EUROPEAN SCIENCE FOUNDATION
SHORT VISIT-GRANTS

Scientific Report for the Urbino Summer School in Paleoclimatology 2014: *Past Global Change Reconstruction and Modelling Techniques*

ÁNGELA GARCÍA-GALLARDO

1. Purpose of the visit

I am involved as a PhD student in FWF-project P25831-N29 of the Austrian Science Fund, part of the research goals of Expedition 339 of the Integrated Ocean Drilling Program (IODP) that explores the environmental significance of the Mediterranean Outflow water (MOW) and its role as a component of North Atlantic circulation and thus in global climate.

The opening and closing of ocean gateways play an important role amongst climate forcing mechanisms: surface and deep-water circulation are altered and hence global heat transport. An important component of North Atlantic circulation patterns is the warm and saline Mediterranean Outflow Water (MOW) that enters the North Atlantic via the Gibraltar Strait. Its onset and early history after the opening of the Gibraltar Strait are poorly constrained and its impact on oceanography and climate in the Pliocene are largely unexplored. The scientific objectives of this project aim to improve our knowledge about the early phase of MOW. My research is focused on the analysis of micropaleontological (foraminifera) and geochemical proxies (stable isotopes, trace elements, organic/inorganic carbon content) to upper Miocene-Pliocene sediments of IODP Sites U1387 (upper Miocene-lower Pliocene; ~5.8-3.8 Myrs) and U1389 (middle-upper Pliocene; ~3.7-2.8 Myrs) (Figure 1) drilled during IODP Expedition 339 in the northern Gulf of Cádiz.

The short visit consisted on the attendance to the Urbino Summer School in Paleoceanography (USSP): *Past Global Change Reconstruction and Modelling Techniques* (http://www.urbinossp.it/) in Italy during July 2014. The program of the USSP 2014 included in-depth courses on paleoclimatology and paleoceanography by experts in the respective fields. A high percentage of the talks were topics directly applicable to my PhD thesis as key tools to reconstruct the Miocene-Pliocene history of MOW. This summer school has provided me with crucial knowledge to achieve the research goals of my PhD thesis and, ultimately, IODP Expedition 339.

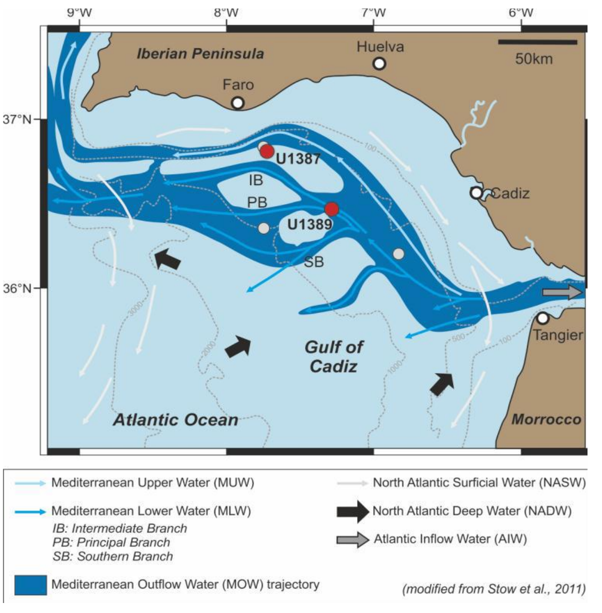

Figure 1. Sketch map of the study area in the Gulf of Cadiz. The location of the selected sites U1387 and U1389 are indicated in red.

2. Description of the work carried out during the visit

The USSP consisted of a series of lectures, conferences and field trips and practicums on different fields but all of them related to the study of the past climate, with up to date information about the tools and use of paleoproxies in reconstructing and modelling of past climates and also the implications and interpretations for an appropriate understanding of present and future climates.

The program was quite varied and wide so that in this report I will focus on the most interesting points I learned at the summer school that are directly applicable to the development of my PhD. Here I present a summary of the different talks (the lecturer is indicated in brackets), as well as a brief paragraph detailing how I can apply that knowledge/technique to my PhD project.

<u>Climate and ocean interactions-Orbital forcings (Sietske J. Batenburg, Goethe-University Frankfurt)</u>

The radiation coming from the Sun is not equitably distributed over all the Earth’s surface due to the astronomical forcing and other internal factors (tectonic processes, volcanos, energy exchange, atmosphere-ocean interactions,…). The annual distribution of radiation is higher at low latitudes and the differences between both hemispheres vary depending on the seasons, which in turn are the result of the rotation and the inclination of the axis (obliquity). As a consequence, poles lose more energy than they gain, and the opposite occurs in the Equator. The energy is transported from the equator to the poles by a mechanism in cooperation between atmosphere and ocean, and different cells are formed, determining the climate in the different regions. On the other hand, feedbacks play an important role on the intensification or attenuation of the effects.

