

# Grain Size Data Analysis of Marine Sediments, From Sampling to Measuring and Classifying. A Critical Review

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**Abstract - The grain size analysis of marine sediments is considered as a basic tool in the marine environmental research. In particular, information on sediment characteristic is needed, for example, for studies on sediment contamination, ecology of benthic communities, seismic studies, remote sensing surveys, beach nourishment, etc. A critical review of the main methods used for sampling, measuring and classifying marine sediments is reported here. It was deduced that no ideal method in order to obtain the highest accuracy of data exists, but the choice of the most suitable one should be adapted to the specific aim of the study.**

## I. INTRODUCTION

Different types of sediments characterize different kinds of marine environments; generally, coarser sediments are present close to the coast, at shallow water depth, where high energy processes are active, and their size decreases with increasing bathymetry, because far from the coast the terrestrial sediment supply considerably diminishes. This general rule is not always valid, for example for enclosed coastal marine and transitional settings, where fine sediments may be prevalent. Once sediment particles are supplied to the sea, they are dispersed under the combined action of currents and waves. Hydrodynamics, meteorology, climate and bottom morphology are the main factors influencing their distribution. Successively, particles may be affected several times by resuspension, transport and deposition, over the continental shelf and slope, before being definitively deposited. The grain size is considered as a basic feature of marine environment, which have to be characterized because it influences biotic and abiotic aspects. Sediment texture strongly conditions macro and meio benthic communities [1; 2] as well as organic carbon [3] and contaminant distribution [4]. For this reason, textural characteristics of sediments and their distribution are among the key factors, not only for sedimentological studies, but also for ecological characterization of benthic habitats and for environmental assessment of potential contamination of marine coastal

areas affected by anthropogenic impacts. In this context, grain size data are also necessary for the normalization of concentrations of metals and trace elements, because the normalizer element have to be correlated with the clay fraction [5]. Moreover, the direct acquisition of grain size data is necessary for correlating seismic units recognized in the profiles with specific stratigraphic units [6] or calibrating the results of remote sensing techniques with experimental data [7].

Another application of grain size studies is in the field of coastal management; in particular, the sediment characterization is necessary in the beach nourishment, in which sediment features of the borrow area must be as similar as possible to those of the native beach [8].

The activities finalized to the acquisition of grain size data depend on the topic of the research and, according to it, several steps, from sampling to analytical processes and, finally, to sediment classification, may be changed.

This work is aimed to review methods currently used for sampling, analyzing and classifying sediments, taking into account different specific purposes in the area of the marine environmental research.

## II. SAMPLING ACTIVITY

The sampling criteria and instruments selected for marine sediments are generally functional for obtaining an undisturbed sample. Maintaining the integrity of the sample is of great importance because it favors the preservation of the original structure of the sediment and does not alter its physical-chemical and biological characteristics. In the field of the environmental research, this aspect assumes great importance because one of the main consequences of sample alterations, due to the use of unsuitable devices, is the variation in the typology and bioavailability of contaminants.

There are two main categories of sampling devices for marine sediments: grab and core samplers. The first ones are used to collect superficial sediments, while the second ones are used when it is necessary to collect a whole thickness of sediment. The multiple sampling with grabs allows to characterize only spatially the study area, while

the core sampling enables to obtain information also along the vertical direction. In both cases, the choice of a specific device depends on the type of substrate and the aim of the study, but also from bathymetry.

Grab sampling is suitable when the characterization of current environmental conditions of sea bottom, using chemical, biological and sedimentological parameters, is needed. Grabs are relatively easy and fast to handle and operate, allowing the collection of a lot of samples in a short time.

The most commonly used grabs are: Van Veen, Shipek and Ekman-Birge (Fig. 1). The Van Veen grab is constituted by two jaws. As soon as the grab comes down to the bottom, the jaws close by holding the sediment inside. Some models have upper doors that allow collecting the nearly undisturbed upper centimeters of bottom sediment, directly inside the device. This kind of grab is used to collect sediment ranging from muddy to sandy. The Shipek grab has a bucket which rotates into the sediment when it reaches the sea bottom. It is suitable to collect fine sediments and it can be used even on sloping seabed. The Ekman-Birge grab has a box shape with upper windows and lower jaws, and the smaller type can be operated manually by means of a rod which allows the insertion into the sediment. It is mainly used in shallow water environments with muddy sediments like as lagoons or marshes [9; 10].



Fig. 1. Types of grabs: Van Veen, Shipek and Eckman-Birge (from the left to the right).

