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Calabrian and Ionian: A proposal for the definition of Mediterranean stages for the Lower and Middle Pleistocene

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The need to standardise stratigraphical subdivisions of continuous marine sedimentary successions that outcrop for hundreds metres, using clearly defined points fixed in the field is strongly felt. A proposal is presented here to formalize regional stages for the Lower Pleistocene (Calabrian) and for the Middle Pleistocene (Ionian) in Italy. The sections are well exposed, carefully investigated using multiple criteria (an integrated stratigraphical approach) and located in the central part of the Mediterranean. This area is recognized worldwide as a classical region for the Neogene and the Pleistocene sequences. The terrestrial record is directly correlated with the deep-sea record, as determined from ODP Sites 653 (Tyrrhenian Sea), 963 (Sicily Channel) and 964 (Ionian Sea) from the central Mediterranean. The present formal proposal is consistent with the INQUA and ICS decision to define and correlate the Plio/Pleistocene boundary (GSSP at Vrica) within the Olduvai Subchron, at 1.81 My, the Lower/Middle Pleistocene boundary at the Matuyama/Brunhes reversal at 0.78 My and the Middle/Upper Pleistocene boundary with the base of MIS 5, approximately 0.13 My. The present proposal also is consistent with the call for stage unit stratotypes that emphasize both the physical content of a stage and its boundaries (Hilgen et al., 2006).

Introduction and historical background

The Mediterranean, a semi-enclosed ocean basin that became isolated from the Indian Ocean in mid-Miocene times, was temporarily separated from the Atlantic Ocean during the Messinian salinity crisis. It then underwent important paleoceanographic changes after the early Zanclean deluge, with the deposition of climatically modulated, astronomically controlled sapropels (Hsü et al., 1973; Cita, 1975b; Van Couvering et al., 1976; Hilgen, 1991a; 1991b; Langereis and Hilgen, 1991; Lourens et al., 1996a). Actually, it behaves as an amplifier of the palaeoclimatic and palaeoceanographic signal (Cita and Mc Kenzie eds, 1999; 2000).

Open marine successions exposed near the shoreline in Southern Italy, especially in Sicily and Calabria, subject to uplift resulting from the still active geodynamic evolution, have been well known since the early days of stratigraphy.

Several marine stages have been defined as follows, in chronological order:

- Sicilian (Doderlein, 1872)
- Calabrian (Gignoux, 1910)
- Tyrrhenian (Issel, 1914)
- Milazzian (Deperet, 1918)
- Emilian (Ruggieri and Selli, 1949)
- Santernian (Ruggieri and Sprovieri, 1975)
- Crotonian (Ruggieri et al., 1977)
- Selinuntian (Ruggieri and Sprovieri, 1979).

The last was proposed as a super-stage in place of the Calabrian, and included from bottom to top the Santernian (cold), Emilian (temperate) and Sicilian (cold).

Palaeontology played a major role in the definition of all these stages, even during the 1970s much attention was paid to the so-called 'northern guests' that included the pelecypod *Arctica islandica* in shallow water settings and the foraminifer *Hyalinea balthica* and the ostracod *Cyteropteron testudo* in the deep water settings. According to Berggren and Van Couvering (1974) ... 'In actual fact, only the Calabrian, and perhaps the Sicilian, have the requisite characteristics of a time-stratigraphic unit. Pleistocene marine is in need of a more suitable chronostratigraphic subdivision'.

Some of these stage names have been used internationally for several decades (cfr. Haq and Van Eysinga, 1987; 1998) and their names are well established in the literature, in particular the Calabrian and Tyrrhenian, but none meets the current requirements prescribed by the International Commission on Stratigraphy (cfr. Hedberg, 1976; Cowie, 1986; Salvador, 1994).

On the basis of a careful historical analysis, these stages have been considered mostly as '*nomina nuda*' by Vai (1996).

Meanwhile the investigations of the Quaternary successions in the oceans, in ice cores, in lake deposits and in loess have drastically increased our knowledge whereas new techniques have improved the correlation potential in terms of time resolution and of credibility.

