ANoxic VERSus Oxic Sedimentation in the Bannock Basin Area, 35,000 yrs b.p. to present

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Riassunto. Due carote provenienti dall'Area Bannock (Mediterraneo Orientale) sono state studiate e i dati vengono presentati in questo lavoro: una è stata recuperata in una zona di alto e contiene sedimenti pelagici normali mentre l'altra è stata prelevata in una zona depressa ed è caratterizzata da sedimenti scarsi depositatisi in un ambiente anossico recente. L'intervallo studiato in dettaglio è compreso tra il teffra Y-5 (stima stimata 35,000 anni) e l'interfacce acqua-sedimenti.

Introduction.

The Bannock Basin is a depression situated on the southwestern part of the Mediterranean Ridge, North of the Sirte abyssal plain (Camerlenghi & Cita, 1987; Camerlenghi & McCoy, 1990; Fig. 1). It has an area of 22 km² and its shape is elongated in SSW-NNE direction, with a steep eastern wall representing a strike-slip fault. It reaches a maximum depth of 3,520 m with a vertical relief of 800 m. Below 3,200 m the basin is anoxic and brine-filled (Cita et al., 1991).

The geological evolution of the Bannock Basin is influenced by the occurrence of Messinian evaporites at shallow depths below sea floor and conditioned by salt diapirism. The compressive tectonic structures typical of this area of the Mediterranean Ridge are overprinted by local extentional structures, which permit water circulation within the Plio-Quaternary sediments, submarine dissolution of the underlying Messinian salts resulting in large collapse structures.

The Bannock Basin is an enclosed depression with a central bulge and several surrounding smaller basins. The central bulge has been interpreted as a diapiric structure, surrounded by depressions representing collapse features (Camerlenghi & McCoy, 1990). Recent high-resolution seismic investigations (MERSE group, 1995) along the wedge of the Mediterranean Ridge constrain the processes of dewatering in an accretionary prism dominated by an impermeable cap of Messinian evaporites. According to these data, the decollment occurs at the base of Messinian and pre-Messinian sediments are thus subducted. The Bannock Basin area has thus been interpreted as a subducting seamount the peak of which appears to underlie the central structure.
In the Bannock Area the sediment accumulation rate of the Plio-Quaternary sequence is low, of the order of 2 cm/1,000 yrs (Parisi et al., 1987; Cita et al., 1988; Nolli et al., 1991). The entire thickness of the Plio-Quaternary is about 100-150 m, which permits outcropping of the Messinian salts on the eastern flank of the basin. Leaching of the highly soluble Messinian evaporites (composed of gypsum, halite and K-salts) causes brine formation at the bottom of the Bannock Basin and the development of permanent anoxic conditions, in absence of strong bottom currents. Below a depth of 3,200 m brines have been found with an average salinity of 33.4%. (Cita et al., 1985; Corselli & Aghib, 1987; Boldrin & Rabitti, 1990; De Lange et al., 1990).

In the Bannock Area a number of cores have been taken which provide a sedimentary record extending back to the Lower Pliocene. Two cores were raised from the northern part of the basin in 1988: core BAN88-14GC from Borea Dome (water depth 2,790 m) shows a normal pelagic sequence whereas core BAN88-21GC from the sill separating Borea from Maestro sub-basin (water depth 3,250 m) contains anoxic sediments, after the deposition of the volcanic marker bed Y-5 (of Keller et al., 1978; see also Vezzoli, 1991).

**Description of the cores.**

Both cores were recovered from the northern part of the basin and are separated by less than two nautical miles.

Core BAN 88-21GC was collected beneath the brine level, at a depth of 3,250 m.

Core BAN88-14GC was collected from the southwestern flank of a dome, at a depth of 2,790 m.

Core BAN88-14GC shows a normal pelagic sequence, with Nanno-ooze and Nanno-marls as major lithologies and tephras and sapropels as minor lithologies.

Core BAN88-21GC contains normal pelagic sediments in its lower part, anoxic sediments in its upper part. The occurrence of Tephra Y-5 at 180 cm from the top of the core, at the base of the anoxic sediments allows to date with a good approximation the onset of anoxia at 35,000 yrs B.P. (Fig. 2). Tephra Y-5 occurs also in core BAN88-14GC, at a depth of 70 cm from the top of the core, so it is possible to closely compare anoxic sedimentation versus normal pelagic sedimentation after deposition of Tephra Y-5 (Fig. 2 and 3).

