cruise of GeoEcoMar's ship "*Mare Nigrum*", whose objective was the study of gas hydrates and in the course of which sediment cores with a maximum length of 4 meters were gathered from several locations situated at depths ranging from 860 m to 1,414 m, has provided the opportunity to perform measurements of the physical parameters of sediments (porosity, bulk saturated density, grain density, water content and shear strength).

## METHODS

Samples were taken by means of a gravity corer with a maximum length of the core tube of 5 meters. After the corer was brought on the deck, the core liner was pulled out of the gravity corer steel housing tube. The core was then cut longitudinally and a macroscopical description of the sediments was made in accordance with the terminology first used by Ross and Degens (1974) for Black Sea sediments.

Since GRAPE System (<u>G</u>amma <u>R</u>ay <u>A</u>ttenuation <u>P</u>orosity <u>E</u>valuation) equipment was not available on board the ship, the physical properties of deep-sea sediments were measured in the laboratory through classical methods.

Taking into account the lithological uniformity of the formations intercepted, two sites C12 and C18 (Fig. 1) which were found to be more representative from a lithological point of view and from which more undisturbed cores were taken, were selected for physical measurements.

Sediment samples were taken from each significant lithological unit (coccolith ooze, sapropel, clay, etc.) in metallic tubes according to the following procedure: a metallic tube of known volume was inserted in the sediment within a maximum interval of 15 minutes after the core was cut and was then removed together with the sample, excess material was trimmed and the ends were immediately insulated. (Benett & Lambert, 1971). The tubes containing the samples were weighed in their wet state within a maximum interval of 24 hours after being taken, dried in ovens at a temperature of 105ºC, cooled in a dessicator and then weighed in their dried state. Bulk saturated density, dried density and water content were calculated on the basis of the weight of samples in their dried state, of the weight of samples in saturated wet state and of the volume of the sample, according to standard procedures.

Porosity was calculated following the grain density method by means of this formula:

$$\eta = \gamma_s - \gamma_d / \gamma_s * 100$$

$\eta$ = porosity
$\gamma_s$ = grain density
$\gamma_d$ = dried density

Grain density was measured following the pycnometer method on a dried and moulded sample.

Shear strength measurements were performed by means of the Vane apparatus, by inserting a small four blade vane into the sediment and applying an increasing torque until shear occurs. Shear strength is a function of cohesion and the angle of internal friction of the sediment. In the case of marine sediments consisting of clay and silt which are considered to be saturated, the

