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EVIDENCES OF CLIMATIC VARIATIONS IN UPPER PLEISTOCENE AND HOLOCENE SEDIMENTS FROM THE LAGOON OF VENICE (ITALY) AND THE YELLOW SEA (CHINA)

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SUMMARY

The effects of global climatic changes that occurred since the last Quaternary glaciation are recognizable in the stratigraphic sequences from several coastal zones in different locations around the world. The paleoevolution of the Northern Adriatic Sea and the Yellow Sea during the last 25,000 years has been characterized by several similar episodes of climatic changes. We report on the effects of climatic changes on the mineralogical composition and textural characteristics of clay and sand sedimentations in these paleoenvironments that are geographically far apart, correlating regional paleoclimatic changes with the mineralogical composition variations of sand and clay sequences. The mineralogical investigation has evidenced an increase of Quartz and Feldspar percentages and a decrease of Calcite and Dolomite during colder periods.

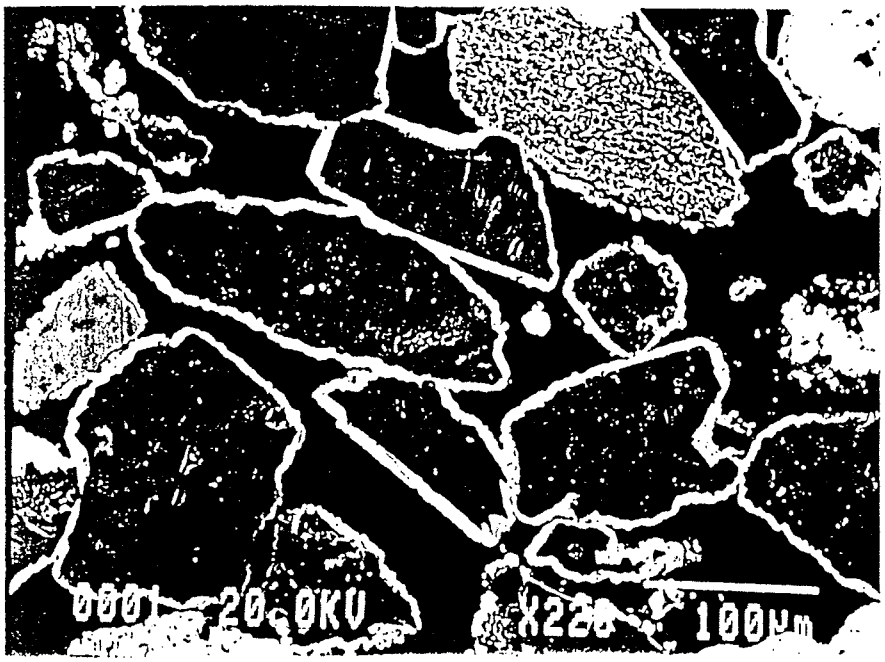
Two depositional events, the hard clay layers and the cemented sand formations, that carry the imprints of the climatic conditions during their diagenesis are here reported and described. The hard clay layers represent the last continental sedimentation deposited during the Upper Pleistocene. The compactness of these clay layers is probably due to a long exposure to a cold and very dry climate. The water inside cemented sands studied were found under and outside of the Venice Lagoon and are similar to the beachrock formations presently found in tropical regions in intertidal zones. These cemented sands are remnants of ancient shorelines and witnesses of warm climate events.

INTRODUCTION

To fully understand the present global climatic changes requires a better knowledge of the climatic variations that took place in the past, in the thousand year scale, and their environmental impact.

The paleoevolution of the Northern Adriatic Sea and the Northern China Sea during the last 25,000 years has been characterized by several

Photo 1 Cemented sand formation from the Venice Lagoon: Calcite cement crust on detrital Dolomite grains. Backscattered electron (BSE) image.