Core BAN88-14GC contains also Tephra Y-1 and Sapropel S-1, which seemed not to be present within the anoxic sediments of core BAN88-21GC. Indeed, the dark nuances (according to the Munsell colour chart, colours ranging from 2.5Y N5 and 5Y 5/1 gray to 7.5YR N4 dark gray to 5Y 3/2 dark olive gray to 2.5Y N3 very dark gray) of the anoxic sediments obscure eventual minor lithologies (Fig. 3 and 4).

Detailed compositional analyses have been carried out also to point out whether or not these marker beds occur in core BAN88-21GC.

Sediment accumulation rate in core BAN88-14GC is normal for the eastern Mediterranean ranging from 1.16 and 2.66 cm/1,000 yrs (Parisi et al., 1987; Nolli et al., 1991). In the anoxic core sediment accumulation rate is 4.6 cm/1,000 yrs. The latter sediment core is watery and partly disturbed in its upper part (top 45 cm). These data are consistent with data by Nolli et al. (1991) concerning sedimentation rate in the Bannock Basin area. The high sedimentation rate of the anoxic facies seems to be due to the high water content.

The first micropalentological studies carried out during the cruise BAN-88 indicated that core BAN88-14GC contains only calcareous microfauna, while in core BAN88-21GC siliceous microfauna is also present.
Sedimentation eastern Mediterranean

The main objectives of this paper are two:
- firstly to compare normal pelagic versus anoxic sedimentation, considering the variability of the major components;
- secondly to identify the diagenetic conditions affecting the preservation of biogenic silica (siliceous fauna) within the anoxic sediments.

Methods.

Compositional analyses were performed at Woods Hole Oceanographic Institution during a summer student fellowship programme. Samples were taken in both cores with a sampling point every 2,000 yrs.

In core BAN88-14GC (oxic), sediment accumulation rate ranges from 2.66 cm/1,000 yrs (from the top of the core to Y-1) to 1.16 cm/1,000 yrs (from Tephra Y-1 to Tephra Y-5); consequently sample density is every 5 cm (core top to Y-1) and every 2.3 cm (Y-1 to Y-5). Sapropel S-1 and Tephra Y-1 were not sampled.

In core BAN88-21GC (anoxic), there are no marker beds evident, so the estimated sediment accumulation rate, from the top of the core to Tephra Y-5, is 4.42 cm/1,000 yrs. Samples were taken every 9 cm.

A schematic flow-diagram of the laboratory processing and analyses is shown in Fig. 5. Compositional analyses were performed on unwashed (dried) samples - 19 from core BAN88-14GC (normal pelagic) and 16 from core BAN88-21GC (anoxic) - determining the content in the following major components:

- Total Inorganic Carbon
- Carbonate
- Organic carbon, Hydrogen, Nitrogen
- Biogenic Silica
- Lithogenics
- Combustible
- Non-combustible

Inorganic Carbon levels were determined using a System 140 Inorganic Carbon Analyzer. For the determination of the Total Inorganic Carbon 3 mg of the core samples were acidified converting all forms of inorganic carbon to CO₂. The CO₂ is then purged into the coulometer for measurements.
For the determination of the carbonate content the dried sample was immersed in 10% acetic acid and ultrasonically dispersed. After 24 hours at room temperature the sample was filtered, rinsed with distilled water, dried and re-weighted. The carbonate content was computed from the weight loss considering the dry weight difference before and after decalcification by acetic acid.

All core samples were analyzed for CHN (Carbon, Hydrogen, Nitrogen) contents: samples were first acidified to remove carbonate and then washed, dried and ground into a fine powder. The organic carbon contents were then determined by analyzing about 10 mg of the decalcified sample using a Hewlett-Packard CHN analyzer.

The biogenic silica contents were obtained from about 10 mg of the decalcified sample material using a method modified after Eggiman et al. (1980) who found that sediments with a biogenic silica/clay ratio larger than 1.0 can be analyzed by a single leach with 2M Na₂CO₃ solution without correction for silica that also had been leached from the clays. Determination of the reactive silicate depends on the production of a silicomolybdate complex forming between silica, leached by the Na₂CO₃ into solution, and ammonium-molybdate which was then added. A reducing solution containing methanol and oxalic acid was then added, which reduced the silicomolybdate complex to give a blue reduction compound. The absorbance of this compound was measured with a spectrophotometer to yield a ppm value of biogenic silica in the sample.

