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# MINERALOGY OF SILT AND CLAY FRACTIONS IN THE SURFICIAL SEDIMENTS OF THE GRADO LAGOON (NORTHERN ADRIATIC SEA) $^{\ast}$

# COMPOSIZIONE MINERALOGICA DELLA FRAZIONE SILTOSA E ARGILLOSA DEI FON-DALI DELLA LAGUNA DI GRADO (ADRIATICO SETTENTRIONALE)

**Abstract** - The composition of detrital and clay minerals in the tidal flats of the Grado Lagoon was determined by X-ray diffraction. The spatial distribution of minerals in silt and clay fractions of the surface sediments shown a higher contents of detrital minerals, a marine source and a selective sedimentation inside the lagoonal basins. A prevalence of dolomite over calcite are observed and a geographic gradient of calcite (maximum contents eastwards - minimum westwards) are found.

Key words: Mineralogy, Silt-clay fractions, Grado Lagoon.

Riassunto breve - La caratterizzazione mineralogica dei depositi pelitici (siltosi e argillosi) della laguna di Grado evidenzia una composizione essenzialmente detritica del sedimento, una sua provenienza dal mare e una sedimentazione selettiva all'interno dei bacini lagunari. Emerge inoltre una netta prevalenza della dolomite sulla calcite e, in particolare, l'esistenza di un gradiente geografico della calcite con massimi contenuti ad Est e minimi ad Ovest.

Parole chiave: Mineralogia, Silt-argilla, Laguna di Grado.

## Introduction

The distribution of minerals in the lagoonal sediments can be used to investigate the sedimentation processes occurring in these tide-dominated environments. In particular, clay minerals in the clay-sized fraction of sediment are transported and uniformly kept in suspension by the tidal currents and settle when the residual currents are weaker (Dronkers & Zimmerman, 1982).

Furthermore, with some rare exceptions, they do not undergo significant chemical and mineralogic changes during transport and after sedimentation. For these reasons they may be seen as excellent natural useful tracers to identify sedimentary inputs into the lagoonal basins.

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The aim of this work is to determine the mineral compositions of the easternmost lagoon of the northern Adriatic Sea (Grado and Marano Lagoons) in order to:

- i) complete the study on the source of the deposits of the Friuli lagoons carried out by Brambati (1972);
- ii) investigate the distribution and dispersal pattern of pelitic sediments in the tidal environment and make a distinction between the characteristics of detrital minerals and clay minerals in the silt and clay fractions of surface sediment.

# **Environmental setting**<sup>(1)</sup>

The Grado lagoon (fig. la) is the easternmost part of the lagoon system of Friuli - Venezia Giulia, which represents the easternmost end of the Venetian lagoon system (Venice - Caorle - Marano and Grado lagoons). It extends for about 75.5 km² (5 km width and 16 km length), 18% of which is occupied by areas above mean sea-level (insels and marshes; 4%) and enclosed areas (fishing farms, 14%). The remaining area (with average depths of less than 1 metre) include tidal flats (about 75% of the lagoon basins), the dense network of lagoon channels (about 16% of the basins) and subtidal floor ("basin 1.s.": about 9% of the lagoonal floors).

The tide has a semidiurnal character with maximum spring range of about  $105~\rm cm$  and minimum neap range of about  $20~\rm cm$ .

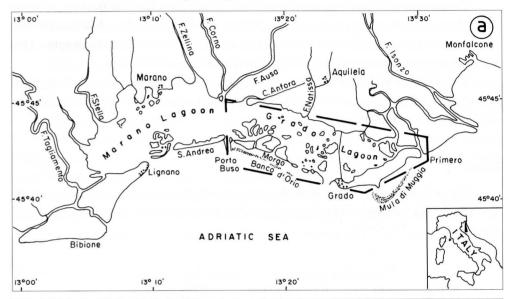
The lagoon sediments are essentially sand seawards and progressively increasing the pelite content towards the inner basins (Brambati, 1969; Marocco, 1995). Brambati (1972) showed that the clay association present in the Marano and Grado lagoons was illite > chlorite > kaolinite. Furthermore, in the Marano Lagoon small percentages of smectite were also found. Considering that the supplies of tributary rivers to the lagoon are relatively scarse and that those clays are more abundant in a marine environment, the author suggested that the clays are mainly of marine origin and that they are transported to the lagoon by tidal currents.