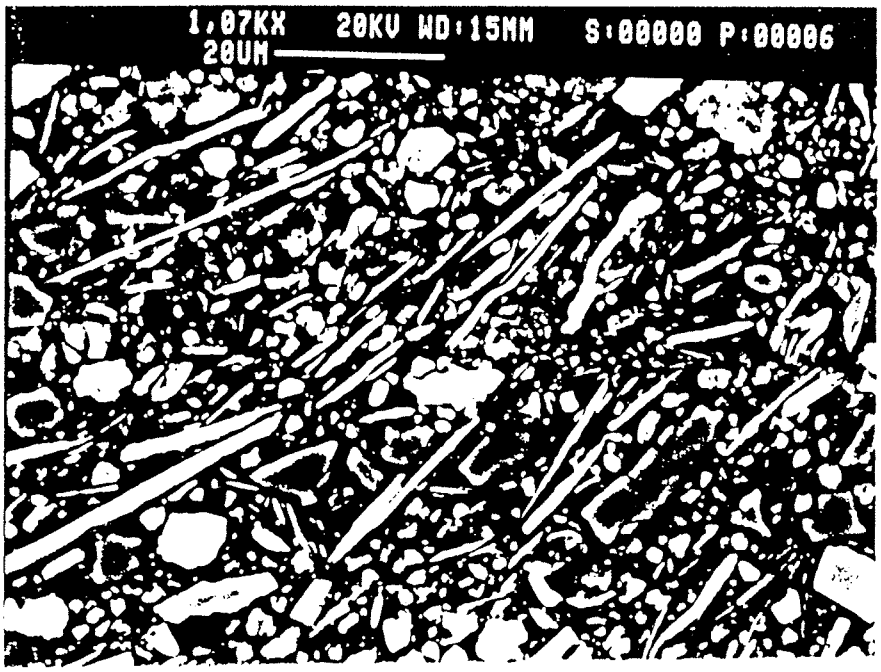


similar episodes related to climatic changes.

During the Last Würmian glaciation about 25,000-17,000 years B.P, when the climate varied from cold and dry to cold and very dry, the Adriatic sea level was about 90 to 130 m lower than present and the coastline was about 300 km further South. Similarly the sea level of the Northern China Sea (Yellow and Bohai seas) was 130 to 150 m lower than present with the coast line extended about 600 km further east. The very dry climate during a period of no sedimentation and a long subaerial exposition, desiccated, compacted and oxidized the Upper Pleistocene clay layer previously deposited, to form the overconsolidated clay level representative of the Holocene/Pleistocene boundary.

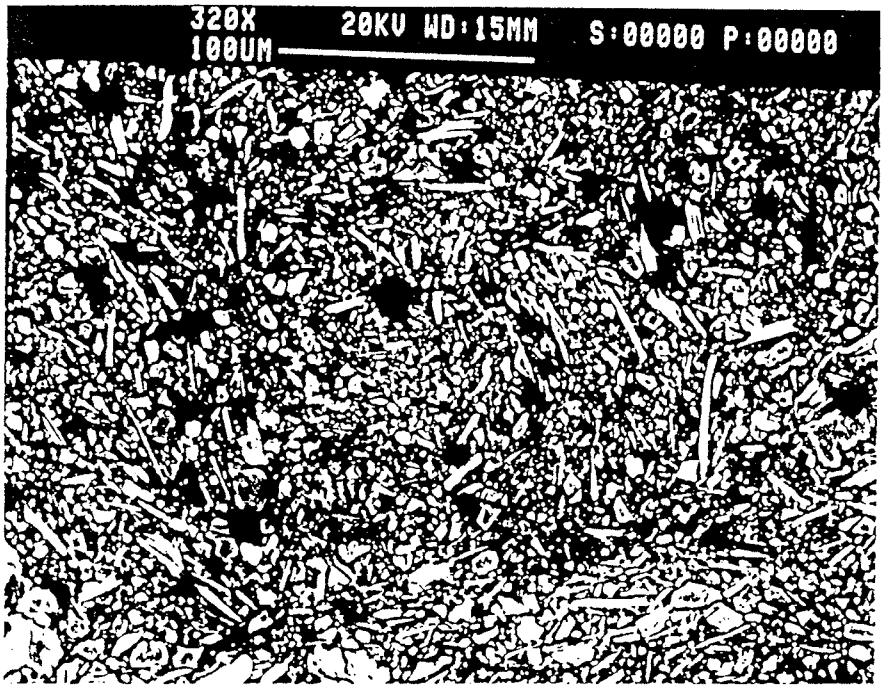
During the Late Glacial period, from 17,000 to 10,000 years B.P., characterized by a lack of sedimentation, the temperature and the humidity slightly rose with alternating colder events (16,000, 12,500, 10,800 years B.P.).

