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Grain Size Analysis: A Comparison Between Laser Granulometer and Sedigraph

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***Abstract* – A total of 24 sediment samples from 5 different Italian marine sites (4 from Tyrrhenian Sea and 1 from Adriatic Sea) were analyzed for grain size using two different instruments: Laser Granulometer (LG) and X-ray Sedigraph (XS). The analysis was carried out exclusively on the fine fraction (<63 µm), obtained by dry sieving, in order to compare data results and highlight potential differences. The results show an increase of 15-25% of clay content in the samples analyzed by XS with respect to the ones analyzed by LG. In spite of analyzing the <63 µm fraction, both instruments recorded the presence of variable amount of sand in most samples, with high percentages (up to 53.3% for XS and 30% for LG) in the Bagnoli samples. The different results supplied by the two instruments may be attributed to the different principles of functioning of the two instruments and to the peculiar physical properties of the particles such as shape, density and mineralogical composition.**

I. INTRODUCTION

Grain size is a fundamental feature of marine sediment, because it gives a lot of information about the deposition area, the typology of sediment for a potential reuse (i.e. beach nourishment), the accumulation of pollutants, etc. For this reason it is important to prevent errors that could change the real determination of sediment grain size.

Traditional methods for grain size analysis are generally based on sieving procedure for coarse fractions and sedimentation procedure for fine ones [1]. The different methods for particle size determination generally include direct measurement, dry and wet sieving, settling tube analysis, pipette and laser granulometer, X-ray Sedigraph and Coulter Counter analysis [2]. Each technique is appropriate for a particular range of particle size; for example, sieving is mainly suitable for the analysis of sand and gravel-sized materials (>63 µm), while sedimentation (pipette analysis) is only suitable for the finer fractions (<63 µm). Coulter Counter and Sedigraph are the best suited choice for finer sediments (silt and clay), while some laser granulometer instruments are capable of analyzing a wide range of particle sizes, from clay to sand [2].

Many Authors have studied the differences between analytical procedures by analyzing the same samples with different methods, or simply by comparing them. One of the first Authors to deal with different methods for particle size analysis was Syvitski [3] who made a review of the principles and methods of the main analytical instruments for the determination of sediment grain size. Later, Merkus [4] wrote a guide for a good practice in particle size analysis. Since the 1980s many Authors have dealt with the comparison between well-established methodologies (pipette, Atterberg, etc.) and the new ones such as Sedigraph, Coulter Counter and also Laser Granulometer [5, 6, 7, 8, 9, 10, 11]. Currently, two of the most commonly used instruments for grain size analysis of marine sediments are Laser Granulometer (LG) and X-ray Sedigraph (XS). These instruments work using different physical principles and measuring different physical characteristics of sediment particles.

The purpose of this work is to compare the raw results of analysis of fine fractions (<63 µm) of sediments from different Italian marine sites (4 from Tyrrhenian Sea and 1 from Adriatic Sea), carried out by Laser Granulometer and X-ray Sedigraph, trying to explain the different results on the base of operation principles and sediment characteristics.

II. MATERIALS AND METHODS

A total of 24 superficial sediment samples were collected by van Veen grab in 5 different marine sites along the Italian coast: Montalto, Torvaianica, Gaeta and Bagnoli on the Tyrrhenian continental shelf, and San Benedetto del Tronto on the Adriatic continental shelf (Fig. 1). These areas are characterized by different types of sediments both from grain size and compositional point of view.

The sediments in front of Montalto range from silty/clay sand, to loam, to silty clay as the distance from the coast increases [12] and they are predominantly constituted by quartz feldspar, with abundant volcanic fraction [13].

Sediments along the Torvaianica coast consist of coarse sand, at low depths, and sand, sandy silt and clay offshore; the composition is mainly carbonate, with quartz, k-feldspar and poor volcanic fraction [13].

The continental shelf in front of Gaeta is characterized by widely variable deposits, mostly consisting of silty clayey sediments, with a composition almost exclusively characterized by quartz, feldspars and carbonate particles [13].

In the Bagnoli area, sediments are characterized by fine and coarse sand close to the coastline (up to 15-20 m in depth), sand and sandy silt in the slope area (25-95 m), and clayey silt in the deepest areas of the gulf [14]. Sediments composition is volcanic with an important anthropic contribution of metal particles.

In San Benedetto del Tronto site, the collected samples were taken at about 30 km offshore, on a regular sea bottom characterized by mostly fine sediments. Their composition is mainly terrigenous with presence of carbonate bioclastic fraction and k-feldspar [15].