The application of the Milankovitch theory (1930) to the interpretation of ocean sediments recovered in deep sea cores, and the discovery that the isotopic composition of oxygen measured from the foraminifera shells, lead to the reconstruction of past climate fluctuations contributed to a revolutionary approach to palaeoclimatology (Hays et al., 1976). Cesare Emiliani was a pioneer in this field and first applied the method to an eastern Mediterranean piston core (Emiliani, 1955) and then to the classical Calabrian section of Le Castella (Emiliani et al., 1961, see below).

The Plio/Pleistocene boundary in the Vrica section has been accepted (Aguirre and Pasini, 1985; Van Couvering ed., 1997), but that definition does not make reference to the Calabrian Stage. Recently the ICS decided that no global stages and related GSSPs will be accepted for the Pleistocene, but only regional stages within a time scale generated from the Marine Isotope Stratigraphy.

Purpose of the present paper is to present to the international community; 1) the various sections originally used to define the Mediterranean stages; 2) those selected as the most representative for a modern, agreed definition, investigated and cross-correlated by means of biostratigraphical, magnetostratigraphical, isotopic and orbitally-tuned stratigraphy, and occasionally tephrochronologically defined; and 3) those investigated from ODP continuously cored drill-sites from the same area. The complete dataset represents a very strong framework, in that it is intercalibrated and has a correlation potential that extends well beyond the classical Mediterranean area.

Calabrian stage

First stage of the Pleistocene Series. Its base coincides with the Pleistocene GSSP in the Vrica section. Its top with the Ionian boundary stratotype (criterion guide the Matuyama/Brunhes boundary).

Figure 1 shows the stratigraphical framework of the interval investigated. Only magnetostratigraphy and calcareous plankton biostratigraphy are considered here, but isotopic stratigraphy and orbitally-tuned stratigraphy have been applied to some of the ten sections in which the Calabrian has been differentiated, and to the ODP drill-sites. References for the sections are as follows (the numbers are those identifying the sections representing the Calabrian in Figure 2).

1. References for the VRICA section are given in Selli et al. (1977), Colalongo et al. (1980), Pasini and Colalongo (1982), Tauxe et al. (1983), Backmann et al. (1983), Aguirre and Pasini (1985), Bassett (1985), Howell et al. (1990), Azzaroli et al. (1996), Rio et al. (1996a) and Lourens et al. (1996b).

2. References for the LE CASTELLA section are given by: Emiliani et al. (1961), Smith (1969), Iaccarino (1975), Raffi and Rio (1980a) and Rio (1982).

3. References for the SANTA MARIA di CATANZARO locality are as follows: Gignoux (1910), Gignoux (1913), Bayliss (1969), Smith (1969), Selli (1970), Sprovieri et al. (1973) and Broelsma and Meulenkaamp (1973).

4. References for the SINGA section include: Zachariasse et al. (1990), Zijdeveld et al. (1991), Hilgen (1991), Lourens et al. (1992) and Lourens et al. (1996b).

All these sections are located in Calabria (Figure 2). Vrica and Singa are considered the best, the latter for the excellent palaeomagnetic and astrochronologically tuned record.

There are four sections in Sicily:

5. MONTE SAN NICOLA (where the Gelasian GSSP is defined). References include; Channel et al. (1992), Rio et al. (1994) and Rio et al. (1998).

6. The CAPO ROSSELLO section. The Rossello composite (Hilgen and Langereis, 1988; Langereis and Hilgen, 1991) is considered the template for the global Pliocene stratigraphy and includes the Miocene/Pliocene boundary GSSP recently approved in 2000 (Van Couvering et al., 2000). The same Miocene/Pliocene boundary stratotype was originally proposed in 1972 at the IGC in Montreal (Cita, 1975b). The Rossello composite also contains the Piacenzian GSSP and a level, within the Monte Narbone Formation, correlated with the Gelasian GSSP (Lourens et al., 1996a; Castradori et al., 1998). This formation extends upwards well above the Plio/Pleistocene boundary, duplicating the Vrica section (auxiliary stratotype) beneath the Capo Rossello lighthouse (Figure 3). References are as follows: Cita and Decima (1975), Gartner (1977), Rio et al. (1984); Di Stefano et al. (1993) and Caruso (2004).