Earth’s climate system is thus determined by a combination of external (solar irradiance, orbital configuration, extraterrestrial dust, meteor impacts) and internal (tectonics, volcanism, sea-level, icesheets, biological evolution, green-house gases) forcing mechanisms (Ruddiman, 2001). Within the external forcing, orbital variations are one of the most important determinants of climate, and it has three components regarding the terrestrial setting: precession, obliquity and eccentricity.

The precession is referred to the gradual shift in the orientation of Earth's axis of rotation, which, like a wobbling top, traces out a pair of cones joined at their apices in a cycle of approximately 26,000 years. The obliquity is the angle of the Earth's axial tilt, which varies with respect to the plane of the Earth's orbit with a small angle of 2.4°, enough to produce climatic variations, the shift on the obliquity variations is periodic and takes approximately 41,000 years to shift between a tilt of 22.1° and 24.5° and back again. The eccentricity is referred to the elliptical orbit that the Earth describes around the Sun, so that the closest point to the Sun is called perihelion and the furthest point is called aphelion. The Earth's orbit undergoes a cyclical change from less eccentric to more eccentric and back. One complete cycle for this kind of variation lasts for about 100,000 years. These cycles are called the Milankovitch Cycles after the Serbian geophysicist Milutin Milankovitch used them to explain the glaciations and the advance and retreat of the polar ice caps, and result in long term fluctuations in the energy that reaches the Earth. There is good evidence that these changes in insolation have influenced the Earth's past climate.

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Ocean currents are the result of different forcings like wind, density, thermic expansion and contraction, and others controlling the direction as Coriolis, gravity, friction and the seafloor morphology. Temperature in the oceans is controlled by solar radiation and salinity by precipitation. The combination of both results in the thermohaline circulation, which is the motor of the deep ocean, acting as a conveyor belt that connects all water masses. Deep water formation occurs in North Pole (Greenland) and Labrador Sea, where the cold temperatures and high densities of water masses make the water to sink, while at lower latitudes, the water is warmer and less salty, so that it flows more superficially.

In application of these parameters to my project, high-resolution records of $CaCO_3$ contents have been already acquired from IODP Site U1389E (Figure 1). The preliminary results reveal distinct cyclic patterns in well recovered intervals potentially related to orbital forcing. The average length of the cycles is 20kyrs and is thus potentially related to precessional forcing. The presence of precessional cycles agrees well with a study by Sierro et al. (2000) that suggests that river runoff into the Gulf of Cadiz is driven by precession during the Pliocene.

Pliocene and MPTO (Christina Ravelo, University of California, Santa Cruz)

Global deforestation and the combustion of fossil fuels have resulted in a pronounced and rapid increase in the concentration of atmospheric CO_2 over the last 150 years. It is predicted that the level will double the pre-industrial (280 ppm) sometime in this century. CO_2 is a greenhouse gas so that its increase will contribute to global warming (Raymo *et al*., 1996).

As a consequence, climate is changing and the uncertainty of the effects promoted paleoclimatologists to focus on possible analogues from the past to predict future climate change. The MPTO (4.5-3.0 Myrs; Cronin, 2009) that culminates in the Mid-Piacenzian Warm Period (MPWP, 3.3-3.0 Myrs; Salzmann et al., 2011) is the most recent period in Earth's history in which global warmth reached temperatures similar to those projected for the end of this century, about 2-3 °C warmer globally on average than today (IPCC, 2007). The Mid-Pliocene is interesting in this aspect because the land-sea configuration, ocean circulation and flora and faunal distributions were similar to the present day, as well as the sunlight incidence on Earth and the concentration of cO2. These similarities to the present day allow us to understand mid-Pliocene climate, from both data and modelling perspectives, in the framework of modern climate (Robinson *et al*., 2008).

One of the main objectives of my PhD project addresses the mid-Pliocene warm-house climate and the transition into the cooler climate of the Late Pliocene – Recent. The MPTO has gained increasing attention in the debate on future climate change (IPCC, 2007). As part of the objectives of IODP Expedition 339, one important point is the significance of variations in MOW for North Atlantic circulation and in turn for paleoclimate (Stow et al., 2011). A detailed Pliocene record of MOW close to its source region will be established, and the proximity of the sampling location to the Strait of Gibraltar will provide a substantially more pronounced MOW signal than in previous studies from more distal areas.

Marine organisms as proxies of climate changes (by Jorijntje Henderiks, Uppsala University, Sweden)

Climatic registers are the source that provides information about past climates. They are given by proxies or indicators of a specific climate parameter. Examples of different registers are the ring trees (dendrochronology), ice cores, sediment cores from lakes/oceans, corals and speleothems. In marine environments, there are different organisms such as algae, plants, and animals like diatoms, radiolarians and foraminifera.

