Research proposal for the 40th cycle of the PhD program in Earth Sciences
University of Roma "Sapienza"

Ph.D school "Vito Volterra" in Astronomy,
Chemistry, Physics, Mathematics and Earth Sciences

Project title:

Resilience of Mediterranean planktonic foraminifera to Plio-Pleistocene transition climatic impact

Candidate:
Name and Surname: Miriam Raimondi
Place and date of birth: Bari (BA) 04/11/2000
E-mail: miriam.raimondi@uniroma1.it

Proposed Internal tutor:
Prof. Fabrizio Lirer
E-mail: fabrizio.lirer@uniroma1.it

Proposed External tutor:
Prof.ssa Isabel Cacho
E-mail: icacho@ub.edu

Introduction

The Earth's climate system, influenced by natural and human factors, is evolving continuously, impacting socio-economic development and ecological systems.
Human societies have been living adapting to a variable climate and environment and recent studies suggested the important role of climate changes in societal and cultural organizations during the last millennia.

The study of historical records, aimed towards a better understanding of the Earth's climatic system and a more accurate prediction of its future evolution, is one of the most important priorities of the scientific community (e.g., IPCC, 2000, 2007).

The Pleistocene time interval spans from 2.58 Ma to 0,117 Ma and represents the transition from the warm Pliocene (3.0-3.3 Ma) to the progressive development of large-scale Northern Hemisphere ice sheets caused a long-term cooling event.

Furthermore, combining all the information will open enormous possibilities for understanding the resilience of past environments to climate changes and will contribute to provide solid insights to develop predictive climatic models, which will contribute to manage environmental dynamics expected to affect the Earth systems over the next years.

State of art

It is well known that the Earth's climate cyclically changed, suddenly passing from glacial to warm phases.
Nowadays, the climate is changing faster than in the recent past, posing potential threats on different ecosystems and biota (Baselga et all. 2009; De lange et all. 2008).
According to *Horizon 2030* and the *IPCC 2007*, the study of fossil archives remains the only valid analytical tool to analyse the Earth's dynamic processes in conditions different than those of the present and will provide a crucial contribution in the determination of the reliability of medium- and long-term predictions models, even if we must be aware that a direct past analogue of future climate changes does not exist.

The Mediterranean Region is a sensitive ecosystem that feels the effects of climate change and is also affected by high anthropic pressure.
Within this scenario, the Mediterranean basin, due to its limited size and morphological characteristic, influenced by mid-latitude westerly winds and subtropical high-pressure belt over northern Africa, and high sedimentation rates over the last 23 Ma, is a natural laboratory where is it possible to acquire and explore historical time series to analyse the resilience of marine ecosystem to past climate change (Margaritelli et all. 2016; Margaritelli et all. 2018).
In addition, the basin experienced the development of past episodes of deep-sea organic carbon accumulation in sediments (sapropels) (De lange et all. 2008; Emeis et all. 2003; Rohling et all. 2015), which occurred periodically (Hilgen et all. 1991; Lourens et all. 1996) throughout Neogene-Quaternary, in the eastern and (less frequently) in the western Mediterranean basins, which are divided by the Strait of Sicily.

Many research efforts have been spent investigating sedimentary successions accumulated in warmer settings to build predictive models and they include i.e. deposits accumulated during the Piacenzian climate optimum (Pliocene Warm Period 3-3.3 Ma), which is supposed to have registered climatic settings similar to those predicted for the near future.

The holistic approach is crucial to developing and testing predictive climatic models, which will greatly contribute to managing environmental dynamics that will affect the Earth systems over the next years.
In this framework, the Plio-Pleistocene Transition *(Fig.1)*, that spans the base of the Gelasian stage (2.58 Ma), is one of the more enigmatic and less understood time-intervals of the overall Quaternary which contains the shift from precessional influence to a predominant obliquity pacing that occurs at ~2.45 Ma (Marine Isotope Stage – MIS 100).