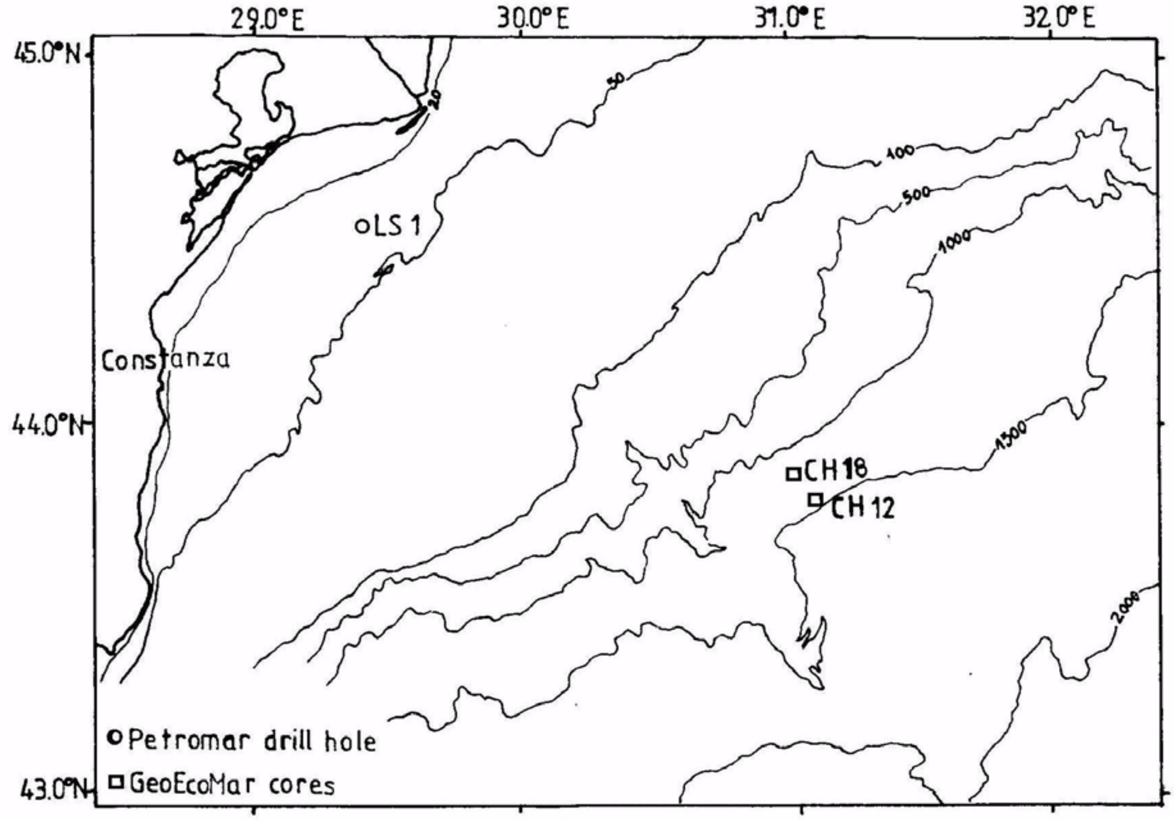


**Figure 1** Localization of the cores

angle of internal friction being practically zero, shear strength is considered to be equal to cohesion. Testing was made on both the undisturbed and remoulded state of the sediment, which provide a measure of the sensitivity (ratio of undisturbed strength, to remoulded strength) of the sediments. Sensitivity is a measure of strength loss due to disturbance.

## TYPES OF ERRORS

### Systematic errors

Removal of sediment cores from in situ conditions results in changes in porosity and saturated bulk in particular, not only as a result of disturbance during the penetration of the gravity corer in the sediment but also because the cores are removed from in situ temperature conditions to surface conditions. These changes are more apparent in the case of superficial muds.

### Procedural errors

Errors occurring during handling of the cores or in the laboratory in the course of measurements of porosity, bulk saturated density and other properties can result from several factors:

- Wrong handling of the cores on the deck during sectioning, transport or processing. Although truly undisturbed sediment cores cannot be obtained with the present coring techniques, sediment disturbance could be substantially minimized by careful core handling.
- Incomplete sample saturation.
  The samples can be incompletely saturated, part of the amount of water being replaced by gases, especially air, which result into porosity and humidity values smaller than the real ones. (Gealy, 1969). In the present case core handling was performed in very high temperature conditions, which allowed for the possibility of loss of an amount of water from the sample so that the water content and bulk density determined might be several percents smaller than in reality. To overcome this inconvenience, porosity was calculated by means of a formula based on dried sample characteristics, grain density and dried bulk density.
- Incompletely dried samples.
  If the sample is not sufficiently dried errors can occur in the measurement of both dried bulk density and water content. This error possibility was eliminated by keeping the sample in the oven for over 24 hours.
- Unapplied corrections.
  Volume measurements by means of analytical balances, as well as temperature measu-rements can allow for errors, an inconvenience which can be removed by a correct use of

standardizations and temperature and salinity corrections.

## RESULTS

### Lithology

The two cores largely contain the same lithological units described by Ross and Degens during the 1969 *Atlantis II* cruise:

Unit 1 (coccolith ooze) is identical to the one previously described, consisting of an alternate sequence of light and dark microlaminae containing a high percentage of calcium carbonate.

Unit 2 (sapropel) described by Ross and Degens (1974) as dark brown in colour, consists in cores CH12 and CH18 of two horizons, a blackish-green superior one and a black inferior one, both of which are microlaminated and jelly-like.

Unit 3 (laminated lutite) consists in the present case of grey clay interbeded with blackish-grey clay or black clay. It must be mentioned that immediately beneath the sapropel there is an intermediate horizon consisting of greenish-grey mud and soft whitish-grey clay.

Studying the two locations under discussion (Table 1) an almost perfect symmetry in terms of lithology and physical parameters values can be noted.

### Porosity, bulk saturated density and water content

Superficial muds in both locations were found to have porosity values of approximately 90% which decrease almost uniformly (Table 1) as a result of the compaction underwent in the course of time by the sediments, reaching a minimum porosity value of approximately 70% at the basis of the core, 3.5 meters deep. Bulk saturated density and water content values are proportional to porosity values. The only porosity values which do not fit this pattern are the exceedingly high porosity values of 91-93% characteristic of sapropel. Porosity values exceeding 90% are normal and have been previously noted in the case of deep-sea superficial sediments, being caused by the presence in the structure of those muds of incompletely degraded organic matter together with clay. Another mention can be made of minor deviations from the uniform decrease in porosity, more difficult to explain and which can be attributed to a different compaction of the sediments according to the lithological composition as well as to admissible procedural errors.