7. The FICARAZZI site which is the type locality for the Sicilian Stage. References include: Doderlein (1872); Gradstein (1970); Sissingh (1973); Ruggieri and Sprovieri (1975); Buccheri (1984); Ruggieri et al. (1984); Di Stefano and Rio (1981) and Rio (1982).

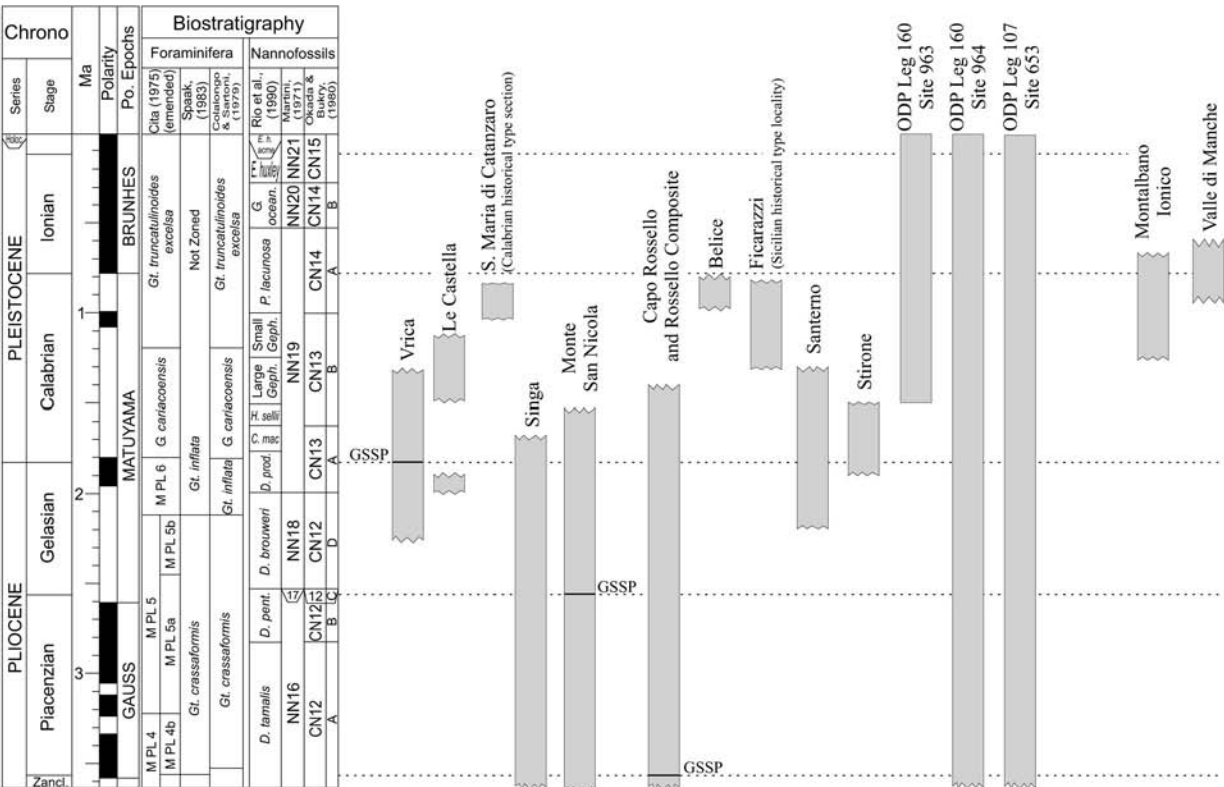
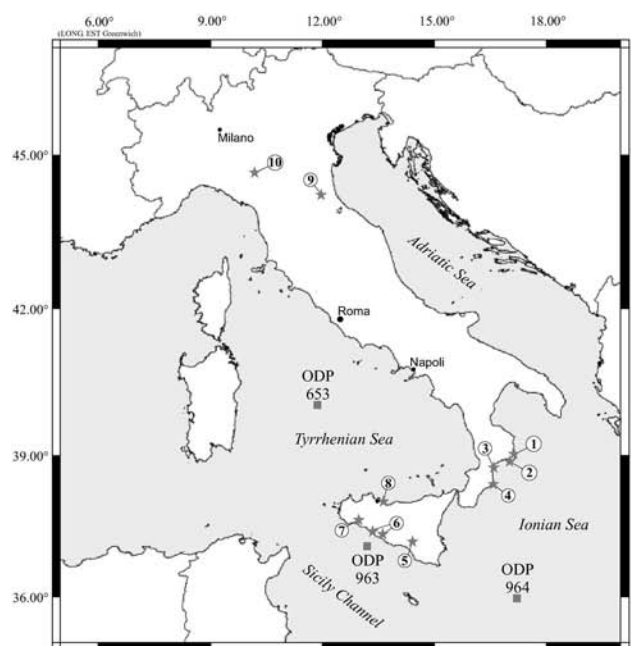
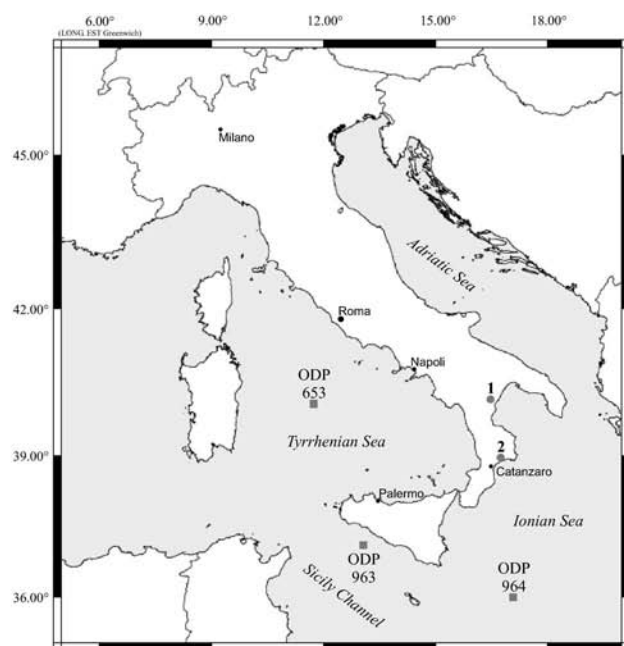


