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Geologia. — *The Tyrrhenian stage in the Mediterranean: definition, usage and recognition in the deep-sea record. A proposal.* Nota di Maria Bianca Cita Sironi, Lucilla Capotondi e Alessandra Asioli, presentata (*) dal Socio M.B. Cita Sironi.

Abstract. — The Tyrrhenian stage of the Quaternary was introduced by Arturo Issel in this Academy over nineteen years ago, in 1914 for a time interval postdating the Sicilian and predating the Holocene. Largerly used in the past not only for the Mediterranean area, but worldwide, the term Tyrrhenian was abandoned in the last few years because it did not meet the strict requirements imposed by the international rules of stratigraphic nomenclature. A brief presentation of the original observational data and the significance of the fossil assemblage collected and investigated by Lovisato from the bay of Cagliari, («*Strombus*-raised beach») containing a tropical fauna and related to a high sea-level stand, clearly shows that a strong climatic significance was given to the Tyrrhenian since the inception. The problem of the validation of the term Tyrrhenian is preceded by the presentation of a new data set arising from recent integrated investigations on a series of deep-sea cores and scientific drillings with continuous coring that form a 3000 km long E-W trans-mediterranean transect. Quantitative micropaleontology originating paleoclimatic and oxygen isotope curves, paleomagnetic reversals and astronomically driven sapropel cycles (in the eastern Mediterranean) are the proxies used to provide a well constrained stratigraphic framework and a series of independent correlation tools. It is now possible to discuss the Tyrrhenian as defined in land outcrops, where the stratigraphic record is necessarily discontinuous and correlations are often questionable, in the framework of a strongly and precisely correlated deep-sea record from the same area. Two options are considered, both plausible and consistent with Issel's original definition, that was formulated well before Milankovitch's discovery of orbital cycles and their influence on Quaternary climate. One option is to restrict the use of the term Tyrrhenian to the duration of isotopic substage 5e, *i.e.* the warmest part of the Last Interglacial, that corresponds to the *Strombus*-raised beach. The term Eemian (defined in a well in Amsterdam) has the same significance and is largerly used in Europe. In this sense, the Tyrrhenian should be better defined as a climatostratigraphic unit, more than a chronostratigraphic unit. A second option is to define the Tyrrhenian as a chronostratigraphic unit (stage) for the Late Pleistocene, whose lower and upper boundaries have been internationally defined as coincident with Termination II (isotopic stage 6/5 boundary at approximately 130 000 yr BP) and Termination I (isotopic stage 2/1 boundary at 11500 yr BP). We prefer the second alternative, that will be discussed in an open forum setting at a Workshop planned for next fall in Spoleto, under the auspices of the Italian Commission on Stratigraphy. Since the International Commission on Stratigraphy recently decided not to use and formalize global stages and global stratotype sections and points (GSSP) for the Quaternary, but to use instead regional stages, we propose to use as regional stages for the Quaternary of the Mediterranean area the Calabrian for the Early or Lower Pleistocene, the Ionian for the Middle Pleistocene and the Tyrrhenian for the Late or Upper Pleistocene.

Key words: Mediterranean; Quaternary; Tyrrhenian; Late Pleistocene.

Riassunto. — *Il piano Tirreniano nel Mediterraneo: definizione, utilizzo e riconoscimento nel record di mare profondo. Proposta.* Il piano Tirreniano del Quaternario fu proposto da Arturo Issel proprio in questa Accademia dei Lincei nel 1914. La sua posizione stratigrafica si estendeva dal Siciliano (definito da Doderlein nel 1872) all'Olocene. Mentre sia il Siciliano che il Calabriano che lo precede sono caratterizzati da associazioni fossilifere fredde, il Tirreniano si distingue per una fauna decisamente calda, associata a evidenze di alto livello del mare. Dopo una introduzione che riassume e inquadra le conoscenze locali sugli affioramenti, il lavoro contiene una nuova documentazione riguardante il record stratigrafico di mare profondo recentemente acquisito mediante perforazioni scientifiche in carotaggio continuo e lo studio integrato con metodiche diverse di carote di mare profondo. Il materiale studiato proviene dai bacini di Alboran, balearico, tirrenico, ionico e levantino e

(*) Nella seduta del 22 aprile 2005.

costituisce un transetto E-W di circa 3000 km. A differenza del record di terra, quello sottomarino è continuo e permette delle correlazioni precise, di carattere fisico, chimico e biologico. È quindi possibile inquadrare il Tirreniano osservato a terra in un contesto regionale e globale di ampio respiro. Nella discussione vengono proposte due opzioni, entrambe compatibili con la definizione originale di Issel: la prima privilegia la connotazione paleoclimatica, che identifica il Tirreniano con la spiagge a *Strombus*, legate a una grande trasgressione marina verificatasi nell'ultimo periodo interglaciale (substadio isotopico 5e) di breve durata e corrispondente all'Eemiano del nord-Europa. La seconda opzione privilegia il significato cronostratigrafico del Tirreniano, che viene proposto come piano regionale valido per la regione mediterranea per il Pleistocene superiore. Questa seconda opzione è preferita alla prima ed è consona con le direttive della Commissione Internazionale di Stratigrafia, che ha recentemente deciso di non riconoscere unità cronostratigrafiche globali, né di validare stratotipi di limiti di carattere globale (GSSP) per il Quaternario, ma di riconoscere formalmente limiti ben definiti fra il Pleistocene inferiore, medio e superiore. Questa proposta, che identifica il Tirreniano con il Pleistocene superiore, verrà presentata e discussa in un *workshop* indetto dalla Commissione Italiana di Stratigrafia che si terrà a Spoleto nel prossimo settembre.

Introduction

One century ago, at the end of the XIX century and at the beginning of the XX century, the geological time scale was almost completed and Southern Italy became increasingly important for the definition of the marine stages of the Quaternary, because fossiliferous sections well exposed exist in various localities of Calabria, Basilicata, Sicily and Sardinia. In other regions the marine sedimentation ends earlier, and does not extend into the Quaternary.

