Integrated analyses of the Maccarone section (northern Apennines, Italy)

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In the Cingoli area (Marche, northern Apennines), the well-known uppermost Messinian Maccarone section crops out in a badlands area. The section mainly consists of marls with thin intercalations of sandstone and carbonate. A well-exposed disconformity surface separates the post-evaporitic Messinian deposits in a lower portion (p-ev1, San Donato Fm p.p.) and an upper portion (p-ev2, San Donato Fm p.p. and Colombacci Fm). A volcaniclastic layer and three organic-matter-rich horizons with ankerite beds characterise the lower portion of the section (p-ev1). In the uppermost part of p-ev2 four carbonate-rich horizons (“colombacci”), which are intercalated within well-laminated marls, define the stratigraphy of the uppermost Messinian deposits, passing upwards to Lower Pliocene marine clays. A 50 cm regular-spaced sampling has been performed on a total thickness of about 230 m, which, in the uppermost part, encompasses the Messinian/Zanclean boundary. On the 460 collected samples, palaeontological, CaCO3 content, rock magnetic, stable isotope and XRD analyses have been performed. Moreover, a field gamma-ray profile has been acquired across the whole section. The well-known volcaniclastic layer at the base of the Maccarone section has been sampled and re-dated. The Ar/Ar geochronological analysis provided a biotite plateau age of 5.49±0.06 Ma, confirming the previous dating.

The Messinian clays are characterized, as in other Mediterranean section, by the presence of high values of smectite (ranging from 63% up to 98%). Bulk mineralogy indicates the occurrence mainly of: clay minerals (11-74%), calcite (0-82%), quartz (2-14%), and plagioclase (1-19%).

Paleontological analyses have been performed on calcareous nannofossils, planktonic and benthonic foraminifers and ostracods. Samples from p-ev1 are generally barren. Samples from p-ev2, on the contrary, are fossiliferous, even if the presence of calcareous nannofossils, foraminifers and ostracods is scattered and only in the Colombacci Fm it is characterised by a more continuous record and higher frequencies. Only reworked forms characterise the nannofossil assemblages in all the p-ev1 and p-ev2 samples, and no Messinian markers were found in the San Donato and Colombacci Fms. A curve of the reworked calcareous nannofossils abundances (number of specimens vs unit area) was elaborated. P-ev1 and the lower part of p-ev2 are evidenced by abundances close or equal to zero. A strong increase of abundances (from 200-300 n°/mm2 to 4000 n°/mm2) was detected starting from the base of the Pliocene deposits. Foraminifers are mostly characterised by small and sorted planktonic specimens with Miocene distribution, Upper Miocene-
Lower Pliocene larger specimens characterised by low frequencies, scattered open marine bentonic species, and only rare in situ Ammonia tepida and Protoelphidium granosum. Ostracods are represented by scarce and oligotypic assemblages made of Amniclythere sp., Cyprideis agrigentina and Loxoconcha muelleri in very few samples from the lower p-ev1 interval, while in the Colombacci Fm they become continuous, abundant and rather diversified, including Loxocorniculina djafarovi. Ostracods from the Colombacci Fm are grouped in three assemblages, which going upsection are: 1) Cyprideis-Loxoconchidae-Tyrrhenocythere assemblage, characteristic of shallow (not more than 10-15 m) and oligohaline waters; 2) “pointed canodonts”-Leptocytheridae assemblage, which points to deeper (some tens of meters) and oligohaline/low mesohaline waters; 3) “pointed canodonts” assemblage (accompanied by Tyrrhenocythere pontica and Tyrrhenocythere ruggierii), which points to a salinity reduction (freshwater/oligohaline). Immediately above the Messinian/Zanclean boundary the paleontological analyses performed on the Argille Azzurre Fm show a drastic and abrupt palaeoenvironmental change towards open marine conditions around 1000 m of depth.

The magnetic susceptibility record is characterised by very low values with both large and small-scale cycles. The small-scale cycles maybe associated to sub-milankovitch astronomical forcing. The susceptibility record is also characterised by sharp changes related to the volcaniclastic level and to the ankerite layers. In addition to magnetite, thermomagnetic analyses indicate the presence of iron-sulphides throughout the studied section. This may indicate that the ferrimagnetic magnetite (Fe3O4), which is the most common terrestrial magnetic mineral, was partially dissolved during anoxic diagenesis via bacterial reduction of sulfate (SO4^2-).

Oxygen isotope values show an evident continental control on both p-ev1 and p-ev2 deposits (average values of -2.5‰) with three stratigraphic intervals characterised by more evaporative conditions (average δ18O values of 0.5-1‰). Both the oxygen and carbon isotope records show high-frequency oscillations superimposed on longer-term trends in turn interrupted by abrupt and consistent shift. The two signals show a general short-term covariance, suggesting a hypothetical E-P budget control on the paleoproductivity system of the studied environment, such as suggested by the δ18O oscillations. Conversely, during the three δ18O positive excursions, carbon isotope show strong negative shifts which may indicate high organic matter preservation at the bottom of the basin induced by reduced ventilation of the water column. The long-term δ18O negative shift at the base of p-ev2 can be explained by strong continental influxes into the Mediterranean Basin, most likely during a period of runoff increase at the end of the Messinian Salinity Crisis.

Gamma-ray profile shows differences between p-ev1 and p-ev2 deposits. The gamma-ray log profile of p-ev1 (San Donato Fm) shows a gently upward increasing trend, with small deflections. In this interval, the natural radioactivity (NRD) background is between 35 and 40 Cps (Count per second). The maximum γ-ray activity is from black shale laminated horizons (50 Cps). At the base of p-ev1, high NRD values come from the volcaniclastic layer (52-65 Cps). The gamma-ray log profile of p-ev2 shows in its lower part (San Donato Fm) a steady trend, with NRD values quite similar to the upper part of p-ev1. Upsection, the p-ev2 (Colombacci Fm) NRD background shows a decreasing trend from 35 Cps up to 25 Cps. The gamma-ray log profile of the Colombacci Fm shows a well-developed cyclic trend, characterized by high amplitude oscillations with minimum values from the “Colombacci” horizons (10-20 Cps) and maximum peaks in black laminated shales (40-50 Cps). Finally, at the base of the Pliocene clays (Argille Azzurre Fm) NRD increases (about 10 Cps), showing a general upward increasing trend.

The results of these analyses evidence for p-ev1 a period of scarce oxygenation of the basin, which was unsuitable for benthic fauna. As a consequence of continental water influxes, due to runoff increase in the whole Mediterranean area, the p-ev2 paleoenvironment became more suitable for ostracods and benthic foraminifers, which show their higher frequencies in the upper part of p-ev2. From NRD, stable isotope, magnetic susceptibility and ostracod analyses p-ev2 is distinguishable in a lower (upper San Donato Fm, p-ev2a) and an upper part (Colombacci Fm, p-ev2b). Finally, no marine influxes have been evidenced in the Messinian deposits of the Maccarone section.