Figure 1 Stratigraphical framework showing the magnetostratigraphy and calcareous planktonic biostratigraphy of the time interval investigated. The stratigraphical range of the sections is indicative.



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| 1 - Vrica (Plio/Pleistocene GSSP). | 6 - Capo Rossello and Rossello Composite (Piacenzian GSSP and Zanclean GSSP). | 9 - Valle del Santerno. |
| 2 - Le Castella. | | 10 - Stirone. |
| 3 - Santa Maria di Catanzaro. | | ODP Leg 160 Site 963. |
| 4 - Singa. | 7 - Valle del Belice. | ODP Leg 160 Site 964. |
| 5 - Monte San Nicola - Gela (Gelasian GSSP). | 8 - Ficcarazzi. | ODP Leg 107 Site 653. |

Figure 2 Italian sections and ODP drill-sites representing the Calabrian Stage.



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| 1 - Montalbano Ionico. |
| 2 - Valle di Manche - San Mauro Marchesato (Crotone). |
| ODP Leg 160 Site 963. |
| ODP Leg 160 Site 964. |
| ODP Leg 107 Site 653. |

Figure 4 Italian sections and ODP drill-sites representing the Ionian Stage.



Figure 3 The Capo Rossello lighthouse segment section in which the Plio/Pleistocene boundary is well represented. It can be considered an auxiliary stratotype of the Vrica section.

8. The VALLE DEL BELICE site which is the locality for the Selinuntian Superstage: Ruggieri and Sprovieri (1979); Ruggieri et al. (1984); Buccheri (1985) and Di Stefano et al. (1991).

Important Calabrian sections located in northern Italy (Figure 2) include:

9. VALLE DEL SANTERNO. Type locality of the Santernian Stage (Ruggieri and Sprovieri, 1975). References include: Ruggieri (1954), Ruggieri (1957), Colalongo et al. (1974), Kukla et al. (1979), Pelosio et al. (1980) and Raffi and Rio (1980b).