In chronological order, the Sicilian stage was proposed by Doderlein in 1872, the Calabrian by Gignoux in 1910, the Tyrrhenian by Issel in 1914.

Arturo Issel (1842-1922) was professor of Geology at the University of Genova, and a member of the Accademia dei Lincei where he made his presentation on the Tyrrhenian in 1914 soon after the publication of Maurice Gignoux (1913).

Issel had a broad experience on Mediterranean Geology, Seismology and Paleontology, and investigated the slow ground movements, that he called «Bradisismi».

Originally named «Tirreno», the Tyrrhenian was based on a rich fossil fauna collected by professor Lovisato in the Gulf of Cagliari (Cala Mosca, is Mesas, Capo S. Elia, Poetto). The fauna has a typical tropical character, includes taxa as *Strombus bubonius*, *Conus testudinarius*, *Patella ferruginea*, *Cladocora caespitosa*, and is associated with evidence of high sea-level stand.

Lovisato, a hero of the wars of independence of Italy and a follower of Garibaldi in the «Spedizione dei mille», was professor of Mineralogy and Geology at the University of Cagliari where he spent the last thirty years of his life and died in 1916, without having the opportunity to document and illustrate the results of his findings.

The original Tyrrhenian fauna collected by Lovisato is kept at the Paleontological Museum of the University of Cagliari, and has been described and illustrated by Comaschi Caria (1968), Comaschi Caria and Pastore (1959) and more recently by Spano (1982, 1991, 1993). Unfortunately, these papers had a very limited distribution and are largerly ignored, because printed in local journals, or published as excursion guidebooks of the INQUA Commission on shorelines (see Spano, 1982).

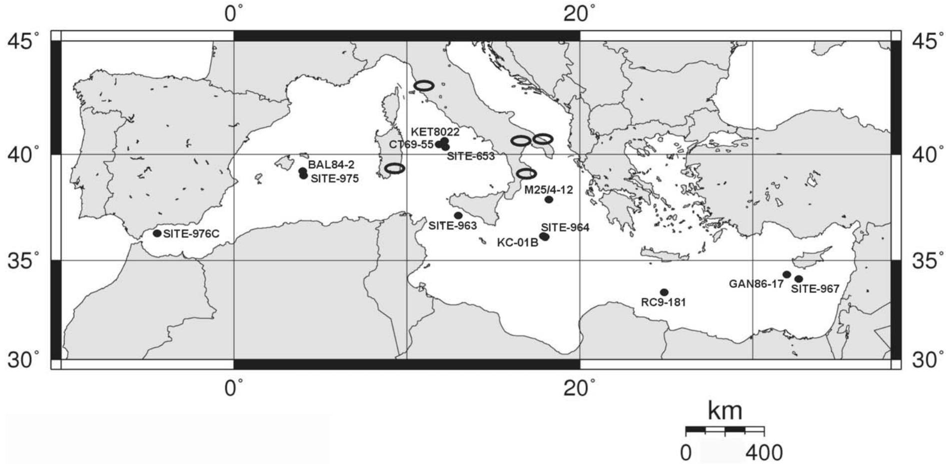

Fig. 1. – Location map of available sites and cores for the time interval considered in this work. Asterisks indicate the sections discussed in the text. The circles mark some examples of Tyrrhenian sections exposed on land in Italy.

Definition and usage of the Tyrrhenian

Issel (1914) defined the Tyrrhenian with reference to outcrops in the Gulf of Cagliari that contain a warm-water fossil fauna indicative of a near shore setting. These outcrops still exist today and are well exposed.

Numerical ages of 139,000 y BP have been obtained by Hearty (1986) on U-series calibration of aminoacid racemization dates on the coral *Cladocora caespitosa*.

Similar ages were obtained on *Strombus*-raised beaches from various localities around the Tyrrhenian and Ionian Seas, as shown in fig. 1. We do not want to mention here all the rich pertinent literature, but just point out that *Strombus*-raised beaches are a common and chronologically well constrained record (*inter alias* Belluomini *et al.*, 1985; Hearty, 1986; Antonioli *et al.*, 2000; Carobene, 2003, 2004).

But Issel's original definition has a wider chronostratigraphic range, since according to him the Tyrrhenian has a position comprised in between the Sicilian (below) and the Holocene (above). At the beginning of the XX century radiometric ages available were just a few, and Milankovitch's theory (1941) on astronomically induced, cyclically repeated changes in solar constant had not been formulated yet.

The Holocene/Pleistocene boundary was founded at the time on two basic criteria: the extinction of large carnivors in Europe, and the end of the Paleolithic. Paleontology of continental faunas and Palethnology were more advanced than other more sophisticated techniques used nowadays, as stable isotopes or astronomical cycles, but the old definition is acceptable and consistent with the modern one.

The international usage of the Tyrrhenian has been widespread worldwide, as shown by the geological time-tables published, that are exposed in all the universities and scientific institutions on earth sciences (see for instance Haq and van Eysinga, 1998)