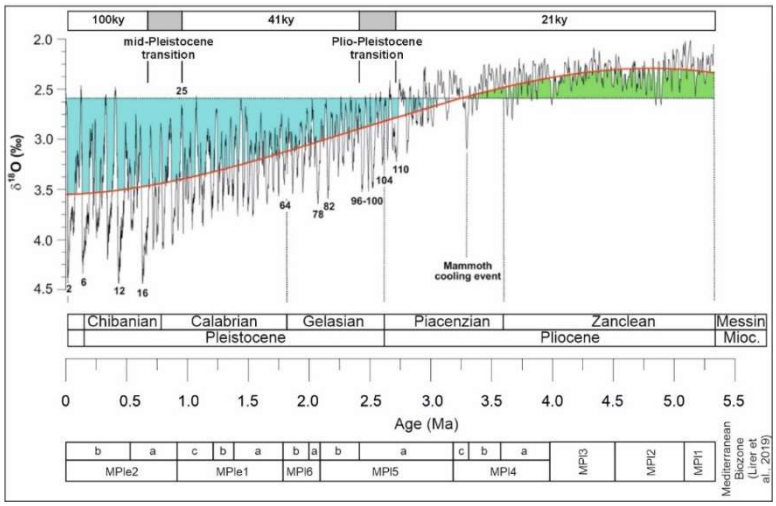

Figure 1
Comparison between major events in the global benthic foraminiferal d^{18}O stacked record (Lisiecki et all. 2005), chronostratigraphic subdivision of the late Cenozoic, Mediterranean biostratigraphy scheme and the position of PPT. The grey bars represent the transition interval between changes in astronomical forcing.

The PPT approximates a cluster of prominent "cold" episodes (MIS100-MIS96) interpreted as the global climatic response to the definitive onset of large and stable ice sheets in the northern hemisphere. The cooling is evidenced by changes in calcareous plankton assemblages, changes in SST, the beginning of loess sedimentation in China, palynological Pretiglian/Tiglian boundary in Europe, and important migration events in mammalian fauna in the Eurasian region (Rio et all. 1998; Herbert et all. 2015; Lisiecki et all. 2005).

In the Mediterranean the PPT is stratigraphically documented in central (Hilgen et all. 1991; Becker et all. 2005; Sprovieri et all. 1998) and eastern basin (Becker et all. 2005), where no distinct sapropels are recorded and associated to a weakened monsoonal circulation (Grant et all. 2022; Colleoni et all.2012).

This interval probably includes the impact of the Panamanian gateways closure that determined the eastwards branch of the El Labrador Current, with consequent cold waters inflow (North Atlantic Current and Subarctic Front) (Lourens et all. 1992; Becker et all. 2005) into the basin. However, the impact of this series of events (short-term cooling and shift from precessional influence to a predominant obliquity) in the Mediterranean area was not analysed in detail and not entirely understood.
From the northern part of the hemisphere to the south, environmental changes at the PPT are not uniformly expressed, and understanding the overall Mediterranean response to the PPT climate change is crucial to open new scenarios on the global significance of climate change. In addition, insight on the Mediterranean region can provide some clues about past significant climate changes since the basin reflects the climate dynamics of both high-latitude and low-latitude regions, being connected to the North Atlantic and subjected to monsoon influence.

Overall objective

Analysis of Mediterranean planktonic foraminiferal resilience to Plio-Pleistocene Transition (PPT; 2.4-2.7 Ma) climate oscillation, when glacial periods start to be controlled by obliquity in the Northern Hemisphere.