Determining the porosity, bulk saturated density, grain density and water content of a 2 meter long core drawn during the 1967 global cruise of the NOAA ship Oceanographer from the western part of the Black Sea from a water depth of over 2000 meters. Keller (1974), has come to values quite close to the ones presented in this paper, with the mention that in the case of sapropel he has determined porosity and water content values of 95% and 700% respectively, which he has regarded as the highest reported values for marine sediments.

Undoubtedly, these extremely high porosity values which involve equally high water content values are a result of the fiber-like characteristics of the organic matter which consists largely of tubular and lamellar membranes as well as of organic fragments resembling bacterial cell walls (Degens *et al*., 1970).

### Grain density

Grain density values do not depend on the degree of compaction of the sediments but on the mineralogic composition. Thus, coccolith ooze and sapropel have lower grain density values than clay due to the presence of larger quantities of organic matter, with values ranging from 2.41 to 2.51 gr/m$^3$.

A noticeable difference in grain density values can also be noted in the case of superficial muds, as coccolith ooze has higher values than sapropel due to the presence of organic carbonates. Unlike the bulk saturated density which increases with depth, grain density has rather homogenous values ranging from 2.60 to 2.70 gr/cm$^3$ in the case of clays. The several values which exceed 2.70 gr/cm$^3$ cannot be correlated with mineralogic composition due to the lack of complete mineralogic analyses. These higher values could indicate the presence of iron sulphates.

### Shear strength

Shear strength measurements are generally avoided in the case of the first 5 meters of sediment and especially of the first metre, because of the extremely low values which are very close to the method's accuracy. For this reason determined values are strictly informative, being more significant for the size order than for absolute value. Shear strength values (Table 2) are very low, ranging from 9 gr/cm$^2$ to 42.9 gr/cm$^2$. The lowest values, 7-9gr/cm$^2$ are characteristic of sapropel and soft clays. Although Keller (1974) thinks that the shear strength of coccolith oozes is higher than that of sapropel, without providing the absolute value, in the present case higher values were measured for sapropel, than for the coccolith ooze and soft clays, probably caused by the jelly-like aspect of the sediment. Shear strength values of clays, with the exception of the soft clays at the base of unit 2, range from 20 to 42 gr/cm$^2$.

In both cores maximum shear strength values were measured for black clays and can be attributed to the presence in the mass of these clays of wood fragments or grains of iron sulphates which can cause slight increases in shear strength.

Comparing the values of the physical parameters of the sediments in these two locations with the values obtained in the case of cores taken from shelf regions of the Black Sea, it can be noted that porosity values as well as the values of the other parameters are similar (with the exception of the extremely high values measured in the case of coccolith ooze and sapropel) to the extent to which sediment lithology is similar. Comparisons were based on boring LS1 (Table 3) made by PETROMAR at a depth of 40 meters on the Black Sea shelf.

**Table 1** Mass physical properties of sediments from cores CH12 and CH18 from water depths of 1414 meters and 1217 meters