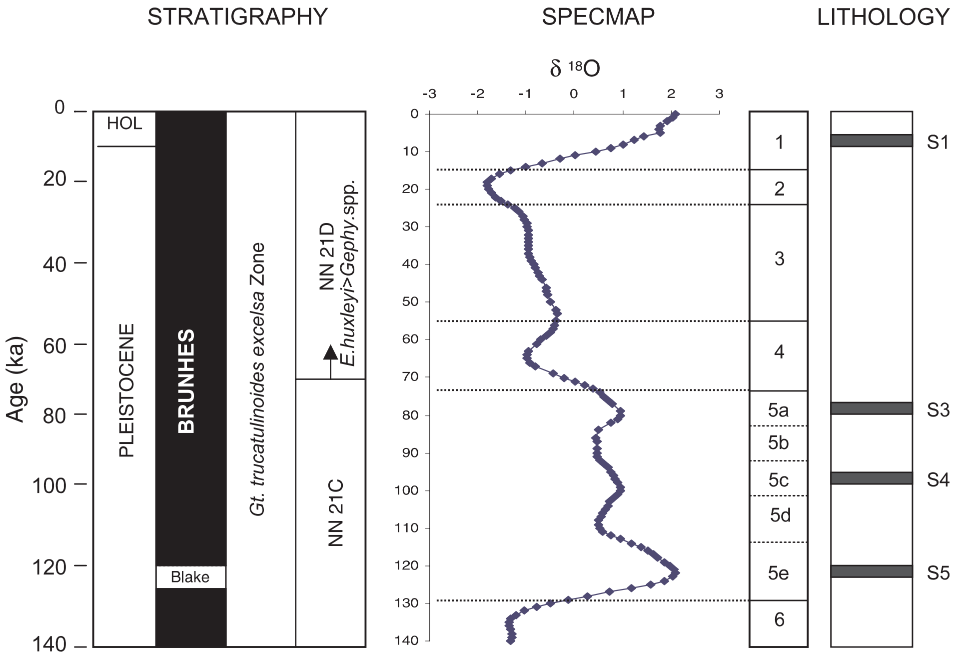

Fig. 2. – Age model used in this paper. SPECMAC curve is after Martinson *et al.* (1987).

always as synonymous with the Late Pleistocene, terminating at the Pleistocene/Holocene boundary.

An attempt to revitalize and better define the Tyrrhenian made during an International Workshop held in Bari in September 1994 (Cita and Castradori, 1994*a*, *b*; van Couvering, 1995), was unsuccessful. Moreover, Vai (1996) in his ample review of all the Quaternary marine stages defined in Italy considered the Tyrrhenian a «nomen nudum» because of its poor definition, absence of a type section, etc. Of course a beach deposit, as are all the so-called «*Strombus*-raised beaches» cannot provide the continuous sedimentary record required for the definition of a stage, or of a stage boundary, but according to our shared philosophy, it is important to keep the traditional, historical, well rooted terms, without introducing new names, if it is possible to precisely locate the original data in a modern well-constrained stratigraphy founded non only on fossil faunas but on an integrated approach with an age model based on paleoclimatic, isotopic and paleomagnetic data.

This new attempt to revitalize and better define the Tyrrhenian results from a comparative study of seven deep-sea cores and six continuously cored ODP sites recently investigated, where the time-interval considered is well expressed in open marine, continuous sediments. The W-E transect some 3000 km long is depicted in fig. 1, where typical outcrops of Tyrrhenian *Strombus*-raised beaches are also shown.

A former version of the present paper has been presented in 2000 at a meeting of the Italian Association for Quaternary Research (AIQUA) on «l'Eemiano e il Tirreniano in

Italia» held in Verona (Cita *et al.*, 2000). Our final proposal for the usage of the term Tyrrhenian will follow after the Discussion.

A Trans-Mediterranean deep sea record

A west-east Trans-Mediterranean transect.

In order to substantiate our proposal, we concentrated on the deep-sea record, which is remarkably continuous unlike the discontinuous near-shore records. A longitudinal transect of seven deep-sea cores and six continuously cored (multiple) ODP sites is available in bibliography and we considered one section for each basin (fig. 1). The undisturbed hemipelagic sediments display sedimentation rates than range from a maximum of 39 cm/kyr (Sicily Channel) to a minimum of 2.5 cm/kyr (Ionian Basin). The age-model used to interpret the stratigraphic record is shown in fig. 2.

For the selected sequences investigated we present the oxygen isotope curve plus the paleoclimatic record, when available.

The oxygen isotope signal represents a global chronostratigraphic proxy.

The paleoclimatic curve is based on planktonic foraminifera distribution and represents the sum of percentages of warm-water indicators (positive values) and the cold water indicators (negative values) according to the method proposed by Cita *et al.* (1977).

As evidenced by several authors (Cita *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977; Sanvoisin *et al.*, 1993; Capotondi *et al.*, 1994), the paleoclimatic curve, although affected by several limits, such as the different mesh of the sieve used by the authors and the species considered to plot this curve, parallels, in general, the oxygen isotope records: positive and negative peaks in the planktonic foraminiferal record represent interglacial and glacial $\delta^{18}O$ fluctuation, respectively.

From West to East, the sections considered are as follows.

ODP Site 976 (Alboran Sea).

The ODP Site 976 is located in the Alboran Sea, about 60 km off southern Spain and about 110 km east of the Strait of Gibraltar (fig. 1, table I). This sedimentary sequence is very important because it allows us to monitor the hydrographic variability in the westernmost part of the Mediterranean Sea.

The 45 m-thick interval investigated consists of hemipelagic nannofossil clay without changes in colour. The sedimentation rate is very high ranging between 30 and 50 cm/kyr (Comas *et al.*, 1996). Many levels are rich in TOC (Total Organic Carbon) (about 2%) but do not correspond with the eastern Mediterranean-type sapropels. They have been attributed to the presence of local phenomena such as hydrological and productivity fronts that are associated with the Atlantic inflow and wind-driven meso-scale gyres in the western Mediterranean (Murat, 1999). However, paleomagnetic data and foraminiferal assemblages show the presence of anoxic layers equivalent in time to the sapropel S1, S3 to S5 deposition in eastern basin (Capotondi and Vigliotti, 1999).

TABLE I. – *Location of the discussed cores and mean sedimentation rates during the investigated time interval.*

Core	Latitude	Longitude	Water depth (m)	Sedimentation rate (mean) (cm/kyr)
ODP Site 976 C	36°12.32′N	04°18.76′W	3454	30.8
Core KET 8022	40°35.00′N	11°42.50′E	2430	6.6
Core KC 01B	36°15.25′N	17°44.34′E	3643	6.84
Core RC 9-181	33°25.00′N	25°01.00′E	2286	2.5

The oxygen isotope profile (von Grafenstein *et al.*, 1999), performed on *Globigerina bulloides*, displays clearly the shift corresponding to the Termination II, as well as the three peaks of low δ^{18}O values (ranging between 0 and +0.5‰) correlative with the substages 5a, 5c and 5e. The subsequent increase of the δ^{18}O composition (> + 3 ‰) at m 25 indicates the presence of the Marine Isotopic Stage (MIS) 4. It is worthy to highlight the close similarity of the δ^{18}O trend with the paleoclimatic curve, that, in turn, displays three positive peaks (warming) just in correspondence of the substages 5a, 5c and 5e (Capotondi and Vigliotti, 1999) (fig. 3). However, the strongest warming recorded by the foraminiferal assemblage (+ 40) occurs during MIS 5.5, while MIS 5.3 and 5.1 reach values quite lower (ca. −60).