Specific objective

- High-resolution multi-proxy study (planktonic foraminifera, geochemistry, cyclostratigraphy) of Plio-Pleistocene Transition (2.4-2.7 Ma) from Marine Isotope Stages 111 (MIS111) to 96 (MIS96) in the eastern Mediterranean marine records (ODP-site 964 and ODP-site 967)
- Reconstruction of Sea Surface Temperature (SST) in the deep marine ODP sites 964 (Ionian Sea) and 967 (Levantine Sea)
- Analysis of the synchronicity of Mediterranean planktonic foraminiferal and SST responses to rapid changes in continental ice-sheets, confirmed by major shifts in benthic foraminiferal oxygen isotope records (Lourens et all. 1992; Rio et all. 1998)
- Analysis of the resilience of Mediterranean planktonic foraminiferal assemblages during the PPT climate perturbation

Implications and/or applications

These project aims to bridge key knowledge gaps in climate science, for instance, high-resolution quantitative analyses of the foraminifera assemblages have never been carried out on these successions, which would be easily correlated through the well-developed sapropel intervals.
In three years, I'll be able to link all the taxonomic and chemical data in order to achieve the main goal of the project. This correlation will open enormous possibilities for understanding the resilience of past environments to climate changes and will contribute to provide solid insights to develop predictive climatic models, which will contribute to manage environmental dynamics expected to affect the Earth systems over the next years.
Advanced research tools acquired through the project will develop technological capabilities, fostering international collaboration and training the next generation of climate scientists.

Research activities

The two strategic records are present from ODP Leg 160: Site 967 and Site 964.
Site 967 is located south of Cyprus on the slope of Eratosthenes Seamount was cored at a water depth of 2554 m, while Site 964 is located in the Pisano Plateau (Ionian Basin) was cored at a water depth of 3650m.

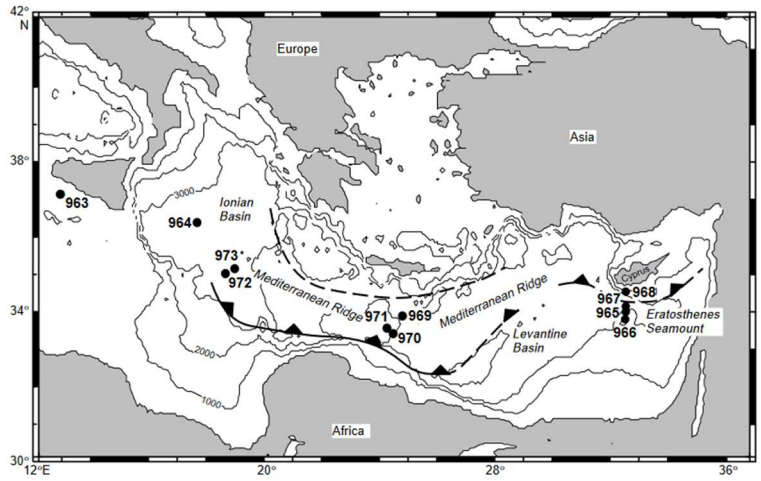

Figure 2
Map showing the location of ODP Leg 160 Site 964 and 967 da Kroon D. et al.,1998

Both cores recover a succession from present-day sediments to Pliocene deposits dated up to ~2.8 Ma. These deep marine records cross several sapropel layers whose origins were closely related to climate changes induced by astrochronological forcing.
Solid datasets are available for these records, including chronological and geochemical data (ODP 967 - *Grant et al. 2022*; ODP 964 also quantitative calcareous nannofossils and planktonic foraminifera - *Sprovieri et al., 1998*).

However, high-resolution quantitative analyses of planktonic foraminifera assemblages, stable isotopes and SST records have never been carried out on these successions, which would be easily correlated through the well-developed sapropel intervals.

This goal will be achieved by doing and integrating all of the following activities and methodologies.

Study sites and Sampling

The ODP Leg 160 sites 964 (Grant et all. 2022) and 967 (Sprovieri et al 1998; Howell et al 1998) *(Fig.2),* contain a well-developed and astro-chronologically constrained sapropels succession over the last ~4 Ma (Rohling et all. 2015; Emeis et all. 1996) (*Fig.3)*. Both sites stored at MARUM ODP core repository in Bremen have been sampled every cm with a time resolution of ca. 4 kyr for about 300 samples.
Both ODP sites contain a well-developed sapropels succession well astro-chronologically constrained (Sprovieri et all. 1998; Grant et all. 2022).