Photo 2 Preferred parallel orientation of phyllosilicates (needle-like grains) in the hard clay layers underlying the Venice Lagoon (BSE image).



The postglacial period that started about 10,000 years B.P. was characterized by an increase of the temperature with alternating periods of dry and humid climate conditions. During the early phase of this period, the increase of the temperature and the dry climate caused the melting of the glacial and the sea level to rise over the Würmian paleoplain, the Upper Pleistocene continental sediments were partly eroded, reworked and dispersed by the intense fluvial activity. At the maximum temperature (hot and humid climate), about 6-7,000 years B.P., the coast line that moved northwards, reached approximately the present position in the Venetian basin, but up to 150 km inland in the Northern China Sea. After the climate optimum, with a general decrease in temperature and increase in humidity, the heavy sediment load carried by the rivers and controlled by the climatic variations, caused, in both locations but at different rates and scales, the prograding of the river estuaries and the coastal lines moved gradually towards the sea to reach their present positions.

Photo 3 Preferred circular orientation of phyllosilicates (needle-like grains) in the hard clay layers underlying the Venice Lagoon (BSE image).



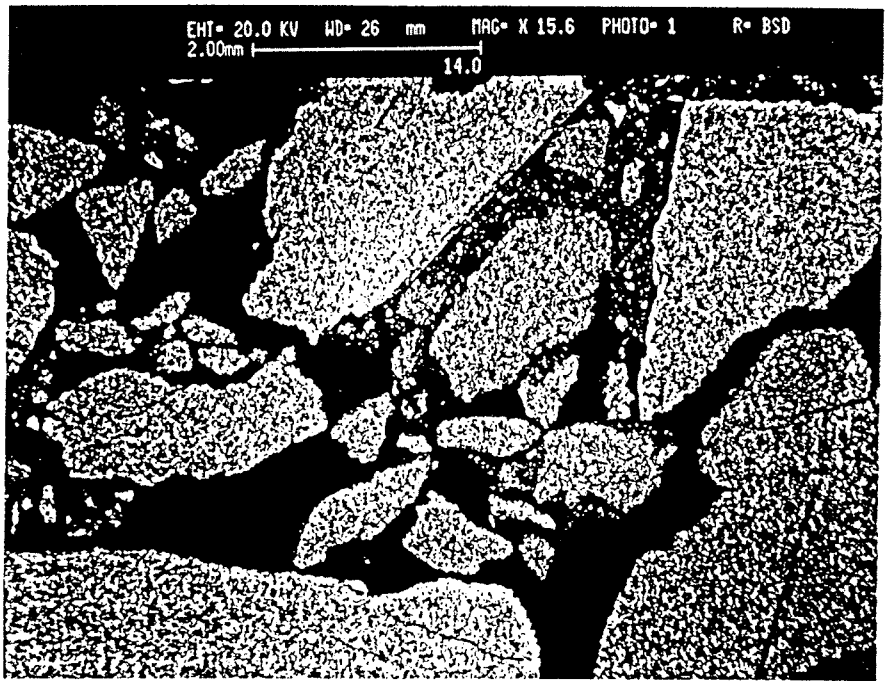
Evidences of paleocoastal lines movements during the Late Holocene, are the intertidal cemented sand formations found inside and outside the Lagoon of Venice. These sands of backshore deposition exposed and affected to fresh water seepage are cemented by carbonates precipitation.

MATERIALS AND METHODS

The mineralogical composition of twenty-one sand samples underlying the Venetian littoral was obtained using an Electron Microprobe (EPMA) equipped with a Backscattered Detector (BSD) and an Energy Dispersion Spectrometer (EDS).