By extending the area of investigation to the northern Adriatic sea and, in particular, to the Gulf of Trieste (Brambati, 1968; Mantovan et al., 1985; Ogorelec et al., 1991), the finest sediments are made up of clay minerals such as illite, kaolinite, chlorite, mixed layers and smectite and by detrital minerals including quartz and feldspars, and especially dolomite and calcite, with the former mineral prevailing over the latter in the western sector of the basin and, viceversa, in the eastern sector. The circumlagoonal soils are basically silt and sand-sized and are characterized by high concentrations of carbonates with the calcitic component (60%) prevailing over the dolomitic one (20%) (Brambati, 1970).

### Materials and methods

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The surficial sediments of the Grado Lagoon were sampled in 16 stations (figg. 1a and 1b) located only in tidal flat and "basin" (deeper lagoon-floor) in order to concentrate the attention on the areas of accumulation of suspended sediments. Analogous sampling were carried out in 13 stations site in the Marano Lagoon (fig. 1a).



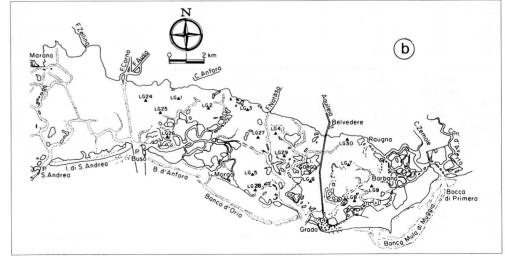


Fig. 1 - a) Map of Marano and Grado Lagoons and study area. b) Location of bottom samples.

- a) Localizzazione della Laguna di Grado e Marano e dell'area in esame. b) Ubicazione dei campioni di sedimento.

<sup>1)</sup> For a more detailed description of the lagoon environment, see Dorigo, 1965; Brambati, 1969; 1970; 1972; 1974; Brambati et al., 1983; Marocco et al., 1984; Marocco, 1989; 1991 a; 1991 b; Gatto & Marocco, 1992; 1993; Marocco, 1995.

Sediments were collected in October 1991, by means of a grab, only in the areas not covered by halophyte vegetation. The most surficial part of the sampled sediment (on average 5 cm thikness) was subsampled and mineralogical analyses were carried out by X-ray diffraction. Analyses were performed on two grain size fractions separated by standard pipette method: the 50-  $4 \, \mu m$  fraction (silt) and the  $< 4 \mu m$  one (clay).

The mineralogical analyses were carried out on both granulometric fractions by using oriented preparations, with a scanning angle (2  $\theta$ ) between 2° and 40°. The < 4 $\mu$ m fraction were also analysed after glycolation (60°C, for 24 h) in the range a 2°-14° (2  $\theta$ ). The samples of the Marano Lagoon was performed only on the < 4 $\mu$ m fractions (see Table I).

The qualitative analysis of clay minerals was carried out according to the method suggested by Carrol (1970) and Thorez (1975). The semi-quantitative estimation of clay minerals was obtained following the Schultz's (1964) method.

## Results

Clay minerals found in the sediments collected in the floor of the Grado Lagoon include illite, chlorite and kaolinite in decreasing order of abundance. Smectite is absent, or in negligible quantities.

		CDAD	0.1.4600	N _Silt_size fr	action of the s	sediment		
	detrital	clay	Il	Cl+Kaol	Qz	Feld	Cal	Dol
	minerals	minerals	0	6	46	10	19	44
max	94	13	8 3	3	28	4	10	24
min	87	6 9	5	4	36	6	15	34
mean s.d.	91	2.2	1.7	0.8	5.9	1.8	2.6	5.9
0.4.		GRADO	LAGOO!	N - Clay-size	fraction of the	sediment		
	detrital	clay	I1	Cl Kaol	Qz	Feld	Cal	Dol
	minerals	minerals				0	24	24
max	76	52	31	12 11	44	9		12
min	48	24	13	5 5	23	0	0	16
mean	64	36	21	8 7	33	5	9	
s.d.	8.9	8.9	6.1	2.1 1.8	6.1	2.1	6.3	3.2
		MARAN	O LAGO	ON - Clay-size	e fraction of th	e sediment		
	detrital	clay						
	minerals	minerals						
max	56	75						
min	25	24						
mean	46	54						
s.d.	12.1	12.1						

Tab. I - Comparison between the mineralogic composition of the silt and clay fractions of the Grado Lagoon sediments.

In order of frequency detrital minerals are mainly given by quartz, dolomite, calcite, and feldspars. Table I reports the elementar statistical parameter of the detrital and clay minerals in the silt (50-4 $\mu$ m) and clay (< 4  $\mu$ m) fractions of the sediment. It shows as follows:

- a very small variation of the percentages of the single minerals. Except for calcite, that shows an geographic increase eastward, where maximum contents are related to Isonzo River supplies (Brambati, 1969; Marocco, 1995), the other minerals are quite homogeneous within the lagoon floor;
- ii) both the silt and the clay fractions show a prevalence of detrital minerals over clays. The detrital minerals average in the silt-sized fraction is about 90%, while in the clay fractions is about 64%. Student's t-test was performed to compare the silt and clay fractions content in the floor of Grado Lagoon. The silt and clay fractions are clearly distinct on the mineralogical basis (p<0.001) except for quartz and feldspars.