Core KET 80-22 (Tyrrhenian Sea).

The piston core raised in 1980 by the French R/V Le Noroit in the Tyrrhenian Sea (fig. 2, table I) is well known in literature, because it was used for the chronological reconstruction of the explosive activity of the South Italian volcanoes during the late Quaternary time (Paterne *et al.*, 1986, 1988). Numerous tephra layers were detected but no sapropels have been found along the 8.40 m-thick sequence (fig. 3).

The chronology of the core was assessed using both the oxygen isotope analyses performed on *G. bulloides* (sampling interval every 10 cm) and correlation of the marine ash layers to their terrestrial equivalents dated by the traditional radiometric methods (Paterne *et al.*, 1986). The sediments provide a detailed record extending from stage 1 to stage 6 and this is also confirmed by the position of the Blake magnetic polarity episode (Tucholka *et al.*, 1987).

For this core, only the oxygen isotope record is available. The curve shows the Terminations I and II well developed, with the two steps of Termination I relatively well detectable. Within this quite complete sequence, MIS 5, including substages 5.5 (values up to ca. + 0.5‰), 5.3 and 5.1, along with MIS 4 (+ 4‰), MIS 3 and MIS 2 (ca. + 4‰) are well represented.

Core KC 01 B (Ionian Basin).

The piston core KC01B, considered a reference core for the Ionian Sea, was raised by the French R/V Marion Dufresne in 1991 at the same location of ODP Site 964, Leg 160 (fig. 1).

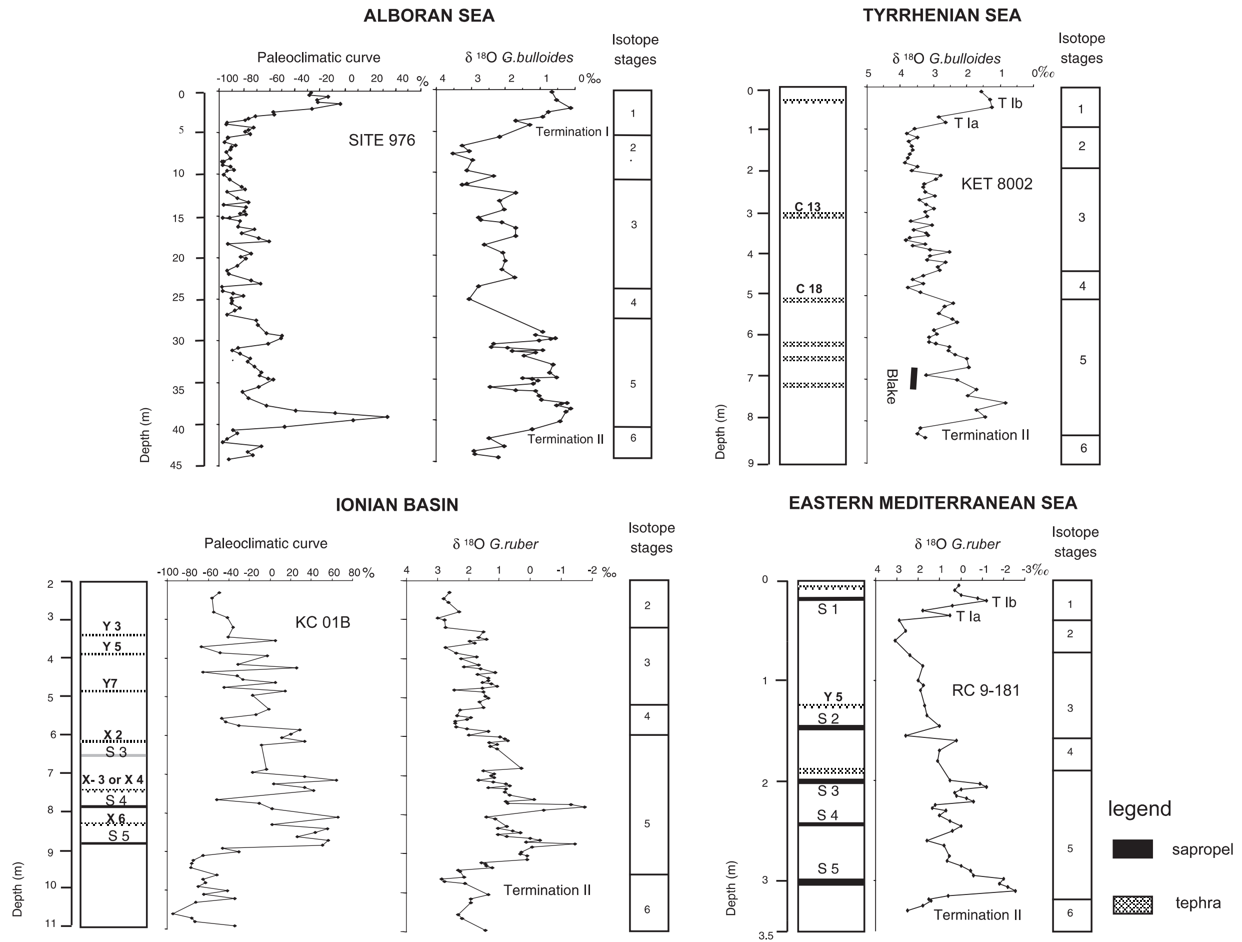

Fig. 3. – Lithology, paleoclimatic curve, δ^{18}O stratigraphy of ODP Hole 976 (Capotondi and Vigliotti, 1999; von Grafenstein *et al.*, 1999); core KET 80 02 (Paterne *et al.*, 1986, 1988); core KC01B (Sanvoisin *et al.*, 1993; Castradori, 1993) and RC 9-181 (Cita *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977). Notice that the scale of the columnar logs is different in the various sites.