The fifty-five clay and clayey silt samples taken from a 6 m-long core in 70 m of water in the Yellow Sea and the twenty-one samples taken from a 30 m-long core, in the Yangtze River Delta were analyzed using X-Ray

Photo 4 Low consolidation of a Holocene marine paleoenvironment clay layer from the Yangtze River Delta (BSE image).



Diffraction (XRD) (Bonardi and Tosi, 1994a, 1994b).

Photos of cemented sand formations and clay layer samples were taken using Scanning Electron Microscope (SEM) equipped with EDS and Backscattered electron (BSE) imaging.

Radiocarbon age and paleoclimatic data are from the available literature (Fairbrige, 1971; Bortolami, et al., 1977; Congxian, 1984; Veggiani, 1994; Ortolani and Pagliuca, 1994; Congxiang, et al., 1985; Gatto and Carbognin, 1981; Wamg, 1988; Marabini and Veggiani, 1991; Yang and Lin, 1991; Tosi, 1994a; Zang, et al., 1995).

CASE STUDIES

Some examples of the effects of the major climatic changes during the Upper Pleistocene and Holocene recognizable in the sedimentary sequences from the Northern Adriatic Sea and the Northern Yellow Sea are given.

The case study of the Northern Adriatic Sea is the Venice Lagoon where examples of sand sequences, hard clay deposition and cemented sand formations are reported. The case study of the Northern Yellow Sea are referred to the Bohai Sea and the Yangtze River Delta and report examples of clay sequences and the hard clay layers.

The sand and clay sediments carry the traces of the climatic changes, temperature and humidity, caused the advance and recession of the glaciers, the sea level, coast lines and fluvial activity variations, the different weathering rates and the diagenetic processes.

Sand Sediments

The mineralogical investigation of the sand sediment layers underlying the Venetian littoral has given indication of the good correlation between mineralogical composition and paleoclimate variations.

Given in Figure 1 are the Carbonates (Calcite and Dolomite) and Silicates (Quartz and Feldspar) percentages of the Upper Pleistocene and Holocene sand sequences.

During the Würm 3 glaciation, when the climate varied from cold and dry to cold and very dry, the sand sedimentation, deposited in the continental paleoplain environment, is quite homogeneous in its mineralogical composition with the total silicate percentage more abundant than the total carbonate percentage. During the Holocene post-glacial and the Flandrian transgression, instead, the mineralogy of sand sediments present vertical variations, with the carbonates prevailing over the silicates during warm periods and the Silicates more abundant during the cold events as indicated by

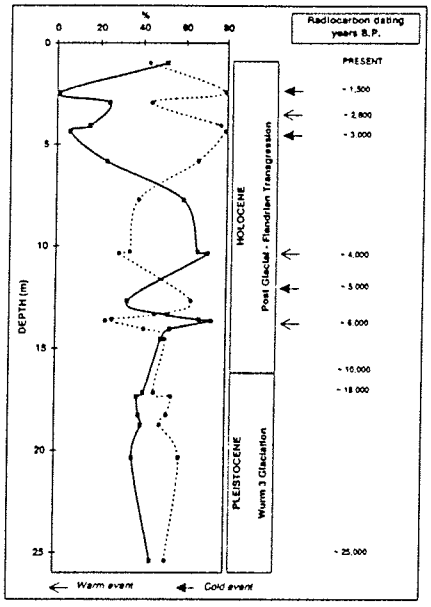


Figure 1 Silicates (dotted line) and Carbonates (continuous line) percentage variations in relation to paleoclimatic changes in the Venice Lagoon sand sedimentation

the arrows. The variation of the Silicates and Carbonates percentages are in very close correlation with the major climatic changes.