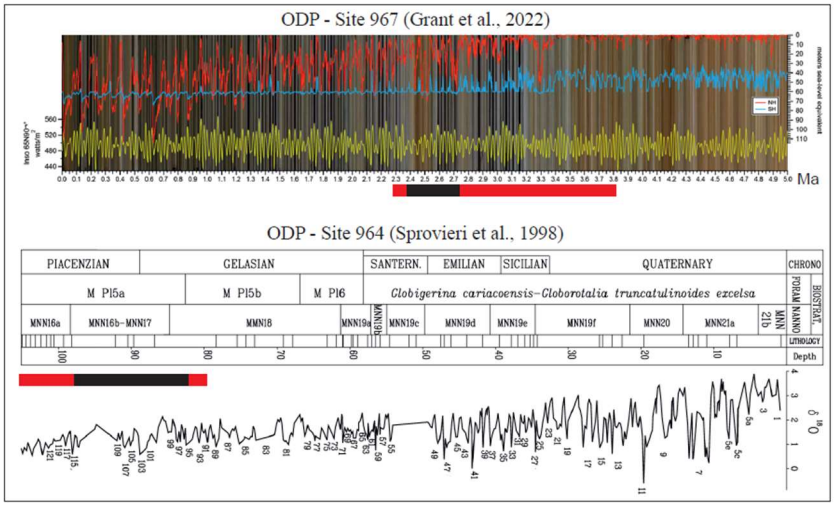

Figure 3
Sapropel chronology of ODP-Site 967 from Grant et al., (2022) and integrated biostratigraphy and stable isotope stratigraphy ODP – Site 964 from Sprovieri et al., (1998).
Colored line from top: sea level N hemisphere, S hemisphere, isolation curve
Black vertical line sapropels
Rectangle red and black, study area

Bibliographical analysis

The first months of the first year will be dedicated to study and analyse all the Mediterranean and extra-Mediterranean scientific literature on PPT time interval, on the ODP site 964 (Ionian Sea) and ODP Site 967 (Cyprus area), as well as to recover all the useful data spanning the PPT interval. This activity will improve my knowledge about the study area, the PPT scientific issue and the tools / methodologies (cyclistratigraphy, stable isotope and Mg/Ca SST reconstruction) those will be used to investigate the study marine cores.
In addition, I will prepare samples from ODP-Site 967 for micropaleontological analysis, and I will work, in collaboration with Lucas Lourens from Utrecht University, to prepare the new composite depth record for ODP-Site 964 (Ionian Sea). This last activity is preparatory to ask samples for this site at Bremen ODP-core repository and for the astronomical tuning of the study record.

Biostratigraphy

Quantitative analysis on planktonic foraminifera (counting ca. 300 specimens > 125 μm), will provide the first data from eastern Mediterranean, useful to verify the high-resolution correlation between the Ionian and Levantine basins and identify sub-Milankovitch climate oscillations.
The study interval (2.7-2.4 Ma) falls within the MPL5 planktonic foraminiferal zone, according to *Lirer et al. (2019)*. However, to validate the site 964-967 correlation, biostratigraphic study will extend from 3.8 to 2.3 Ma to identify the occurrence of following bioevents: *G. margaritae* Last Common Occurrence (LCO) and Last Occurrence (LO), *G. puncticulata* LO, *G. crassaformis* and *G. bononiensis* First Occurrence (Fos), *G. bononiensis* LCO and LO.

Mg/Ca Ratio Analyses

Mg/Ca ratio on planktonic foraminifera *Globigerinoides ruber* white variety (ca. 60 individuals) will be used to reconstruct Sea Surface Temperature (SST) and it will measure at the CCiT-UB Centers of Barcelona University under the supervision of Prof.ssa Isabel Cacho.
Planktonic foraminifera cleaning (Pena et all. 2005) and dissolution procedure will be performed at the Grey Lab of Barcelona University.
The cleaning part is important in order to have only the shell without oxides or additional dirt and is carried out on already crushed foraminifera while the dissolution one dissolve sample in liquid because the machine work only with plasma at very high temperature.
Instrumental analyses in an inductively coupled plasma mass spectrometer (ICP-MS Perkin Elmer ELAN 6000) at the CCiT-UB Centers of Barcelona University.
The Mg/Ca ratios will be converted in Sea Surface Temperature (SST) values according to the *G. ruber* calibration of *Elderfield and Ganssen (2000)*.