The lithology (fig. 3) is characterised by hemipelagic marls with intercalations of sapropels, tephra and thin turbiditic sandy levels (Castradori, 1993). The sedimentation rate based on astronomical ages of sapropels (Hilgen, 1991) and magnetic boundaries ranges between 1.8 and 7.7 cm/kyr. For this work we utilised the high-resolution isotope stratigraphy established by Rossignol-Strick *et al.* (1998) and the paleoclimatic record performed by Sanvoisin *et al.* (1993). The lithological log displays the presence of sapropels S4 and S5. Trace elements (Ba e S) and magnetic property (χ) measurements (Langereis *et al.*, 1997) reveal the presence of sapropel S3.

Unfortunately the uppermost 231 cm, possibly spanning the last 18 ka, could not be studied by Sanvoisin *et al.* (1993) because of coring disturbances.

The oxygen isotope record (based on *Globigerinoides ruber*) displays a well-developed Termination II, as well as the light values marking the substages 5.5 (−1.46‰), 5.3 (−1.76‰) and 5.1 (+ 0.3‰) (fig. 3). Again, each sapropel (S5 and S3) corresponds to (or it is immediately followed by) a peak of light $\delta^{18}O$ values. MIS 4 is characterized by values around + 2.5‰, while MIS 3 and MIS 2 are documented with values between + 2.44‰ and + 1.5‰. The paleoclimatic curve shows a general coherent trend with the oxygen isotope profile.

Core RC 9-181 (Levantine Basin).

Core RC 9-181 (fig. 1), collected south of Crete at 2286 m water depth in 1965, represents the most complete piston core recovered from the eastern Mediterranean (Ryan, 1972; Vergnaud-Grazzini *et al.*, 1977; Cita and Ryan, 1978). The pelagic sediments contain sapropel and ash layers very well correlated throughout the eastern Mediterranean Sea (Ryan, 1972). The sedimentation rate, based on oxygen isotope stratigraphy, is ~2.4 cm/kyr.

This core is very well known in the literature because it was used to formalise the relationships between Late Pleistocene sapropel sequence and astronomical solution (cycles of precession and eccentricity) by Hilgen (1991). This tuning, extended to older sapropels exposed in land sections, provided the new chronology for the Mediterranean late Neogene sapropels (Mediterranean Precession-Related Sapropel) very similar to the astronomically calibrated ages obtained by Shackleton *et al.* (1990) based on oxygen isotope record from ODP Site 607.

In this core the oxygen profile (based on *Globigerinoides ruber*) is reported (fig. 3) where the Terminations I and II are well recognisable. As in the Tyrrhenian core KET 8002, Termination I is split in the two steps Ia and Ib, separated by the cold spell Younger Dryas. Moreover, substages 5.5 and 5.1 are well marked (values up to −3‰ and −1.5‰, respectively), while substage 5.3 is less pronounced (+ 0.5‰). MIS 4 is characterised by values around +1‰, while, after the base of MIS 3, a general trend with increasing $\delta^{18}O$ values culminates into MIS 2 (ca. + 3‰). The sapropels S5, S4 and S3 correspond to the lightest peaks of the oxygen curve. Finally, it is noteworthy the presence of sapropel S2 in the lower part of MIS 3.

Discussion

Besides the Calabrian, the Sicilian and the Tyrrhenian (see p. 298) other stage names have been proposed in Italy for defining marine stages as follows (in chronological order):

Milazzian (Dépéret, 1918) in Sicily;
Emilian (Ruggieri and Selli, 1949) in northern Italy;
Santernian (Ruggieri and Sprovieri, 1975) in northern Italy;
Crotonian (Ruggieri *et al.*, 1977) in Calabria;
Selinuntian (Ruggieri and Sprovieri, 1979) in Sicily.

The last was proposed as a superstage in substitution of the Calabrian, and included from bottom to top the «cold» Santernian, the «temperate» Emilian and the «cold» Sicilian.

None of these stage names succeeded to reach an international or even a national recognition for various reasons (see ample discussion in Vai, 1996, to which reference is made). It is pointed out that none of them overlaps chronologically with the Tyrrhenian: they are definetely older (mostly Early Pleistocene).

Meanwhile the investigations on Quaternary successions in the deep sea, in ice cores but also in coastal areas, in the mountains, in alluvial plains increased drastically our state of knowledge, whereas new techniques improved the correlation potential both in terms of time resolution and of credibility.

The application of Milankovitch's theory to the interpretation of oceanic sediments recovered in deep-sea cores and the discovery that the isotopic composition of oxygen measured on the calcitic test of foraminifera could lead to reconstruct past temperatures of the oceans, contributed to revolutionize the approach to paleoclimatology. Cesare Emiliani was a pioneer in this kind of investigations, and applied them to the Mediterranean deep-sea record (Emiliani, 1955) and to the classical Calabrian section of Le Castella (Emiliani *et al.*, 1961).

At the same time, stratigraphy developed a rationale and set up a series of internationally agreed upon rules (see Hedberg, 1976; Cowie, 1986; Salvador, 1994). The old, fairly vague concept of «stage» as basic unit in chronostratigraphy was substituted by a new one, where a stage is defined by a Global Stratotype Section and Point (GSSP), nicknamed «Golden Spike» that has to be formally proposed, voted by the International Commission on Stratigraphy (ICS), and ratified by the International Union of Geological Sciences (IUGS).

Only the Pliocene/Pleistocene boundary has been ratified in 1985, and recently ICS decided that no global stages and relative GSSPs will be accepted for the Pleistocene, but only regional stages within a framed time scale.

After this brief historical review on the evolution of stratigraphic principles, techniques and applications to the Quaternary stratigraphy of Italy, and considering the well founded correlations available for the Upper Pleistocene of the Mediterranean area, let us discuss in some detail the Tyrrhenian, that was defined in outcrops, where the stratigraphic record is necessarily discontinuous, and correlations are often questionable.