After Würm 3 glaciation during the global warming the Carbonates are more abundant than Silicates and present a maximum in the climate optimum at 7,000-6,000 years B.P. Following the temperature decrease the Carbonates present minimum percentages during cold and humid events around 5,000 (Piora Age), 3,000 (Iron Age) and 1,500 (Medieval minimum) years B.P. The higher percentage of Silicates after 3,000 years B.P., in particular during the cold periods, with respect to the Würm 3 glaciation and Early Holocene, is probably due to climatic changes from very cold and dry or warm and humid to cold and humid or dry and warm.

An example of the climate effect on the diagenesis of sand layers are the intertidal flat or back shore zone sand formations found under water inside and outside the Lagoon of Venice. These are sands that one time were exposed to enhanced evaporation or affected by fresh water seepage and cemented by carbonates precipitation. Since similar present sand formations, the beachrocks, are commonly found in tropical areas; it can be assumed that the old cemented sand formations are an indication of warm climate events and paleocoastal lines during the Late Holocene.

Backscattered electron (BSE) image of high Mg calcite cement crusts on mainly detrital dolomite grains (all grains in central portion of photo) and minor altered feldspar (potassium Feldspar and Plagioclase) grains and peloids are shown in Photo 1. The Mg content of the cement is exceptionally high, much higher than what would be expected from a normal abiogenic marine precipitate probably due to enhanced evaporation rate.

Clay Sediments

The mineralogical composition variation in the clay sedimentation sequence of the Yangtze River Delta gives an example of the impact of paleoclimatic events.

In the clay sedimentation sequence during the Upper Pleistocene and Holocene the Silicates (Quartz and Feldspar) are always higher than the Carbonates (Dolomite and Calcite) (Figure 2). The high relative percentage

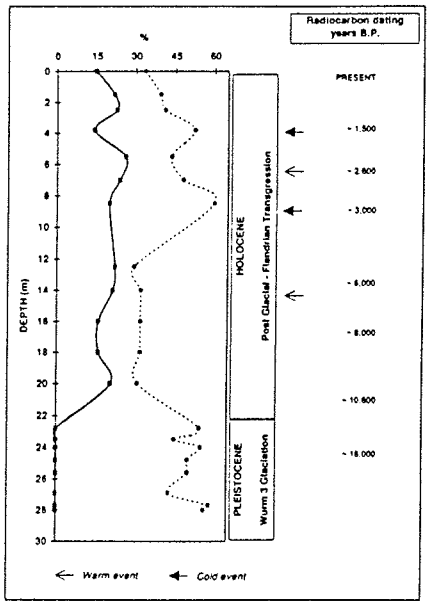
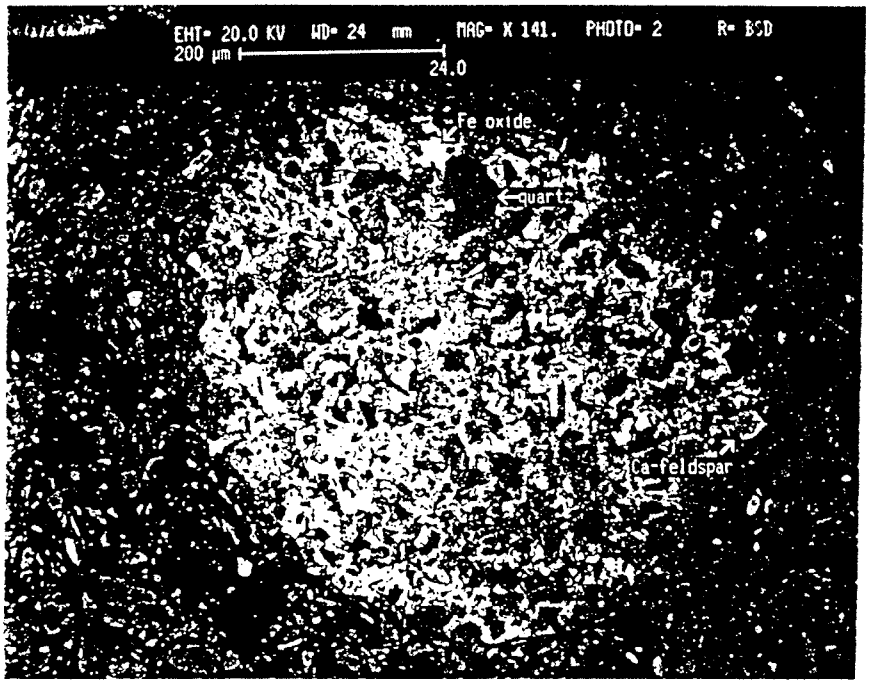