10. STIRONE: Papani and Pelosio (1962), Bertolani Marchetti et al. (1979) and Pelosio et al. (1980).

The references for the ODP drill-sites are given under the Ionian below.

Ionian Stage

Second stage of the Pleistocene Series. Guiding criterion for its definition is the base of the Brunhes Chron. Its top is defined by the boundary stratotype of the third stage of the Pleistocene, for which

the proposed criterion guide is the base of MIS 5.

Unlike the Calabrian, this is a fairly new name, although it has been presented several times in the last few years. The location of the Ionian sections and of the ODP drill-sites are shown in Figure 4.

Two land sections straddling the Brunhes-Matuyama boundary have been investigated in detail to date. The first one is the Montalbano Ionico section, located in the core of the Apennine foredeep, continuous and spectacularly exposed, although magnetostratigraphic control is presently lacking (Figure 5). The second one is that of Valle di Manche Nord, located near the San Mauro Marchesato village (Figure 6), a less spectacular outer shelf section that is well constrained in time on the basis of biomagnetostratigraphy integrated with astronomically tuned stratigraphy (stable oxygen isotopes and glacioeustatic transgressive-regressive cycles; Rio et al., 1996). Both sections were visited during several international meetings, including that organised by SEQS (Subcommission of European Stratigraphy of INQUA) in 2000. The Montalbano Ionico section represents the most suitable boundary stratotype of the Ionian, once provided with a reliable magnetostratigraphy.



Figure 5 The Montalbano Ionico section (Ideale segment), in which the Calabrian/Ionian boundary will be defined. Arrows indicate the position of prominent ash layers V3 and V4.

Three ODP drill-sites in the Ionian (Site 964) and Tyrrhenian (Site 653) basins and in the Sicily Channel (Site 963) can be very precisely correlated by means of calcareous plankton, palaeomagnetic stratigraphy, sapropel stratigraphy, isotopic stratigraphy, astronomically tuned stratigraphy and tephrochronology.

Of particular importance is Site 963, located in the Sicily channel, off - Capo Rossello. The high sedimentation rate, undisturbed succession and absence of turbidites, provides an ideal continuation of the Rossello composite, and contains a full expression of the Ionian stage, without any hiatuses.

1. References for the MONTALBANO IONICO section are as follows: Cita and Castradori (1994; 1995), Van Couvering (1995); Ciaranfi et al. (1997); Ciaranfi and D'Alessandro (2000; 2004); Ciaranfi et al. (2000); D'Alessandro et al. (2003); Maiorano et al. (2004) and Stefanelli (2004).

2. The VALLE DI MANCHE (San Mauro Marchesato) section references are: Rio et al. (1996b); Massari et al. (1999); Massari et al. (2001); Massari et al. (2002) and Capraro et al. (2005).

ODP SITE 963 (Sicily Channel). References include: Emeis, Robertson, Richter et al., (1996); Robertson, Emeis, Richter and Camerlenghi (eds.) (1998); Di Stefano (1998) and Howell et al. (1998).

ODP Site 964 (Ionian Sea). References include: Emeis, Robertson, Richter et al. (1996); Robertson, Emeis, Richter and Camerlenghi (eds.) (1998); Sprovieri et al. (1998) and Howell et al. (1998).

ODP SITE 653 (Tyrrhenian Sea). References include: Kastens, Mascle et al. (1990); Rio et al. (1990a); Thunell et al. (1990); Rio et al. (1990b) and Glaçon et al. (1990).

Discussion

The present proposal results from a thorough discussion of all the data available after most shorebased studies deriving from ODP Legs 160 and 161 were published, and compared with the results obtained by a number of high-resolution stratigraphical studies carried out from measured sections in Sicily and Calabria. It is the third and final attempt to present a concrete proposal for the formalisation of regional stages for the Mediterranean classical area in order to stabilise the controversial chronostratigraphical subdivision (see discussion in Vai 1996).