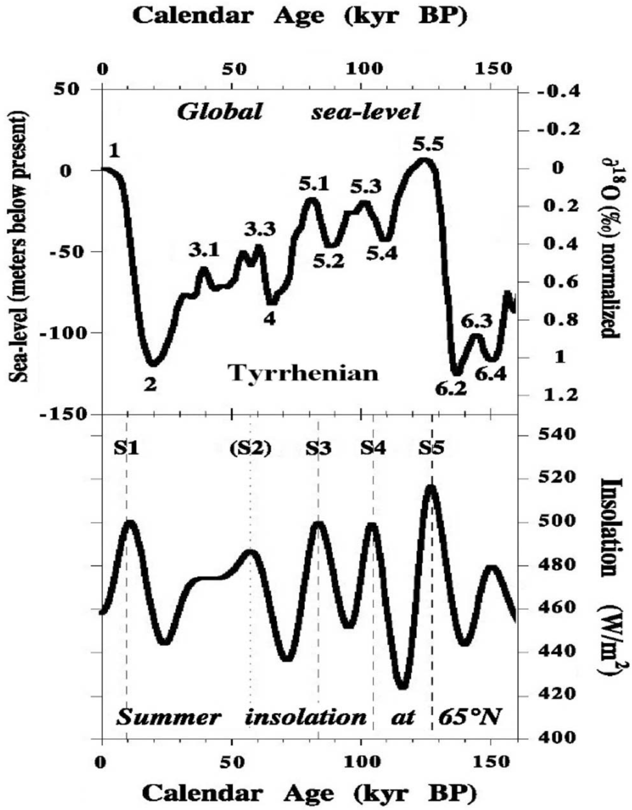

Fig. 4. – Diagram summarizing the chronological relationship between the five recent sapropel events (S1-S5), the global sea level and the insolation variations dominated by the 22-kyr orbital precession cycle. Modified from Bard *et al.* (2002). The Tyrrhenian chronostratigraphic unit as here defined is well expressed and easy to be recognized.

Strombus-raised beaches often accompanied and/or substituted by erosional notchs or litofages borings have been investigated in Italy, France, Spain, Tunisia, Greece, Israel, and Turkey. Due to the strong neotectonic activity characterizing the orogenic belts that surround and cross the Mediterranean, their position versus present-day sea-level ranges from negative to +150 m (see Carobene, 2003; Bigazzi and Carobene, 2005; Climex Map, 2004).

Two options are considered, both plausible and consistent with Issel's (1914) original definition that was formulated well before Milankovitch discovery of orbital cycles and their influence on Quaternary climate and sea-level changes (Milankovitch, 1941).

One option is to restrict the use of the term Tyrrhenian to the duration of isotopic substage 5e (MIS 5.5), *i.e.* the warmest part of the last interglacial, that corresponds to the *Strombus*-raised beach. The term Eemian (Zagwijn, 1961), used originally in the Netherlands to identify the Late Pleistocene transgression coincident with the maximum sea-level rise of the last interglacial, was recently defined in a well in Amsterdam, and is largerly adopted even in the deep-sea record.

In this scenario, the Tyrrhenian should be re-defined as a climatostratigraphic unit, more than a chronostratigraphic unit, and is in competition with the now very popular Eemian.

A second option is to define the Tyrrhenian as a strictly chronostratigraphic unit, that starts with the *Strombus*-raised beach and correlative level in the deep-sea record, and extends upwards to reach the base of the Holocene.

We prefer the second option that is precisely defined in the Conclusion.

Conclusion

As a conclusion of the above discussion, we propose to use the Tyrrhenian as a regional stage for the Upper Pleistocene of the Mediterranean area.

Its age spans from ~130 000 yr BP (beginning of Termination II, Marine Isotopic Stage 6/5 boundary) to the Pleistocene/Holocene boundary dated at 11500 calendar yr BP (Termination I, Marine Isotopic Stage 2/1 boundary).

With reference to the Marine Isotopic Scale, the Tyrrhenian as defined above corresponds to MIS 5 through MIS 2.

With reference to the eastern Mediterranean deep-sea record, it includes sapropels 5 through 2 and tephras X-6 through Y-1 (see fig. 4).

With reference to the Magnetic Polarity Time Scale, it is entirely developed within the Brunhes Epoch, and includes near its base the Blake event (identified in the Balearic Basin at ODP Site 975 and in the Tyrrhenian Basin core KET 8022).

This almost 120 000 years long interval corresponds to the Eemian interglacial (= MIS 5.5), to all the intra MIS 5 interstadials, to the entire duration of the Wurm glaciation, inclusive of the Last Glacial Maximum (LGM) and to the deglaciation (see Orombelli *et al.*, in press).

This proposal obviously downplays the paleoclimatic significance of the Tyrrhenian as currently used by many Italian workers, but it is consistent

a) with the original definition given by Issel in 1914, that extended its duration to the base of the Holocene;

b) with the international usage of the Tyrrhenian, that lasted for more than half a century;

c) with the decision of the International Commission on Stratigraphy to subdivide the Pleistocene in three parts, using as main correlation tools for their base reversals in magnetic polarity for the Lower and Middle Pleistocene, a strong isotopic excursion (Termination II) for the Upper Pleistocene.

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References

Antonioli F., Bard E., Rostek F., Schrag D.P., Silenzi S., 2000. *The Last Interglacial & Termination II as viewed from geochemical and stratigraphical data measured in a submerged speleotheme in Argentarola Island (Italy)*. In: *L'Eemiano e il Tirreniano in Italia.* Congresso AIQUA (Verona, 12-13 settembre 2000): 27-29.

Bard E., Delaygue G., Rostek F., Antonioli F., Silenzi S., Schrag D., 2002. *Hydrological conditions over the western mediterranean basin during the deposition of the cold sapropel 6 (ca. 175 kyr B.P.)*. Earth Plan. Sci. Lett., 202: 481-494.