Fig. 1. Sampling sites.

All samples were pre-treated with a solution of hydrogen peroxide (30%) and distilled water in ratio 1:4 for 48 hours to remove the organic fraction. Then, they were washed twice with distilled water to remove salts.

Each sample was then wet separated into two grain size fractions using a 63 μm mesh sieve.

In order to take a representative aliquot, the fine fraction (<63 μm) was accurately dry splitted. For each analyses, by LG and XS, a total of 2.5 g of sediment sample were taken and suspending in 80 mL of distilled water and sodium hexametaphosphate solution (Fig. 2). Only one analyses for each sample was carried out. XS used as average density 2.510 g/cm^3.

In this paper only the analytical results of fine fraction (<63 μm) are discussed.

The high surface-volume ratio of platy particles of clay creates interparticle attractive forces. The consequence is the predisposition to agglomeration of the clay particles. Aggregates present a larger target to the optical laser and thus skew the particle distribution towards the larger size fraction [16]. For this reason, the addition of a dispersant and a sonication treatment should reduce the aggregates formation.

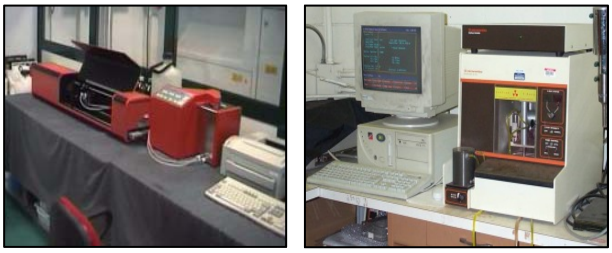

Fig. 2. Laser Granulometer (LG) and X-Ray Sedigraph (XS).

III. WORKING PRINCIPLES OF USED PARTICLE SIZE INSTRUMENTS

For this study, Sympatec Helos Laser Granulometer by FKV and Sedigraph 5100 by Micromeritics were used for the fine fraction analyses.

The first one is based on the principle of laser diffraction method where particles diffract light through a given angle. The diffraction angle is inversely proportional to the particle size, and the intensity of the diffracted beam at any angle is a measure of the number of particles with a specific cross-sectional area in the beam's path [17]. A parallel beam of monochromatic light passes through a suspension contained in a cell and the diffracted light is focused onto detectors. For calculating particle size from light intensity sensed by detectors, two diffraction theories, the Fraunhofer [18] and Mie [19] ones, are used. Both theories assume that all particles have a spherical shape; this means that the particle dimension is represented by the diameter of the sphere having a cross-section area equivalent to the measured ones by laser diffraction [11].

It calculate the grain size in terms of an equivalent volume diameter.

The analysis of Sedigraph is performed by means of a 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 Stokes Law [20]. It states that the terminal settling velocity of a spherical particle in a fluid medium is function of its diameter. It detects the size of the particles according to their sedimentation rate [21]. This technique calculate the grain size in terms of an equivalent sedimentation diameter, i.e. the diameter of a sphere settling with the same velocity as that of the particle.

Because of the different physical principle of these instruments, it is important to take into account that LG data are calculated as volume percentage while XS as mass percentages.

IV. RESULTS AND DISCUSSIONS

The percentage of sand, silt and clay fractions, together with some of the main statistical parameters of all analyzed samples are reported in Tab. 1.

The clay percentage determined using XS is always higher than LG while, at the same time, the silt content has an opposite trend (Figs. 3 and 4). This is due to the clay fraction of marine sediments that consists mainly of clay mineral that are platy; consequently, their optical diameter, measured by LG, is greater than the equivalent spherical diameter [10].

In general, the non-spherical shape of the particles influences both working principles of instruments. In sedimentation the most stable position of a settling non-spherical particle is that in which the maximum cross-sectional area is perpendicular to the direction of motion. This position increases the particle drag and decrease the settling velocity. Thus, the fine size fraction is overestimated [17]. Laser diffraction is also affected by the particle shape. The projected cross-sectional area of a non-spherical particle, averaged over all the particle's possible orientations relative to the direction of the beam is larger than that of a sphere with an equal volume. This could assign a particle to a grain size class greater than what it would have according to its apparent radius, shifting the distribution toward its coarser fraction [17].

Although only <63 μm fraction was analyzed, a variable percentage of sand was recorded in most samples by both the instruments (Fig. 5). It was generally low, with the exception of Bagnoli samples.