Table I shows that when mean size of the pelitic sediments decreases the clay minerals (illite, chlorite and kaolinite) increase, thus compensating dolomite and calcite decrease. On the contrary, quartz and feldspar remain virtually constant.

The comparison between the clay-sized fraction of the Grado and the Marano Lagoons shows that the Grado clay minerals are less abundant than the Marano ones (Student's t-test: p < 0.001). These data are in agreement with those reported by Brambati (1972).

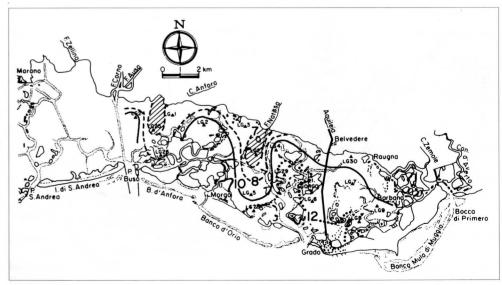


Fig. 2 - The Grado Lagoon: areal distribution of detrital/clay minerals ratio of silt-sized particles of sediments.

 Laguna di Grado: distribuzione areale del rapporto minerali detritici/argilla nella frazione siltosa dei sedimenti.

Confronto tra le composizioni mineralogiche delle frazioni siltose e argillose dei sedimenti della Laguna di Grado.

Evidence of the changes in mineral proportion within the lagoon system is provided by the areal distribution of the detrital/clay minerals ratio. It can be observed that the detrital minerals in the silt-sized particles (fig. 2), are fundamentally of marine source and spread into the lagoonal basins through the tidal inlets and related channel network.

The sediments are characterized by abundant quartz and dolomite, less abundant calcite, medium feldspar concentrations and low clay mineral contents.

The same analysis carried out on the clay-sized fraction ( $<4 \,\mu m$ ) of the sediments shows (fig. 3) a lower detrital/clay minerals ratio (ranging 1-3; i.e. a high concentration of clay mineral) than the silt-sized fraction (ranging 7-12). Maximum concentrations of clay minerals are present in the area behind the lagoonal inlets and, viceversa, a high concentrations of detrital minerals (especially quartz) in front of Natissa River.

Finally, the sediments of the eastern part of the lagoon show a geographic gradient of calcite, with maximum contents eastwards and minimum westwards.

#### Discussion and conclusion.

The distribution patterns of the silt and clay fraction minerals of lagoon deposits reflect different sources and transport pathways within the lagoon environment. The silt-sized fraction

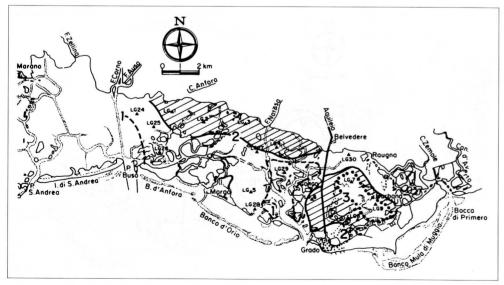


Fig. 2 - The Grado Lagoon: areal distribution of detrital/clay minerals ratio of clay-sized particles of sediments.

 Laguna di Grado: distribuzione areale del rapporto minerali detritici/argilla nella frazione argillosa dei sedimenti. of lagoon deposits essentially comes from the sea and secondarily from the hinterland. It settles in the lagoon following the tidal circulation and the fluvial plume.

The clay-sized fraction of the sediments also enters in the lagoon essentially from the sea, whose floor is covered by clay minerals in greater quantities than that of the lagoon (Mantovan et al., 1985; Ogorelec et al., 1991). It mainly accumulates in the tidal flats connected to the main lagoon channels. The accumulation of clay minerals, however, does not involve the whole canalized area of the lagoon system, but only the basins of Grado, Porto Buso (and Lignano, in the adjacent Marano Lagoon).

The trend of the mineralogical composition of Grado Lagoon-floor (clay-sized fraction) does not significantly differ from that of the adjacent Marano Lagoon, thus testifying the same mechanisms ruling the transport and sedimentation (or re-sedimentation) of pelitic, and especially clay sediments, in both the lagoonal systems.

Nevertheless, one should consider that clays are more abundant in the Marano Lagoon than in the Grado Lagoon. Moreover, in the Marano Lagoon smectite also appears.