Sampling of sediment cores is preferable when it is necessary to reconstruct the environmental history of the study area. Chemical and textural characteristics of sediment cores are important tools to highlight the anthropogenic impact in marine coastal systems, because they preserve the record of sedimentary and chemical input, due both to natural and anthropogenic factors. Deep core levels reflect environmental conditions before the impact and, consequently, they may be used as reference conditions for the assessment of the environmental status [11].

Corers used for environmental purposes must ensure the maintenance of *in situ* conditions of the sediment itself. It is necessary to prevent any kinds of contamination, especially in the lower levels during coring and sub sampling phases; the reworking of sediments and the

destruction of the stratigraphy must also be avoided.

The corers used for the collection of marine sediment are mainly of two types: gravity and vibro corers (Fig. 2). All devices consist of a core barrel, varying in length and diameter, with internal liner used to facilitate the extraction of the core and avoids contamination of the sediment due to the transfer of heavy metals from the core barrel; it also prevents the downward drag of any contaminants during the extrusion of the core.

The gravity corer is equipped at the head with dead weight, variable depending on the number of lead ring masses, which provides the kinetic energy needed to penetrate sediments. A flap valve, at the barrel top, allows water to escape during coring, but it is closed during pullout, ascent and recovery, to prevent sediment being washed out. A sharp cutting edge, at the end of the barrel, bears the core catcher, necessary to hold the core during the ascent. The length of the core barrel can generally vary between 2 and 6 meters. A wide variety of gravity corers is available; among these some models, such as the Kulleberg one, may be equipped with dead weight up to 1000 kg, which allows deep sediment penetration, but determine some disturbance, mainly in upper layer and mostly at the water sediment interface. These heavy devices have the disadvantage to need a substantial secondary apparatus due to the difficulty of handling [12]. On the other hand, the SW-104 bear lower weight at the head (up to 90 kg) and penetrates sediments with scarce disturbance, preserving the water sediment interface, also thanks to the wider core diameter. Nevertheless, the short core barrel allows the recovery of cores not longer than 135 cm [13]. All gravity corers are mainly used to sample fine sediment bottoms.

The vibro corer has a structure similar to the gravity one, but it has a different principle for sediment penetration, because it is equipped with an electric-powered mechanical vibrator at the head, which applies thousand of vibrations per minute, to help the penetration of the sharp cutting edge. This corer is able to recover cores from a wide range of sandy sediments [9].

Another category of samplers, the box corer (Fig. 3), is generally used for collecting sub-superficial samples, no more than 30 cm thick, preserving the water-sediment interface. They consist of a stainless steel square box of a variable size and a support frame that stabilizes the sampler on the seabed and ensures the vertical sampling. When the box has penetrated into the sediments by means of iron weights, a scoop cutting the sediment layer and closing the box is released. The large area of sampled sediment allows the recovery of nearly undisturbed samples [13].



Fig. 2. From left to right: Kulleberg, Rossfelder® and SW-104 corer (photo by ISPRA).



Fig. 3. From left to right: box corer (photo by Elena Romano) and multiple corer (<http://osil.com/Home.aspx>).

A more recent type of sampling device is represented by multicorer (Fig. 3). It is a simple corer for collecting multiple samples of undisturbed sediment, including the sediment-water interface. A range of models is available to sample from 4 up to 12 cores in a single deployment. It is widely used for soft sediment sampling in a wide range of environmental applications. The cores are held together by a stainless steel frame. The core tubing (from 300 to 600 mm length) can be manufactured from acrylic, polycarbonate or stainless steel, depending on requirements. The frame is held by a winch that allows a descent and the penetration is due to a hydrostatic damping system that eliminates the typical bow wave. Corer weight range from 88 to 735 kg. During the ascent, samples are sealed, being capped both top and bottom.

### III. GRAIN SIZE ANALYSES

Because the textural characteristics of sediments and their distribution are among the key factors in the marine environmental research, great attention should be given to the accuracy of grain size determination.

The grain size analysis of marine sediments starts with a pretreatment, which is necessary in order to discrete the colloidal aggregates, to eliminate saline content and to remove any organic material. The saline content can be easily removed by immersing the sample in a solution of distilled or natural water and leaving it for at least 24 hours; if necessary, the operation can be repeated [14; 15]. The organic material, adhered to the sediment granules, is usually removed using hydrogen peroxide (30% H<sub>2</sub>O<sub>2</sub>) [16]. Removal of organic material may be necessary to achieve full dispersion of clay and, in sediments with a high organic content (>3%), to avoid organic matter being counted in the total weight of the sample, thereby affecting the grain size distribution [17].

Successively, the separation of coarse (>63 μm) and fine (<63 μm) fraction is carried out by wet sieving.