Belluomini G., Malatesta A., Branca A., Spano C., 1985. *Aminoacid racemization dating of Sardinia raised marine deposits*. Boll. Soc. Geol. It., 104: 223-228.

Bigazzi G., Carobene L., 2005. *Datazione di un livello cineritico del Pleistocene medio. Relazioni con sedimentazione, sollevamento e terrazzi marini nell'area di Calopezzati in Calabria (Italia)*. Il Quaternario, 17: 151-164.

Capotondi L., Vigliotti L., 1999. *Magnetic and microfaunistical characterization of late Quaternary sediments in the Western Mediterranean (ODP Leg 161). Inference on sapropel formation and paleoceanographic evolution*. In: R. Zahn, M.C. Comas, A. Klaus (eds.), *Proceedings of the Ocean Drilling Program, Scientific Results.* College Station TX, 161: 505-518.

Capotondi L., Asioli A., Borsetti A.M., 1994. *Ecozonazione a Foraminiferi planctonici e paleoceanografia dell'ultima deglaciazione nel Mediterraneo centrale*. Atti X Congresso A.I.O.L. (1992): 107-115.

Carobene L., 2003. *Genesi, età, sollevamento ed erosione dei terrazzi marini di Crosia-Calopezzati (Costa ionica della Calabria, Italia)*. Il Quaternario, 10: 43-90.

Carobene L., 2004. *Uplifted coastlines and marine terraces*. In: C. Bosi *et al.* (eds.), *Geology of Italy*: *Quaternary.* Soc. Geol. It., Special Issue: 174-177.

Castradori D., 1993. *Calcareous nannofossil biostratigraphy and biochronology in eastern Mediterranean deep-sea cores*. Rivista Italiana di Paleontologia e Stratigrafia, 99(1): 107-126.

Cita M.B., Capotondi L., Asioli A., 2000. *The Tyrrhenian: definition, usage and recognition in Mediterranean deep-sea record*. In: *L'Eemiano e il Tirreniano in Italia*. Congresso AIQUA (Verona, 12-13 settembre 2000): 22-23.

Cita M.B., Castradori D., 1994*a*. *Workshop on marine sections from the Gulf of Taranto (Southern Italy) usable as potential stratotypes for the GSSP of the Lower, Middle and Upper Pleistocene* (Bari, Italy, Sept. 29-Oct. 4, 1994). Il Quaternario, 7(2): 677-692

Cita M.B., Castradori D., 1994*b*. *Rapporto sul Workshop "Marine sections from the Gulf of Taranto (Southern Italy) usable as potential stratotypes for the GSSP of the Lower, Middle and Upper Pleistocene"*. Boll. Soc. Geol. It., 114: 319-336.

Cita M.B., Ryan W.B.F., 1978. *The deep-sea record of the eastern Mediterranean in the last 150,000 years.* In: C. Doumas (ed.), *Thera and the Aegean world. I.* Second International Scientific Congress (Santorini, Greece, August 1978): 45-60.

Cita M.B., Vergnaud-Grazzini C., Robert C., Chamley H., Ciaranfi N., D'Onofrio S., 1977. *Paleoclimatic record of a long deep sea core from eastern Mediterranean*. Quaternary Research, 8: 205-235.

Climex Map, 2004. *Litho-Paleoenvironmental Maps of Italy during the last two Climatic Extremes. Map 1: Last Glacial Maximum 1:1.000.000*. G.B. Vai, L. Cantelli (eds.). LAC, Firenze 2004.

Comas M.C., Zahn R., Klaus A. *et al.*, 1996. *Proceedings of the Ocean Drilling Program, Initial Reports*. College Station TX, 161: 113-177.

Comaschi Caria I., 1968. *Fossili marini e continentali del Quaternario della Sardegna*. Atti X Congr. Int. Studi Sardi, Cagliari: 141-213.

Comaschi Caria I., Pastore R., 1959. *Fauna del Tirreniano di margine Rosso (Quartu S. Elena) e di Calamosca (Cagliari)*. Rend. Sem. Fac. Sc. Univ., Cagliari, 29: 85-93.

Cowie J.W., 1986. *Guidelines for boundary stratotypes*. Episodes, 9(2): 78-82.

Dépérét Ch., 1918. *Essai de corrêlation chronologique des tempes quaternaires*. C.R. Acad. Sci. Paris, 166: 480-486.

Doderlein P., 1872. *Note illustrative della Carta Geologica del Modenese e del Reggiano 1870*. Atti R. Acc. Scienze, Lett., Arti Modena, IX: 1-74.

EMILIANI C., 1955. *Pleistocene temperature variations in the Mediterranean*. Quaternaria, 2: 87-98

EMILIANI C., MAYEDA T., SELLI R., 1961. *Paleotemperature analysis of the Plio-Pleistocene Section of Le Castella, Calabria, Southern Italy*. Geol. Soc. Amer. Bull., 72: 679-688.

GIGNOUX M., 1910. *Sur la classification du Pliocène et du Quaternaire dans l'Italie du Sud*. Comptes Rendus Académie des Sciencees, V-150, n.v: 841-844.

GIGNOUX M., 1913. *Les formations marines pliocènes et quaternaires de l'Italie du Sud et de la Sicile*. Ann. Univ. Lyon, I-36: 693.

GRAFENSTEIN VON R., ZAHN R., TIEDEMANN R., MURAT A., 1999. *Planktonic $\delta^{18}O$ records at Sites 976 and 977, Alboran Sea: stratigraphy, forcing and paleoceanographic implications*. In: R. ZAHN, M.C. COMAS, A. KLAUS (eds.), *Proceedings of the Ocean Drilling Program, Scientific Results*. College Station TX, 161: 469-479.

HAQ B.U., VAN EYSINGA F.W.B., 1998. *Geological Time table*. 5th revised revision. Elsevier, The Netherlands.

HEARTY P.J., 1986. *An inventory of the Last Interglacial age deposits from the Mediterranean basin: a study of isoleucine epimerisation and U-Series dating*. Z. Geomorphol. Suppl. B., 62: 51-69.