A previous attempt was made after an International Workshop held in 1994, and reported by Cita and Castradori (1994; 1995) and Van Couvering (1995). The workshop proposed identification of the 'cold' Calabrian with the Lower Pleistocene, and the 'new' Ionian with the Middle Pleistocene, using the same sections proposed here. The main difference between the 1994 proposal and that presented here is that the basic criterion for the identification and correlation of the boundary between the two stages is the Matuyama/Brunhes mag-

netic reversal, as prescribed by ICS (Gradstein et al., 2004) and by INQUA (see below). This contrasts with the previous proposal which was to start the Middle Pleistocene close to the top of the Jaramillo Subchron, i.e. in correspondence with the so-called "mid Pleistocene climatic revolution" at the abrupt transition from the pre-glacial Quaternary to the glacial Quaternary. This event is very close to the change from the dominance of the 40 kyr cycles to the 100 kyr cycles (Hays et al., 1976; Shackleton et al., 1990; Berger et al., 1993; Berger, 1997). This proposal was in keeping with the practice of recognising the base of the Middle Pleistocene in the Mediterranean marine and continental records (Ruggieri et al., 1984; Rio et al., 1991) and was preferred by mammal paleontologists.

Moreover, some biostratigraphers did hesitate in supporting the proposal because the most classical Calabrian historical type section, i.e. the Santa Maria di Catanzaro section of Gignoux (1910), would have to be ascribed to the new Ionian Stage according to this definition, in addition to overlapping with the Sicilian of Doderlein (1872) which had priority (Figure 1). The consequence was that the 1994 proposal was not further developed.

At this point, it is worth quoting from Gibbard (2003) ... "The major divisions of the Pleistocene, Lower, Middle and Upper, are agreed to be subseries (or subepochs), according to Richmond (1996) and conform to the International Stratigraphic Guide recommendations (Hedberg, 1976, p.10, 68). At present in the Pleistocene they remain undefined from stratotype localities in spite of the fact that in Europe at least these terms are used in a quasi-formal sense".

The need to define such events at GSSPs has been re-emphasised by Aubry et al. (1999).

According to Gibbard (2003) in order to improve the situation the INQUA Working Group solicited opinions from a large number of concerned workers (Richmond 1996). The results proposed and approved at the XII INQUA Congress were summarized as follows (Anonymous, 1998) "As evolutionary biostratigraphy is not able to provide boundaries that are as globally applicable and time-parallel as are possible by other means, the Lower-Middle Pleistocene boundary should be taken provisionally at the Matuyama/Brunhes paleomagnetic reversal and the Middle-Upper Pleistocene boundary at the base of the deep-sea Oxygen Isotope Stage 5" (Figure 6).

Returning to the 1994 proposal (Cita and Castradori, 1994; 1995, Van Couvering, 1995) it should be stressed that it pre-dated:

- a) the INQUA/ICS decision to use the Matuyama/Brunhes reversal as the major correlation tool for the Lower-Middle Pleistocene boundary (see discussion above and Head and Gibbard, 2005);
- b) the trans-Mediterranean transect of continuously cored drill-sites (ODP Legs 160–161; Emeis, Robertson, Richter, et al., 1996; Comas, Zahn, Klaus, et al., 1996; Robertson, Emeis, Richter and Camerlenghi (eds.) 1998; Zahn, Comas and Klaus (eds.) 1999) that greatly contributed to intercalibration of the Plio-Pleistocene deep-sea record with the sequences exposed on the land.

Conclusion

The aim of this proposal is to clarify the confusion arising from the various and sometimes contrasting interpretations offered in the last several months on the chronostratigraphical versus climatostratigraphical, formal versus informal use of the term Quaternary (cfr. Pillans, 2004; Pillans and Naish, 2004; Gradstein et al., 2004; Gibbard et al., 2005; Aubry et al., 2005; Suguio et al., 2005; Salvador, 2006a, b) or what could be called the "Quaternary Quo Vadis" syndrome.