The lithogenic contents were determined indirectly. About 10 mg of decalcified sample were combusted at 500°C in a muffle furnace to remove the organic material. From the weight of the ash the non-combustible component was determined. The lithogenic component

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Fig. 3 - Lithological log of core BAN88-14GC and close-ups from section 1 (left) showing Tephra Y-1 and (right) showing pelagic sedimentation and Tephra Y-5.
was then computed by subtracting the biogenic silica component from the non-combustible component, under the assumption that the non-combustible component was a sum of biogenic silica and terrigenous detritus (mostly clay, quartz, feldspar and volcanic shards).

Smear slides were made for each sample (35) in order to determine the amount of biogenic/non-biogenic particles, using fresh sample.

**Composition of sediment samples from cores BAN88-14GC and BAN88-21GC.**

Data concerning the compositional analysis of the core samples are shown in Tab. 1. According to the smear slides data, the matrix of core BAN88-14GC (normal pelagic) is composed mostly by biogenic carbonate (mainly coccoliths and planktonic foraminifera), with an average content up to 90%. No siliceous fauna is present.

The matrix of core BAN88-21GC (anoxic) is also composed mostly by biogenic carbonate (with an average content up to 50%) but siliceous fauna (radiolarians and diatoms) is preserved (with an average content up to 30%).

No significant downcore changes are evident in both cores.

The composition of the sediment samples from core BAN88-14GC is drastically different from that
from core BAN88-21GC (Fig. 6 and 7). The normal pelagic sediments contain from 21.63% to 58.15% of carbonate, the anoxic sediments show values from 11.9% to 45.83%. The average content in carbonate for the normal pelagic core is up to 45%, for the anoxic core is 20%. The sharp decrease at the bottom of both cores is related to the occurrence of Tephra Y-5 (Fig. 6).

The concentration of organic carbon in core BAN88-14GC is very low (0.3%). In core BAN88-21GC the anoxic sediments have an average content up to 1.2%, but consistently lower than sapropels (>2%) (Fig. 8a); these sediments correspond to “sapropelitic mud” (Kidd et al., 1978).

The occurrence of Sapropel S-1 in core BAN88-21GC (Fig. 7) is geochemically marked, at a depth of 80 cm, by an increase in organic carbon up to 2% and a decrease in carbonate down to 20%. These values are in agreement with the composition of sapropels according to Kidd et al. (1978).

The ratio organic carbon/inorganic carbon for the anoxic sediments of core BAN88-14GC has always values ranging between that for normal pelagic sediments (BAN88-14GC) and sapropels (Fig. 8a).

The average N content for the normal pelagic sediments is 0.05%, for the anoxic sediments is 0.1% (Fig. 6 and 7); considering the ratio organic carbon/nitrogen the anoxic sediments have always values higher than normal pelagic sediments, which are depleted in N, and lower than sapropels (Fig. 8b).

Biogenic opal is 0.5% in the sediment samples from the normal pelagic core (BAN88-14GC) in contrast to 20% in the anoxic sediments from core BAN88-21GC (Fig. 6 and 7); a sharp increase up to 30% at cm 80 corresponds to sapropel time (org C > 2, see Fig. 7).

Discussion.

Anoxic basins are well-known in marine environments as in the Black Sea, Orca Basin, in the Red Sea, and also in the eastern Mediterranean. A comparison is difficult, due to the different geological setting and sedimentary evolution affecting the Eastern Mediterranean anoxic basins and in particular the Bannock Basin area.

The eastern Mediterranean has shown - in general - low primary production. The biogenic fluxes change over the annual cycle has been documented in the anoxic basins of the eastern Mediterranean in a recent study (Ziveri et al., 1995). According to the study, the biogenic fluxes contain mainly foraminifera consisting of coccolithophores, calcareous dinoflagellates, diatoms, silicoflagellates, and fauna comprising foraminifera and radiolarians.