| Depth cm. | Description | Bulk saturated density gr/cm$^3$ | Dried density gr/cm$^3$ | Grain density gr/cm$^3$ | Water content % | Porosity % |
|---|---|---|---|---|---|---|
| **GH 12** | | | | | | |
| 0,00 - 0,09 | Coccolith ooze | 1,18 | 0,34 | 2,51 | 243,33 | 86,33 |
| 0,09 - 0,23 | Blackish-green sapropel | 1,01 | 0,21 | 2,44 | 379,15 | 91,33 |
| 0,23 - 0,31 | Black sapropel | 1,02 | 0,18 | 2,43 | 476,42 | 92.73 |
| 0,31 - 0,46 | Whitish-grey soft clay | 1,41 | 0,59 | 2,65 | 123,18 | 77,74 |
| 0,46 - 0,88 | Grey clay | 1,47 | 0,70 | 2,68 | 111,97 | 74,07 |
| 0,88 - 1,15 | Black clay | 1,44 | 0,74 | 2,70 | 94,51 | 72,55 |
| 1,15 - 2,40 | Blackish-grey clay | 1,45 | 0,69 | 2,71 | 110,17 | 74,49 |
| 2,40 - 2,71 | Black clay | 1,45 | 0,75 | 2.72 | 93,73 | 72,43 |
| 2,71 - 3,60 | Grey clay | 1,40 | 0,77 | 2,69 | 82,73 | 71,52 |
| **GH 18** | | | | | | |
| 0,00 - 0,19 | Coccolith ooze | 1,12 | 0,28 | 2,49 | 305,27 | 88,91 |
| 0,19 - 0,39 | Blackish-green sapropel | 1,11 | 0,22 | 2,42 | 396,39 | 90,73 |
| 0,39 - 0,45 | Black sapropel | 1,12 | 0,18 | 2,41 | 525,91 | 92,56 |
| 0,45 - 0,52 | Greenish-grey mud | 1,19 | 0,37 | 2,53 | 217,79 | 85,19 |
| 0,52 - 0,61 | Whitish-grey soft clay | 1,35 | 0,53 | 2,60 | 154,74 | 79,64 |
| 0,61 - 1,17 | Grey clay | 1,48 | 0,74 | 2,71 | 99,58 | 72,62 |
| 1,17 - 1,81 | Black clay | 1,47 | 0,74 | 2,72 | 99,19 | 72,92 |
| 1,81 - 3,40 | Brown clay | 1,46 | 0,66 | 2,68 | 119,73 | 75,29 |
| 3,40 - 3,50 | Grey clay | 1,55 | 0,81 | 2,71 | 90,52 | 69,64 |

**Table 2** Shear strength of sediments from core CH12

| Depth cm. | Description | Shear strength gr/cm$^2$ | | Sensitivity $S_u / S_r$ |
|---|---|---|---|---|
| | | Undisturbed $S_u$ | Remoulded $S_r$ | |
| 0,00 - 0,09 | Coccolith ooze | - | - | - |
| 0,09 - 0,23 | Blackish-green sapropel | - | - | - |
| 0,23 - 0,31 | Black sapropel | 9.7 | 2.8 | 3.5 |
| 0,31 - 0,46 | Whitish-grey soft clay | 7.6 | 3.2 | 2.4 |
| 0,46 - 0,88 | Grey clay | 18.4 | 6.8 | 2.7 |
| 0,88 - 1,15 | Black clay | 29.5 | 9.5 | 3.1 |
| 1,15 - 2,40 | Blackish-grey clay | 25.3 | 9,0 | 2.8 |
| 2,40 - 2,71 | Black clay | 43.2 | 13.9 | 3.1 |
| 2,71 - 3,60 | Grey clay | 32.8 | 9.9 | 3.3 |

**Table 3** Physical properties of sediments from boring LS 1 from water depth of 40 meters

| Depth cm. | Description | Bulk saturated density gr/cm$^3$ | Density gr/cm$^3$ | Grain density gr/cm$^3$ | Water content % | Porosity η% | Shear strength gr/cm$^2$ | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | undrained | remoulded |
| 0.00 – 1.20 | Grey very soft mud | 1.39 | 0.64 | 2.69 | 109.1 | 75.30 | 15 | 7 |
| 1.20 – 2.20 | Grey soft mud | 1.38 | 0.69 | 2.68 | 100.7 | 74.30 | 20 | 13 |
| 2.20 – 3.20 | Grey clayey silt | 1.45 | 0.78 | 2.68 | 86.40 | 71.00 | 21 | 10 |
| 3.20 – 4.20 | Grey clayey silt | 1.47 | 0.84 | 2,68 | 86.30 | 68.50 | 24 | 10 |
| 4.20 – 5.20 | Grey clayey silt | 1.52 | 0.87 | 2.69 | 58.50 | 67.70 | 38 | 21 |

## CONCLUSIONS

Sediment cores gathered in 2004 from depths of over 1200 meters in the Black Sea contained typical deep-sea sediments (coccolith ooze, sapropel and clays) with the observation that unit 2 sapropel consists of two horizons which differ in colour, a blackish-green and a black one.

The values of porosity and of the other physical properties of the sediments, bulk saturated density, grain density, water content are close to those previously quoted.

The exceptionally high porosity values, exceeding 95%, encountered in previous papers are confirmed, although the maximum values present in this paper are lower by 2-3%, with an absolute value of approximately 93%.

Shear strength values, which generally involve relatively high errors in the case of unconsolidated sediments and can only be used for the purpose of information, are equally close to previously measured values, ranging from 9 gr/cm² to 42.9 gr/cm².

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