Figure 2 Silicates (dotted line) and Carbonates (continuous line) percentage variations in relation to paleoclimatic changes in the Yangtze Delta clay sedimentation

Photo 5 Overconsolidated hard clay layer with oxidation traces from Upper Pleistocene subaereal paleoenvironment from the Yangtze River Delta (BSE image).



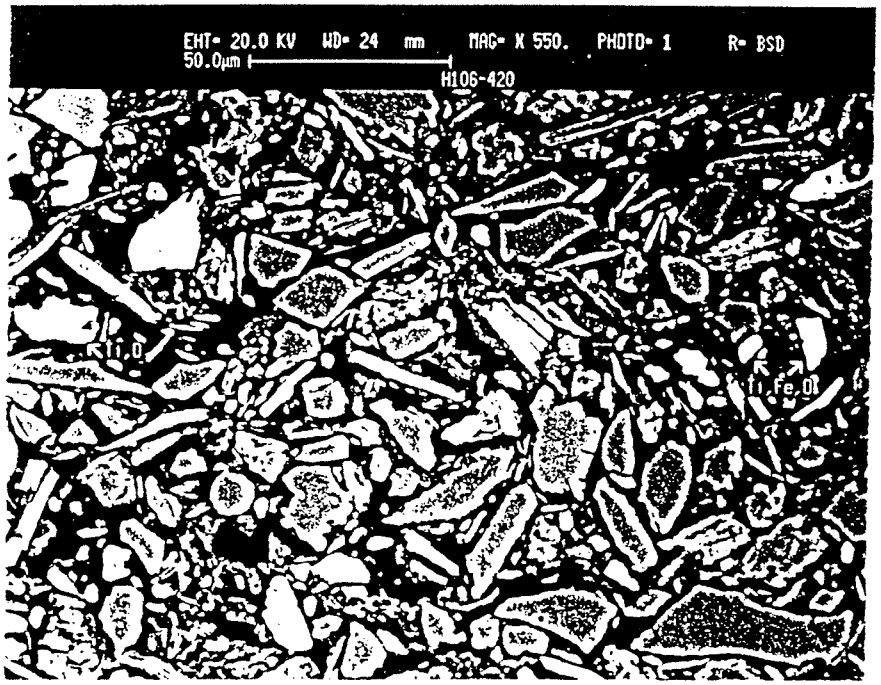
of the Silicates with respect to the Carbonates, is due to the petrology of the area of sediment provenance and not to the paleoclimatic changes.

As in the case of the sand sediment sequence in the Lagoon of Venice, there is a good correlation between the trend of Silicates and Carbonates percentages and the paleoclimate changes. In fact the maximum values for Silicates (minimum for the Carbonates) correspond to three major cold periods (25-17,000 years B.P. Würm 3 glaciation; 3,000 and 1,500 years B.P.).

Another example of the climate impact on the clay sediments is given by a hard clay layer that represents the last Pleistocene continental sedimentation in the Venice Lagoon, the Bohai Sea and Yangtze River Delta.

This clay layer, from few centimeters to few meters thick, shows a fairly high consistence (overconsolidation) due to a prolonged subaerial exposure in cold and very dry climate that favored the drainage and the enhanced consolidation processes. The effect of this paleoclimatic condition

Photo 6 Maximum rate of overconsolidation and low porosity in the top of a hard clay layer from the Yellow Sea Delta (BSE image).