HEDBERG H.D., 1976. *International Stratigraphic Guide*. Wiley and Sons, New York, 200 pp.

HILGEN F.J., 1991. *Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implication for the geomagnetic polarity time scale*. Earth Plan. Sci. Lett., 104: 226-244.

ISSEL A., 1914. *Lembi fossiliferi quaternari e recenti osservati nella Sardegna meridionale dal prof. D. Lovisato*. Atti Acc. Lincei Rend. fis., s. 5., v. 23: 759-770.

LANGEREIS C.G., DEKKERS M.J., DE LANGE G.J., PATERNE M., VAN SANTVOORT P.J.M., 1997. *Magnetostratigraphy and astronomical calibration of the last 1.1 Myr from an eastern Mediterranean piston core and dating of short events in the Brunhes*. Geophys. J. Intern., 129: 75-94.

MARTINSON D.G., PISIAS N.G., HAYS J.D., IMBRIE F.J., MOORE T.C., SHACKLETON N.J., 1987. *Age dating and the orbital theory of the ice ages: development of a high resolution 0 to 300,000-year chronology*. Quaternary Research, 27: 1-29.

MILANKOVITCH M., 1941. *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem*. Akad. R. Serbe, 133, 633 pp.

MURAT A., 1999. *Pliocene-Pleistocene occurrence of sapropels in the western Mediterranean Sea and their relation to eastern Mediterranean sapropels*. In: R. ZAHN, M.C. COMAS, A. KLAUS (eds.). *Proceedings of the Ocean Drilling Program, Scientific Results.* College Station TX, 161: 519-527.

OROMBELLI G., RAVAZZI C., CITA M.B., in press. *Osservazioni sul significato dei termini LGM (UMG), Tardoglaciale e postglaciale in ambito globale, italiano ed alpino*. Il Quaternario.

PATERNE M., GUICHARD F., LABEYRIE L., GILLOT P.Y., DUPLESSY J.C., 1986. *Tyrrhenian Sea tephrochronology of the oxygen isotope record for the past 60,000 years*. Marine Geology, 72, 3-4: 259-285.

PATERNE M., GUICHARD F., LABEYRIE L., 1988. *Explosive activity of the South Italian volcanoes during the past 80,000 years as determined by marine tephrochronology*. J. Volcan. Geoth. Res., 34(3-4): 153-172.

ROSSIGNOL- STRICK M., PATERNE M., BASSINOT F.C., EMEIS K.C., DE LANGE G.J., 1998. *An unusual mid-Pleistocene monsoon period over Africa and Asia*. Nature, 392: 269-272.

RYAN W.B.F., 1972. *Stratigraphy of late Quaternary sediments in the Eastern Mediterranean.* In: D.J. STANLEY (ed.), *The Mediterranean Sea*. Dowden, Hutchinson and Ross, Stroudsburg, PA: 149-169.

RUGGIERI G., SELLI R., 1949. *Il Pliocene e il Postpliocene dell'Emilia*. 18th IGC, London: 85-93.

RUGGIERI G., SPROVIERI R., 1975. *La definizione dello stratotipo del Piano Siciliano e le sue conseguenze*. Riv. Min. Siciliana, 26 (151-153): 8-14.

RUGGIERI G., SPROVIERI R., 1979. *Selinuntiano, nuovo superpiano per il Pleistocene inferiore*. Boll. Soc. Geol. It., 96: 797-802.

RUGGIERI G., UNTI A., UNTI M., MORONI M.A., 1977. *La calcarenite di Marsala (Pleistocene inferiore) e i terreni contermini*. Boll. Soc. Geol. It., 94: 1623-1627.

SALVADOR A., 1994. *International stratigraphic Guide. A guide to stratigraphic classification, terminology and procedure*. 2th ed., IUGS and GSA: 1-214.

SANVOISIN R., D'ONOFRIO S., LUCCHI R., VIOLANTI D., CASTRADORI D., 1993. *1 Ma paleoclimatic record from the Eastern Mediterranean-Marflux project: first results of a micropaleontological and sedimentological investigation of a long piston core from the Calabrian Ridge*. Il Quaternario, 6(2): 169-188.

SHACKLETON N.J., BERGER A., PELTIER W.R., 1990. *An alternative astronomical calibration of the lower Pleistocene timescale based on ODP Site 677*. Trans. R. Soc. Edinburgh, Earth Sc., 81: 251-261.

SPANO C., 1982. *Fauna del Tirreniano-tipo di Is Mesas-Calamosca (Sardegna Meridionale)*. C.R. Excursion-Table Ronde Tyrrhenien de Sardaigne, INQUA: 65-101.

SPANO C., 1991. *La faune benthique des niveaux a* Strombus bubonius *de Is Mesas-Cala Mosca (Sardaigne méridionale, Italie)*. As. Esp. Estudio Cuaternario, VIII Reun. Naz., Valencia, 19 pp.

SPANO C., 1993. *Signification bioécologique et bathymétrique des paléocommunautés pleistoceniques des côtes méridionales de la Sardaigne*. Estudios Sobre el Cuaternario: 27-42.

TUCHOLKA P., FONTUGNE M., GUICHARD F., PATERNE M., 1987. *The Blake polarity episode in cores from the Mediterranean Sea*. Earth Plan. Sci. Lett., 86: 320-356.

VAI G.B., 1996. *Revisione critico-storica dei piani marini del Quaternario*. Servizio Geologico Italiano, Miscellanea, VI: 1-179.

VAN COUVERING J., 1995. *Setting Pleistocene Marine Stages*. Geotimes, 40: 10-11.

VERGNAUD-GRAZZINI C., RYAN W.B.F., CITA M.B., 1977. *Stable isotope fractionation, climate change and episodic stagnation in the eastern Mediterranean during the Late Quaternary*. Mar. Micropaleont., 2: 353-370.

ZAGWIJN W.H., 1961. *Vegetation, climate and radiocarbon datings in the late Pleistocene of the Netherlands. Part 1 Eemian and early Weichselian*. Mededeel. Geol. Sticht., 14: 15-45.

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