As far as the detrital minerals are concernest, it can be observed that quartz and feldspar are virtually constant in the sediments, whereas calcite and dolomite are much more variable either in term of total carbonate contents, or in term of reciprocal proportion. An increase in calcite can be observed going eastwards, which can be explained by considering that calcite and dolomite fundamentally come from tributary rivers and the high percentages of calcite found in the eastern part of the Grado Lagoon are related to the deposits of Isonzo R. channeled into the lagoon by Grado inlet mixed by a paleo-bed of the Isonzo R., which has been abandoned owing to the continuous diversions to the East.

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### References

GAMFSNU 19 (1997)

Brambatt A., 1968 - Mixing and settling of fine terrigenous material (<16µm) in the Northern Adriatic Sea between Venice and Trieste. *St. Trent. Sc. Nat.*, 45: 103-117.

Brambati A., 1969 - Sedimentazione recente nelle Lagune di Marano e di Grado (Adriatico settentrionale). *Studi Trent. Sc. Nat.*, sez. A, XLVI(1): 142-239.

Brambati A., 1970 - Provenienza, trasporto e accumulo dei sedimenti recenti nelle lagune di Marano e Grado e nei litorali tra i fiumi Isonzo e Tagliamento. *Mem. Soc. Geol. It.*, 9: 281-329.

Brambati A., 1972 - Clay mineral investigation in the Marano and Grado lagoons (Northern Adriatic Sea). *Boll. Soc. Geol. It.*, 91: 315-323.

Brambati A., 1974 - Il regime sedimentologico delle spiagge dei Banchi d'Orio. *Mus. Friul. St. Nat.*, 91 pp. Brambati A., Fanzutti G.P. & Marocco R., 1983 - Suspended matter transport in lagoons: the Grado Lagoon. *Boll. Ocean. Teor. Appl.*, 1: 5-18.

CARROL D., 1970 - Clay minerals in Artic Ocean sea-floor sediments. J. Sediment. Petrol., 40: 814-821.
DORIGO L., 1965 - La laguna di Grado e le sue foci. Ricerche e rilievi idrografici. Ufficio Idrografico del Magistrato alle Acque, Pubbl. n. 155, pp. 231, Venezia.

- Dronkers J. & Zimmerman J.T.F., 1982 Some principles of mixing in tidal lagoons. *Oceanologica Acta*, S.P.: 107-117.
- GATTO F. & MAROCCO R., 1992 Caratteri morfologici e antropici della Laguna di Grado (Alto Adriatico). Gortania, Atti Mus. Friul. St. Nat., 14: 19-42.
- Gatto F. & Marocco R., 1993 Morfometria e geometria idraulica dei canali della Laguna di Grado. Geogr. Fis. Dinam. Ouat., 16: 107-120.
- MANTOVAN P., MENEGAZZO VITTURI L., PAVONI B. & RABITTI S., 1985 Sediments and pollution in the Northern Adriatic Sea: a statistical analysis. *Contin. Shelf Res.*, 4: 321-367.
- MAROCCO R., 1989 Lineamenti geomorfologici della costa e dei fondali del Golfo di Trieste e considerazioni sulla loro evoluzione tardo-quaternaria. *Int. J. Speleol.*, 18: 87-110.
- MAROCCO R., 1991a Evoluzione tardo pleistocenica olocenica del delta del F.Tagliamento e delle lagune di Marano e Grado (Golfo di Trieste). *Il Quaternario*, 4: 223-232.
- MAROCCO R., 1991b Le dune di Belvedere San Marco. Una antica linea di riva? 1) Considerazioni geomorfologiche. *Gortania, Atti Mus. Friul. St. Nat.*, 13: 57-76.
- MAROCCO R., 1995 Sediment distribution and dispersal in northern Adriatic lagoon (Marano and Grado paralic system). *Giornale di Geologia*, 57: 77-89.
- MAROCCO R., PUGLIESE N. & STOLFA S., 1984 Some remarks on the origin and evolution of the Grado Lagoon (Northern Adriatic Sea). *Boll. Ocean. Teor. Appl.*, 2: 11-17.
- Ororelec B., Misis M. & Faganelli J., 1991 Marine geology of the Gulf of Trieste (Northern Adriatic): sedimentological aspects. *Mar. Geol.*, 99: 79-92.
- Schultz L.G., 1964 Quantitative interpretation of mineralogical composition from X-ray and chemical data for the Pierre Shale. *U.S. Geol. Surv. Prof. Papier.*, 391-C: 1-31.
- THOREZ J., 1975 Phyllosilicates and clay mineral. Ed. G. Lelotte, Dison, pp. 579.

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