The presence of sand in analyzed fine fraction can be due to these factors. In LG the shape of particles, which considerably differs from the spherical shape, may deviate the monochromatic light of the laser granulometer and its real dimensions become overestimated; while in XS, the particles with higher or lower density than the average density taken as a reference, may settle faster or slower, respectively, within the analysis cell. These differences also clearly affect the values of the Average Diameter (Mz) estimated by the two instruments.

The effect of density for XS analysis is complicated because a sediment sample is composed of a mixtures of particles of differing densities [3].

It is also possible that aggregates of smaller particles are detected as sand, although pretreatment, ultrasounds and dispersant should reduce their formation.

In particular, the Bagnoli samples which recorded sand content up to 30% for LG and 53.3% for XS, may be attributed to the particular compositional and morphological characteristics of the particles. In XS, this is due to the presence of volcanic heavy minerals and anthropogenic metal grains, resulting from the waste of the nearby steel plant; while, in LG the sand is probably detected due to the non-spherical shape of particles, above all the anthropogenic particles constituted by iron scoria. Indeed, in the sediments of Montalto, with no anthropogenic contributions, but with strong compositional analogies with those of Bagnoli site (vulcanoclastic sediments), the overhang worked by the instrument is completely irrelevant.

Table 1. Sand, silt, clay percentages and statistical parameters in sediment fraction passed at 63 μm sieve by XS and LG analyses.

Site	Sample code	Sand (%)		Silt (%)		Clay (%)		M_z (ϕ)		σ_1 (ϕ)		Skewness	
		XS	LG	XS	LG	XS	LG	XS	LG	XS	LG	XS	LG
Montalto	MTZ 30	3.0	4.9	50.6	68.8	46.4	26.4	8.1	6.5	2.7	1.9	0.1	0.2
	MTZ 40	2.1	1.7	44.6	65.7	53.3	32.6	8.5	7.0	2.5	1.8	0.0	0.0
	MTZ 50	2.2	0.1	38.5	56.1	59.3	43.8	8.9	7.6	2.3	1.6	0.0	-0.2
	MTZ 60	3.4	0.0	36.6	56.6	60.1	43.4	8.8	7.6	2.0	1.5	-0.1	-0.1
Torvaianica	TVF 20	2.6	6.5	48.8	69.2	48.6	24.3	8.3	6.5	2.6	1.9	0.1	0.1
	TVF 40	4.7	9.6	59.5	72.2	35.8	18.2	7.5	6.0	2.7	1.8	0.3	0.3
	TVF 60	0.0	1.1	56.3	69.5	43.7	29.4	8.2	6.9	2.5	1.7	0.3	0.1
	TVF 90	0.0	0.0	31.4	53.0	68.6	47.0	9.2	7.8	2.0	1.3	-0.1	-0.1
	TVF 110	2.4	0.0	27.2	56.2	70.5	43.8	9.4	7.7	2.0	1.3	-0.1	-0.1
Bagnoli	BE 13	48.4	24.2	44.8	69.3	6.7	6.5	4.3	4.9	1.4	1.3	0.5	0.6
	BE 22	53.3	30.0	39.9	66.8	6.8	3.2	3.9	4.4	1.3	0.9	0.9	0.4
	BE 23	50.5	27.8	42.2	67.2	7.3	5.1	4.1	4.7	1.4	1.2	0.8	0.6
	BE 24	30.8	23.7	53.1	71.1	16.1	5.2	5.3	4.8	2.4	1.2	0.6	0.5
	BE 25	28.6	23.6	60.2	70.8	11.2	5.6	4.9	4.8	1.9	1.3	0.5	0.5
Gaeta	GTE 20	4.5	14.8	57.2	65.1	38.3	20.1	7.4	5.9	2.8	1.9	0.3	0.4
	GTE 30	1.4	8.2	63.6	78.3	35.0	13.4	7.4	5.6	2.6	1.7	0.5	0.5
	GTE 40	2.0	3.1	58.8	73.9	39.2	22.9	7.8	6.4	2.7	1.8	0.4	0.2
	GTE 60	0.0	0.0	38.7	63.3	61.3	36.7	9.0	7.4	2.2	1.5	0.0	0.0
	GTE 70	5.2	0.0	35.2	54.2	59.6	45.8	8.8	7.7	2.5	1.4	-0.1	-0.1
San Benedetto del Tronto	A 2	1.3	0.0	27.0	51.2	71.7	48.8	9.4	7.9	1.9	1.3	0.0	-0.1
	A 11	2.2	0.0	27.8	53.1	70.0	46.9	9.3	7.8	1.9	1.3	0.0	-0.1
	B 2	0.9	0.0	29.1	52.8	70.0	47.2	9.3	7.8	1.9	1.3	0.0	-0.1
	C 1	0.3	0.0	29.6	53.0	70.1	47.0	9.3	7.8	1.9	1.3	0.0	-0.1
	K 1	0.4	0.0	31.1	55.6	68.5	44.4	9.3	7.8	1.9	1.3	0.0	-0.1