Stable Isotope Analyses

Oxygen and Carbon stable isotope analyses will be performed on planktonic foraminiferal species (*G. ruber* white, *Neogloboquadrina pachyderma* and *Globigerina bulloides*) hand-picking ca. 15 specimens from studied samples (>150 µm). *(Fig.4)*

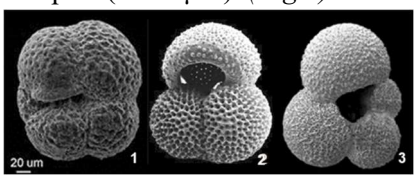

Figure 4
1 Neogloboquadrina pachyderma right coiled 2 Globigerinoides ruber white, 3 Globigerina bulloides (Schiebel et all. 2017)

The samples were crushed and sonicated in methanol to remove fine-grained detrital particles.
These analyses will be performed at the DST Geochemical Laboratory of Sapienza Rome University with a Thermo Scientific Delta V Advantage continuous flow mass spectrometer according to the standard procedures (Coplen et all.1996).

Project innovation and Impact

PPT interval is well-studied at higher latitudes in the northern hemisphere, but there is a lack of data for middle and low latitudes. An innovative approach, based on both well-established and newly-developed analytical methods will be applied to understand and to characterize quantitatively the biotic and abiotic responses to climate perturbations at middle latitudes (Mediterranean) creating a communicative bridge for future studies at lower latitudes.
This project proposal aligns with the "fundamental research" framework of *Horizon2030* Goals 13, 14 and 15 for sustainable development, and the main objectives of the *PNRR* (Piano Nazionale di Ripresa e Resilienza), emphasizing the importance of scientific outputs for better management of natural systems under climate change and anthropogenic pressure.

Dissemination

Results will be shared following EU regulation 2021/24, article 34, as follows:

- Scientific Community: participation in thematic meetings (e.g., EGU, AGU) and publication in open-access journals (at least 2 articles). Presentation at national and international conferences to illustrate and disseminate the overall results, create a meeting point of discussion with other researchers and develop forthcoming collaborations.
  Data will be available in open repositories (eg Scientific Data, NOAA).
- Pop Science: dissemination to the public through events like White Night of Laboratory and European Researchers' Night. Use of social media platforms to reach younger audiences. Publication in local and science divulgation journals (e.g. Geologicamente, Pages Magazine)

Education

I will attend courses and seminars at Sapienza University and other international institutions (e.g. Marine Geology Advanced School Deep Sea Frontiers, Urbino Summer School in Paleoclimatology, Bremen ECORD Summer School), as well as participate in relevant international and national conferences (EGU-Vienna, TMS-CFFR Foraminifera Meeting, SPI, AIQUA, SGI…).

International mobility

International mobility will be carried out at the Departament de Dinàmica de la Terra i de l'Oceà of Barcelona University under the supervision of Prof. Isabel Cacho, a Spanish geologist specialised in the reconstruction of climate variability based on the analysis of marine sediments. The main activities will be focused of Mg/Ca SST reconstruction and to improve the collaboration with the Research group in Marine Geosciences of Barcelona University.

Time schedule and key results

Research activity:

- I year: bibliographical analysis on PPT and ODP sites, planktonic foraminifera quantitative analysis (sites 964 and 967correlation) and handpicking for stable isotopes.
- II year: stable isotope and Mg/Ca analysis, submit manuscript on planktonic foraminifera site 964 and 967.
- III year: submit new manuscript on SST reconstruction and write PhD thesis.