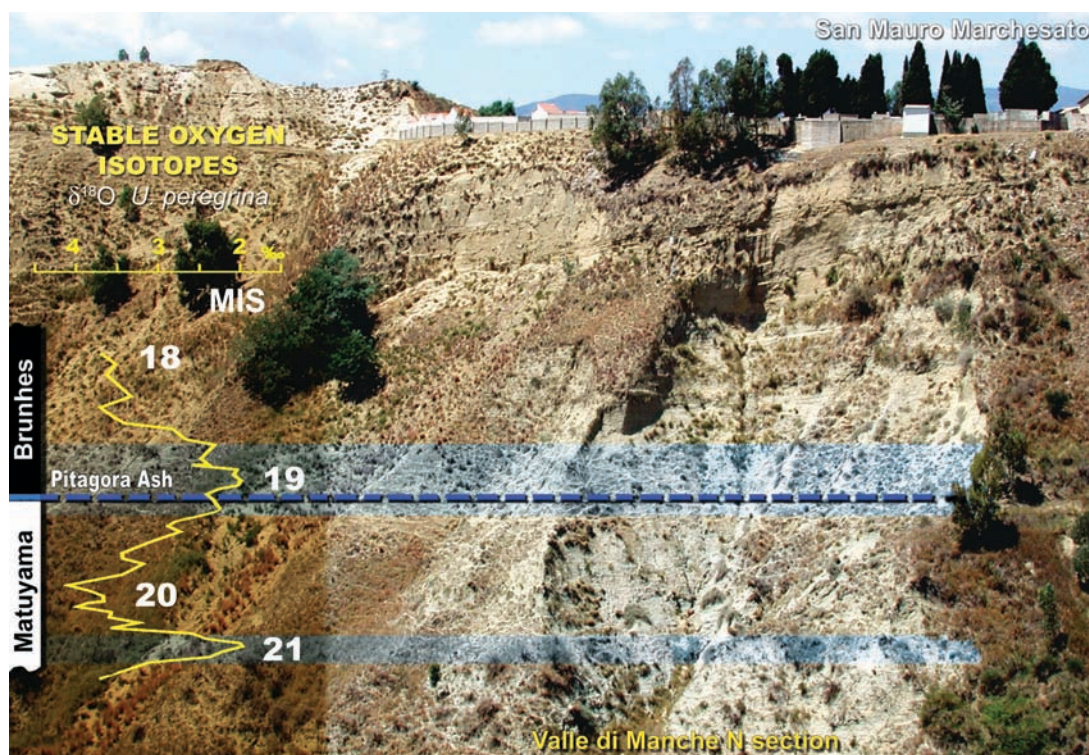


Figure 6 The coarsening and shallowing-upward middle-outer shelf Valle di Manche N section, where the Matuyama-Brunhes magnetic reversal was confidently detected. The section, which is some 50 meters thick, spans from full MIS 24/22 glacial to late MIS 18 glacial. Above, further stratigraphy is preserved (see the prominent clinoforms just below the build area), however chronology becomes poor due to the inner shelfal setting. Thick bands in light blue indicate interglacial intervals based on the benthic foraminiferal $\delta^{18}\text{O}$ record. Position of the Brunhes-Matuyama boundary (middle MIS 19) is easily recognizable in the field, as it occurs close to a prominent ash layer (Pitagora Ash, here indicated by the blue dashed line).

The sections presented are well exposed, carefully investigated using multiple criteria (a fully integrated stratigraphy) and located in the central part of the Mediterranean, an area recognised globally as a classical reference area for the Neogene and for the Pleistocene. In this region the terrestrial record can be directly correlated with that in the deep-sea, as achieved at ODP Sites 653 (Tyrrhenian Sea), 963 (Sicily Channel) and 964 (Ionian Sea). The present formal proposal is consistent with the INQUA and ICS decision to recognise the Plio/Pleistocene boundary (GSSP at Vrica) the basic criterion for definition and correlating within the Olduvai Subchron, at 1.81 My, the Lower/Middle Pleistocene boundary close to the Matuyama/Brunhes polarity reversal at 0.78 My and the Middle/Upper Pleistocene boundary with the base of MIS 5, approximately 0.13 My.

A full report on the Calabrian and Ionian unit-prototypes and their deep-sea equivalents, based on selected sections, is in preparation, and will follow shortly. The complete dataset is very strong within a well-constrained time frame and provides an excellent reference sequence for the Pleistocene Mediterranean marine successions.

Acknowledgments

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