The coarse fraction can be efficiently characterized by dry sieving through of a set of sieves, whose number and range of coverage depend on the required detail of the granulometric classes that is placed on a vibro-tilting mechanical stirrer. After sieving, the individual dimensional classes are weighed and recorded, and then their relative abundances are calculated. Data obtained from sieving are normally integrated with those of the fine fraction and, if present, of the gravelly fraction.

As regards the analysis of the fine fraction, up to a few decades ago, sedimentation methods such as the pipette or the hydrometer, based on the Stokes law, were used. The analysis, assumes the preparation of a homogeneous sample suspension in a dispersant solution, and subsequent particle sedimentation within a graduated cylinder. The procedure is completely manual and requires a high level of precision and competence of the operator [18]. In the last decades, several new instruments have been developed; they can characterize variable dimensional ranges based on particle electroresistance (e.g. Coulter Counter), photometric techniques (e.g. Microtrac, Malvern Laser Sizer, Coulter LS) or on automated image analysis (QICPIC).

Instruments based on laser diffraction have become one of the most widely used for determining particle size. The speed of analysis and the possibility of using extremely small sample quantities are the strengths of such instruments. Samples can be analyzed either in a liquid suspension or in a dry dispersion. A small, but representative, quantity of sample is crossed by a laser beam, which is deviated of an angle, inversely proportional to the size of the single particle. Although laser diffraction can theoretically be easily applied in a

dimensional range from sand to clay, some studies have shown that it is preferable to limit the analysis to lower granulometric classes [19].

Sedigraph, an instrument which utilizes the X-ray attenuation principle, is another widely used for grain size analysis, in particular for the fine fraction. The analysis is performed through an X-ray beam, suitably collimated in a thin horizontal band that allows to calculate the concentration of particles in the liquid medium, following the principle of the Stokes Law. In practice, it detects the size of the particles according to their sedimentation rate [20].

The problem of comparing grain-size analyses based on different techniques and different physical principles has been discussed by several authors. For example, a detailed comparative study analyzing four sediment samples with ten techniques indicated that, although the trends were generally similar, minor differences between the results of grain size analyses, attributable to different instruments, were observed [21]. Advantages and limitations of two main instruments for grain size analysis for fine fraction (<63 μm) - laser granulometer and X-ray Sedigraph – are reported in Tab. 1.

Table 1. Advantages and limitations of Laser Granulometer (LG) and X-ray Sedigraph (XS).

Instruments	Laser granulometer	X-ray Sedigraph
Advantages	Wide range of measuring (variable depending on the instrument from gravel to clay)	Wide range of measuring (0,1 μm - 300 mm)
	Short analysis times (only few minutes)	Excellent spectrum analysis resolution above 1 μm
	Small amounts of sample	Possibility of serial analysis (using an accessory)
Limitations	Need to make accurate splitting	Long measurement times (25 minutes or more)
	High cost	Relatively high cost
	Greater range of measurements, less accuracy in finer fractions	

#### IV. CLASSIFICATION OF SEDIMENTS

Defining a sediment according to a given classification scale allows to have unique classes with defined limits and also to easily compare different types of sediment. The choice of one among the several existing classifications depends mainly on the purpose of the study and on the type of the studied sediment.

The Wentworth scale defines limits and names of grain size classes (Fig. 4) [22]. Range limits are expressed in phi (φ), which is calculated as follows:

$$\phi = -\log_2 (D/D_0)$$

where D is the diameter of the particle in millimeters and D<sub>0</sub> is a reference diameter, equal to 1 mm [23].

The binary classification of Nota may be used also in case there is no possibility of analyzing the fine fraction [24]. This classification is given by the ratio between sand and mud (silt+clay):

Sand: > 95 %

Muddy sand: sand 95-70%; mud 30-5%

Very sandy mud: sand 70-30%; mud 30-70%

Sandy mud: sand 30-5%, mud 70-95%

Mud: >95%

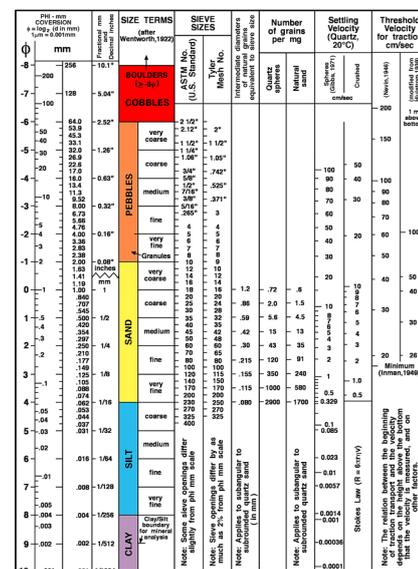


Fig. 4. Wentworth grain size chart from United States Geological Survey Open-File Report 2006-1195.