The peculiar geological setting of the Bannock Basin controls the evolution of the recent persistent anoxic conditions occurring at the basin floor. Sedimentation in the Bannock Basin is controlled by the deep-seated high density brines derived from the submarine dissolution of Messinian evaporites. Anoxic sediments consist
of non-bioturbated muds, dark in colour, rich in organic gelatinous pellicles and containing large gypsum crystals (Erba, 1991). The sediment accumulation rate in the deeper part of the Bannock Basin area ranges from 4 to 10 cm/1,000 yrs (Montagnana & Sala, 1993) higher than that related to the normal pelagic sedimentation in the eastern Mediterranean (1-2 cm/1,000 yrs) (Parisi et al., 1987). According to Ziveri et al. (1995) the total biogenic fluxes are always higher in the trap positioned in the anoxic brines probably due to reworked biogenic material sliding from the slopes of the basin. This suggests that the mechanism of the particle transport throughout the stratified water column to the basin floor is controlled by the interface between normal seawater/brines (Ziveri et al., 1995). The high density of the hypersaline brines slows down the suspended particles but inhibits compaction of the sediments materials on the basin floor. The bottom sediments, due to the high porewater content, are therefore only slightly compacted, soft and watery. The local biogeochemical environments existing at the bottom of the basin inhibits consumption of organic matter, the related high content in organic C of the anoxic sediments ranges from 0.5 to 1.5% and is always higher than that of the normal pelagic but lower than sapropels (>2%). In the anoxic sediments siliceous fauna is always abundant and preserved; a positive correlation between biogenic opal and organic carbon content (Fig. 9) may suggest that the anoxic and hypersaline conditions inhibit dissolution of opal within the anoxic sediments. Preservation of biogenic opal and low consumption of organic matter may also contribute to a higher sediment accumulation rate, as observed in the anoxic basins of the Bannock Area.

Geochemical data of core BAN88-21GC shows at cm 80 a sharp decrease in carbonate content and a sharp increase in organic C. This suggests that the regional signal related to Sapropel S-1, a climatically-induced basin-wide anoxia, recorded throughout the eastern Medi-

![Fig. 6 - Lithological log of core BAN88-14GC and concentration vs. depth profiles (TIC=Total Inorganic Carbon, Carbonate, Biogenic Opal, Organic Carbon, Hydrogen, Nitrogen, and Lithogenic).](image-url)
The occurrence of Sapropel S-1 within the anoxic sediments of the Bannock Basin has been previously discussed by Olausson (1991) considering the carbon and oxygen isotope composition of Globigerina bulloides and Globigerinoides ruber from two cores of the Bannock Basin: one containing a normal pelagic sequence recovered from a topographic high (BAN84-08GC), and one consisting of anoxic sediments deposited beneath the brines (BAN84-02PC). Sapropel S-1 is geochemically marked within the anoxic sediments of core BAN84-02PC at cm 130 by a slight decrease in carbon and oxygen isotope composition as recorded in normal pelagic sequences from nearby areas (Paris, 1987). On the same cores studied by Olausson, Tomadin and Landuzzi (1991) carried out a detailed clay mineral investigations which showed that the clay mineralogy reflects the different sedimentation environments. The anoxic sediments showed an important decrease in smectite crystallinity whereas well-organized smectite and a higher amount of kaolinite characterize the normal pelagic sediments. Moreover, the correlation of the clay-dependent climatic curve obtained by Tomadin and Landuzzi (1991) and the oxygen isotope curve obtained by Olausson (1991) has shown a good correspondence for warm and cold oscillations registered from the Middle-Pleistocene and Holocene.

Concluding remarks.

The anoxic versus normal pelagic sedimentation in the Bannock Basin shows that:

1) preservation of siliceous fauna and the related high content in biogenic opal seems to be by the high level in organic C in the anoxic sediments of core BAN88-21GC; on the other hand, it seems that siliceous fauna is completely dissolved in core BAN88-14GC: the low concentration of biogenic opal in the

terranean is superimposed to the local one related to the episodic and persistent geologically-induced anoxia (Cita et al., 1991).
normal pelagic sediments is thus apparently caused by selective solution of the sedimented material.

2) The occurrence of Sapropel S-I within the anoxic sediments of core BAN88-21GC at a of 80 cm is geochemically marked by an increase in organic carbon up to 2%, and a decrease in carbonate down to 20%. These values are in agreement with the composition of sapropels according to Kidd et al. (1978, see Fig. 7 and 8a). The anoxic sediments from the Bannock Basin have always values corresponding to those of "sapropelic muds".

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REFERENCES


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