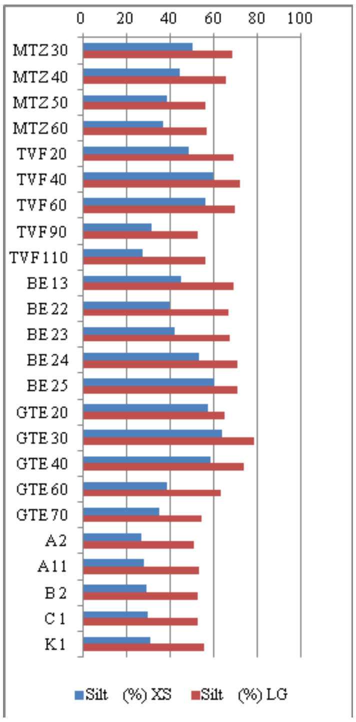

Fig. 3. Percentage of silt detected by XS and LG in the sediment fraction passed at 63 μm sieve.

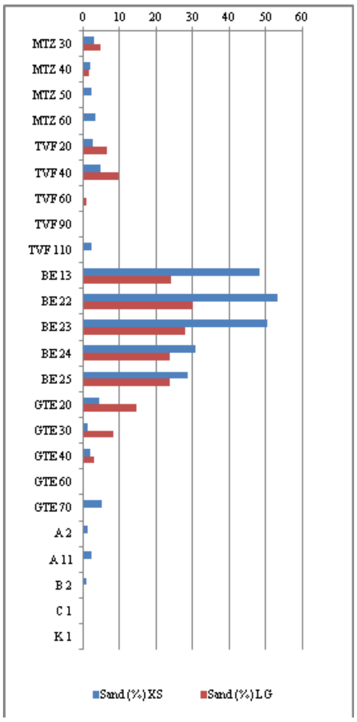

Fig. 5. Percentage of sand detected by XS and LG in the sediment fraction passed at 63 μm sieve.

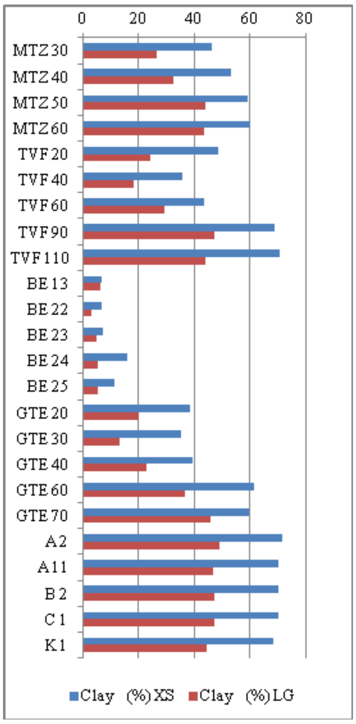

Fig. 4. Percentage of clay detected by XS and LG in the sediment fraction passed at 63 μm sieve.

V. CONCLUSIONS

In this study, the analytical data detected the unexpected presence of sand in samples sieved at 63 μm. This can be explained by considering the physical principles upon which the XS and LG instruments are based. The differences in the results can also be attributed to the peculiar physical properties, shape, density and composition of the analyzed sediment particles. Moreover, another factor that could affect the detection of sand is the formation of smaller particle aggregates. In the Bagnoli samples sand is too high to be justify by aggregates only.

The clay fraction is always lower in the LG analysis because this instrument underestimates this fraction due to the platy shape of the clay minerals.

This study indicates that results of the <63 μm fraction, obtained both by XS and LG, should be regarded taking into account the mineralogical and compositional characteristics of sediment.

Starting from these results, more in-depth studies are needed. Above all, it is necessary to verify how factors such as density and shape can influence the instrumental particle size analysis.

Some recommendation for future works could be adjust the density of media solution for XS analysis and prevent aggregates formation both XS and LG analysis.

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VII. REFERENCES

[1] D.Goossens, "Techniques to measure grain size distributions of loamy sediments: a comparative study of ten instruments for wet analysis", Sedimentology, vol. 55, 2008, pp. 65-96.