Education: Seminars and Summer schools (I-II year)

Dissemination: Congress and publications (I-II-III year)

(Gantt chart, Fig.5)

Milestones:

- I year, preliminary high-resolution quantitative analyses of planktonic foraminifera assemblages
- II year, results from Mg/Ca and stable isotopes
- III year, final SST reconstruction and conclusions

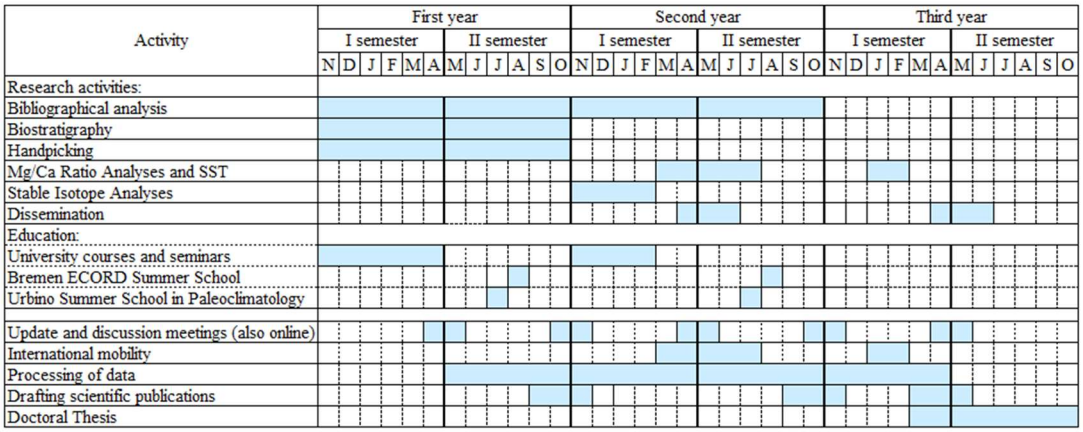

Figure 5

References

- *Baselga et all. 2009.Ecography 32.1 : 55-65*
- *Becker et all. 2005.Palaeogeography, Palaeoclimatology, Palaeoecology 228.3-4 : 338-360*
- *Colleoni et all.2012. Earth and Planetary Science Letters 319: 35-44*
- *Coplen et all.1996. Eos, Transactions American Geophysical Union 77.27: 255-255*
- *De lange et all. 2008*
- *Emeis et all. 1996. Emeis, K.-C., Robertson, AHF, Richter, C., et al., Proc. ODP, Init. Repts. Vol. 160*
- *Emeis et all. 2003 Paleoceanography 18.1*
- *Grant et all. 2022 Communications Earth & Environment 3.1: 11*
- *Herbert et all. 2015 Earth and Planetary Science Letters 409: 307-318*
- *Hilgen et all. 1991 Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences 357.1757: 1931-1947*
- *Horizon 2030*
- IPCC, 2000, 2007
- *Kroon et all. 1998 Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 160; Chapter 14*
- *Lirer et al. 2019 Earth-Science Reviews 196 (2019): 102869*
- *Lisiecki et all. 2005 Paleoceanography 20.1*
- *Lourens et all. 1992 Marine Micropaleontology 19.1-2: 49-78*
- *Lourens et all. 1996 Paleoceanography 11.4: 391-413*
- *Margaritelli et all. 2016 Global and Planetary Change 142: 53-72*
- *Margaritelli et all. 2018 Global and Planetary Change 169: 179-187*
- *Pena et all. 2005 Geochemistry, Geophysics, Geosystems, 6(9)*
- *Rio et all. 1998 Episodes Journal of International Geoscience, 21(2), 82-87*
- *Rohling et all. 2015 Earth-Science Reviews, 143, 62-97*
- *Schiebel et all. 2017 Planktic foraminifers in the modern ocean*
- *Shackleton et all. 1984 Nature 307.5952: 620-623*
- *Sprovieri et all. 1998 Integrated calcareous plankton biostratigraphy and cyclostratigraphy at site 9641*