One of the most commonly used classifications of marine sediments is the Shepard ternary classification [25]. It considers the relative abundance of sand, silt and clay fractions with the identification of 10 sediment classes (Fig. 5).

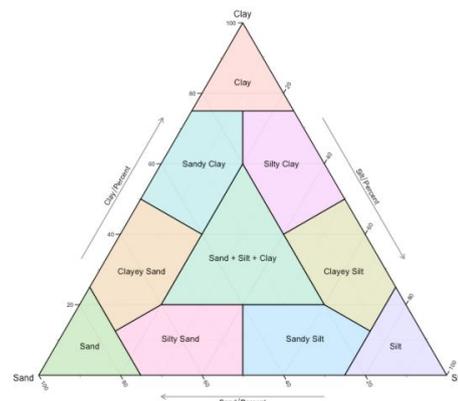


Fig. 5. Shepard ternary diagram.

It is possible to use this diagram even if small percentages of gravel fraction are present. When a large amount of gravel is recorded, the modified Shepard diagram, is preferable. In this ternary diagram the vertices consist of gravel, sand and mud (silt+clay). The use of this classification is recommendable for studies on contamination assessment, because of the great importance of clay mineral for the accumulation of heavy metals and organic compounds.

Also the Folk classification is suitable for gravelly sediments [26] (Fig. 6). The basis of this classification is a triangular diagram on which are plotted the proportions of gravel, sand and mud. Depending on the relative proportions of these three constituents, 15 major textural groups are defined.

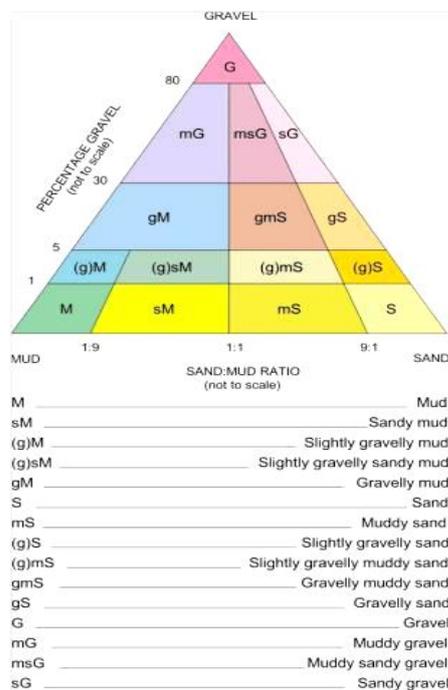


Fig. 6. Folk ternary diagram and nomenclature.

## V. GRAIN SIZE DATA

Data resulted from the analysis of the coarse and fine fraction should be integrated and processed for the determination not only of percentages of the main grain size fractions (sand, silt, clay), but also to reconstruct the frequency and the cumulative curves and to obtain the main statistical parameters defined by Folk and Ward [27].

For each diameter class, the frequency curve expresses its percentage of the total sample. It could have only one (unimodal curve) or more peaks (bimodal or polymodal curves), indicative of the presence of a mixture of different sediments.

The cumulative curve represents the percentage, referring to the total of the sample, of the finest sediment (also referred to as passing) relative to each diameter class. It's a curve growing up to 100%.

In order to compare sedimentary environments with each other quantitatively, it is necessary to calculate measures of average size, sorting, and other frequency distribution properties. These properties may be determined either mathematically by the method of moments or graphically by reading selected percentiles off the cumulative curves [27]. The statistical parameters defined by Folk and Ward are mean size, standard deviation, skewness and kurtosis. Important parameters are also mode, median ( $D_{50}$ ) and other percentiles which are derived from the frequency curve the first and cumulative curve the others.

Different environmental contexts are characterized by a different distribution of statistical parameters. The grain size distribution will depend on the source rock.

Mean size, mode, median and first percentile diameters give us information on transport capacity. In general, more coarse sediments indicate greater energy (higher transport capacity) than the finer sediments.

The standard deviation parameter indicates the selective capacity of the medium of transport. A well-sorted sediment is subjected to a constant selection.

## VI. CONCLUSION

From this methodological review it may be deduced that, in order to obtain the highest accuracy of data, the choice of the most suitable method in sampling, measuring and classifying sediments should be adapted to the specific aim of the study. Especially as regards sampling and sediment analysis, there is not, in absolute an ideal instrument. Type of sediment, sea bottom bathymetry and morphology, necessity of collecting more or less deep sediment layers and the specific aim of the study should be taken into account for sampling. For the grain size analysis the instrument should be selected considering several factors such as type and quantity of available sediment, speed of measurement and reproducibility of the results. Finally, also sediment classification should consider type of analyzed sediment and the availability of silt and clay data.

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