[2] K.Pye, S.J.Blott, "Particle size analysis of sediments, soils and related particulate materials for forensic purposes using laser granulometry", Forensic Sci. Int., vol. 144, 2004, pp. 19-27.

[3] J.P.M.Syvitski, "Principles, methods, and application of particle size analysis", New York, Cambridge University Press, 1991.

[4] H.G.Merkus, "Particle size measurements. Fundamentals, practice, quality", Springer Particle Technology Series, vol. 17, 2009.

[5] G.F.Coates, C.A.Hulse, "A comparison of four methods of size analysis of fine grained sediments", New Zeal. J. Geol. Geop., vol. 28, 1985, pp. 369-380.

[6] R.Stein, "Rapid grain-size analysis of clay and silt fraction by Sedigraph 5000D: comparison with Coulter Counter and Atterberg methods", J. Sed. Petr., vol. 55, no. 4, 1985, pp. 590-615.

[7] L.Beuselinck, G.Govers, J.Poesen, G.Degraer, L.Froyen, "Grain-size analysis by laser diffractometry: comparison with the sieve-pipette method", Catena, vol. 32, 1998, pp. 193-208.

[8] E.Molinaroli, G.DeFalco, S.Rabitti, R.A.Portaro, "Strea,-scanning laser system, electic sensing counter and settling grain size analysis: a comparison using reference materials and marine sediments", Sed. Geol., vol. 130, 2000, pp. 269-281.

[9] P.Buurman, Th.Pape, J.A.Rejneveld, F.deJong, E.vanGelder, "Laser-diffraction and pipette-method grain sizing of Dutch sediments: correlations for fine fractions of marine, fluvial and loess samples", Geol. Mijnb., vol. 80, no. 2, 2001, pp. 49-57.

[10] V.Ramaswamy, P.S.Rao, "Grain size analysis of sediments from the northern Andaman Sea: Comparison of laser diffraction and sieve-pipette techniques", J. Coast. Res, vol. 22, No. 4, 2006, pp. 1000-1009.

[11] C.DiStefano, V.Ferro, S.Mirabile, "Comparison between grain-size analyses using laser diffraction and sedimentation methods", Biosyst. Eng., vol. 106, 2010, pp. 205-215.

[12] ICRAM, "Studio per l'impatto ambientale connesso allo sfruttamento di depositi sabbiosi sommersi ai fini di ripascimento lungo la piattaforma continentale laziale - area Montalto di Castro (VT)" Relazione tecnica, 2002.

[13] G.Gandolfi, L.Paganelli, "Petrografia delle sabbie del litorale tirrenico fra i monti dell'Uccellina e Monte di Procida", Miner. Petrogr. Acta, vol. 28, 1984, pp. 173-191.

[14] P.Colantoni, M.Del Monte, A.Fabbri, P.Gallignani, R.Selli, L.Tomadin, "Ricerche geologiche nel Golfo di Pozzuoli", CNR, Quaderni de "La Ricerca Scientifica", vol. 83, pp. 26-76.

[15] A.Brambati, M.Ciabatti, G.P.Fanzutti, F.Marabini, R.Marocco, "Carta sedimentologica dell'Adriatico Settentrionale", Istituto Geografico De Agostini - Officine Grafiche, Novara, 1988.

[16] M.Sperazza, J.N.Moore, M.S.Hendrix, "High-resolution particle size analysis of naturally occurring very fine-grained sediment through laser diffractometry", J. Sed. Res., vol. 74, no. 5, 2004, pp. 736-743.

[17] G.Eshel, G.J.Levy, U.Mingelgrin, M.J.Singer, "Critical evaluation of the use of laser diffraction for particle-size distribution analysis", Soil Sci. Soc. Am. J., vol. 68, 2004, pp. 736-743.

[18] J.Fraunhofer, "Bestimmung des Brechungs - und des Farbenzerstreungs - Vermögens verschiedener Glasarten, in Bezug auf die Vervollkommnung achromatischer Fernröhre", Annalen der Physik, 56-3, 264, 1817.

[19] G.Mie, "Beitrage zur Optik truber Medien, speziell kolloidaler Metallosungen" Ann. Physics, 25, 3, 377, 1908.

[20] G.G.Stokes, "On the effect of the internal friction of fluids on the motion of pendulums", Trans. Cambridge Phil. Soc., Math. Phys. Papers, IX, 8–106, 1851, vol. 3, pp. 1–141.

[21] P.A.Webb, "The perseverance of the Sedigraph method of particle sizing", Micromeritics, 2004.