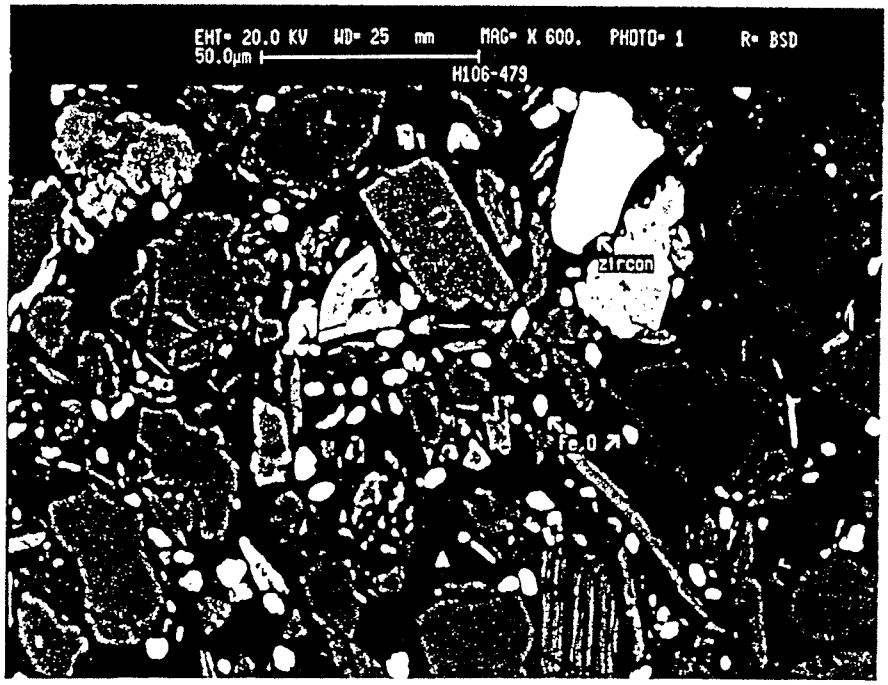
can be found in the mineralogical, chemical compositions, textural and geotechnical (Gatto and Previatello, 1974; Tosi 1994b) characteristics that are quite different from those of the clay layers above and below. The clay layer from the Venice Lagoon and the one from the Yangtze Delta (personal communication by Baozhu Liu, Tongji University, Shanghai) are considered to be a paleosol.

BSE image Photos 2 and 3 show the preferred orientations of phyllosilicates (needle-like grains) in the hard clay layers underlying the Venice Lagoon.

A comparison between the low consolidated Holocene clay level of marine deposition and the overconsolidated Upper Pleistocene and oxidized subaerial hard clay layer from the Yangze River Delta is shown in Photos 4 and 5.

An example of different rates of overconsolidation, occurring during the Upper Pleistocene Würm 3 glaciation, between the top and the bottom of a hard clay layer from the Yellow Sea is shown in Photos 6 and 7.

Photo 7 Minimum rate of overconsolidation and higher porosity in the bottom of a hard clay layer from the Yellow Sea Delta (BSE image).



CONCLUSION

A more accurate forecasting of the environmental impact on sea level and shoreline changes due to global warming, may benefit from a detailed investigation and interpretation of the events that occurred during the past 25,000 years. This time interval in fact corresponds to two significant climatic global changes: the last Würmian glaciation, during the Upper Pleistocene, and the warming during the Holocene.

The mineralogical composition variations of the sands and clays deposited during these periods are correlated with the major paleoclimate

events. The Silicates (Quartz and Feldspar) and Carbonates (Calcite and Dolomite) percentage variations show a good correlation with the climatic changes. In fact the Silicates increase and the Carbonates decrease during the cold events and present an opposite trend during the warm climate intervals.

The imprints of climate impact on the sediments are here elucidated with the textural investigation of two significant sedimentary events: the Upper Pleistocene hard clay layers and the Late Holocene cemented sand formations.

The hard clay layers exhibit a preferred orientation of the phyllosilicate, as result of overconsolidation, and trace of oxidation due to subarial exposure to cold and very dry climate.

Cemented sand formations are of intertidal or back shore facies. Chemical and textural investigation of the cement indicates that their diagenesis is due to a subaerial exposure during warm events that allowed the evaporation of the fresh water seepage and the precipitation of carbonates in solution.

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