Foraminifera are protist organisms within the order Foraminiferida. They are defined by Loeblich and Tappan (1987) as "*cytoplasmic body enclosed in a test or shell of one or more interconnected chambers*…". The tests remain in the sediments as fossils making them a fundamental tool in biostratigraphy, age-dating and paleoenvironmental interpretation (Loeblich and Tappan, 1987) and they can be composed of different material. There are foraminifera whose tests are composed of organic matter, but they are not very useful owing to they are cannot be preserved and thus they are rarely represented in fossil assemblages. Most of the foraminifera have calcitic tests, and three types of walls are recognized. A) Agglutinated tests have a composite appearance made of foreign agglutinated particles imbedded in calcareous cement secreted by the organism. B) Porcellaneous tests are calcareous, imperforate, smooth and homogeneous and it is secreted entirely by the organism. C) Hyaline tests are calcareous, perforate, secreted by the organism and they can contain ornaments. Another type of calcareous test is made of aragonite instead of calcite (Bellier et al., 2010). Foraminifera are excellent proxies for environmental changes because they have a short life and live within specific niches, which make them to quickly response to environmental changes, they are commonly well preserved in the sedimentary record, they are widely distributed, diverse, small, abundant and easily sampled, and their collection implies a minimal impact on environmental resources (Carnahan et al., 2009):

At this moment, I am focused on the foraminifera from the IODP Site 1387 (Figure 1). The evaluation of foraminiferal assemblages will estimate paleoceanographic parameters including productivity, bottom-water oxygenation, ventilation and current velocity of the MOW during the Miocene-Pliocene.

Stable Isotopes (Howie Spero, University of California Davis, United States)

To reconstruct the past, we use proxies, which are measurements of a variable that can be transferred to an environmental parameter.

Isotopes are atoms with the same number of protons in the nuclei, but different number of neutrons, what means that they have the same electronic load and different mass. Oxygen isotopes are of interest because they are used as proxies of water temperatures. The oxygen atom has different isotopes, so that ^{16}O contains 8 protons and 8 neutrons, ^{17}O contains 8 protons and 9 neutrons, and ^{18}O contains 8 protons and 10 neutrons. In the nature, evaporation and precipitation processes cause changes from liquid to vapor and vice versa, and it produces what is called isotope fractionation. The Isotopic fractionation that occurs during condensation in a moist air mass can be described by Rayleigh Distillation. As a consequence, the ratio of light to heavy isotopes varies. When water vapor condenses (an equilibrium fractionation), the heavier water isotopes ($\delta^{18}O$) become enriched in the liquid phase while the lighter isotopes ($\delta^{16}O$) tend toward the vapor phase.

In turn, oxygen isotopes are present in the carbonates of the fossil tests. Tests of foraminifera present a desviation on the isotopic signal between the test and the theoric composition of the calcite fromed in equilibrium with the seawater dissolved inorganic carbon. Calcification of the tests occur at different water temperatures, so that, colder temperatures favor the intake of the heavier isotopes, whilst warmer temperatures favor the intake of lighter isotopes. The isotope measurements using the shells of foraminifera reveals the isotopic composition of the seawater at the moment of their formation, so that they are important indicators of past seawater parameters such as temepratures and salinity.

Results of isotope measurements on foraminifera will be addressed in order to reveal seawater temperatures and salinity of the Mediterranean Outflow Water at the Gulf of Cadiz after the opening of the Gibraltar Strait. Results will be shown in future publications.

Trace elements (Yair Rosenthal, Rutgers University, United States)

Element geochemistry is usually found in the analysis of bulk sediments and it depends on the oceanic trace element distribution, the bottom water oxygenation and in turn, elements are incorporated in biogenic carbonates so that fossils can be useful indicators of the element content and processes occurred.

As a next step in my PhD project, I will work on the acquisition of an elemental record (in particular Zr, Al, Br, Ba, Fe, K and Ti) from upper Pliocene (~2.9-3.6 Ma) sediments of IODP Site U1389E (Figure 1) in the Gulf of Cádiz. The intended results from XRF-scanning will make an important contribution to the ongoing research efforts by providing a proxy record for MOW.

3. Description of the main results obtained

No results have been deduced from the USSP 2014 due to the content was mainly theoretical. The only practical activity was a field trip, which consisted on visits to different outcrops near Urbino, Italy.

The first stop was the Vispi Quarry in the Contessa Valley, which is the most spectacular outcrop of pelagic Cretaceous sediments in the Umbria-Marche Basin of Italy. The Umbria-Marche (U-M) Apennines (Figure 2) of North-Eastern Italy form part of a foreland fold-and-thrust belt, created in the latest phase of the Alpine-Himalyan orogenesis. These mountains are made entirely of marine sedimentary rocks and they are composed of a relatively thick sequence of largely pelagic limestones and marls recording. This sequence provides a remarkable record of many aspects of Earth history during an interval of 170 million years and we were shown the most prominent organic-rich horitons, which are well recognizable (Figure 2).

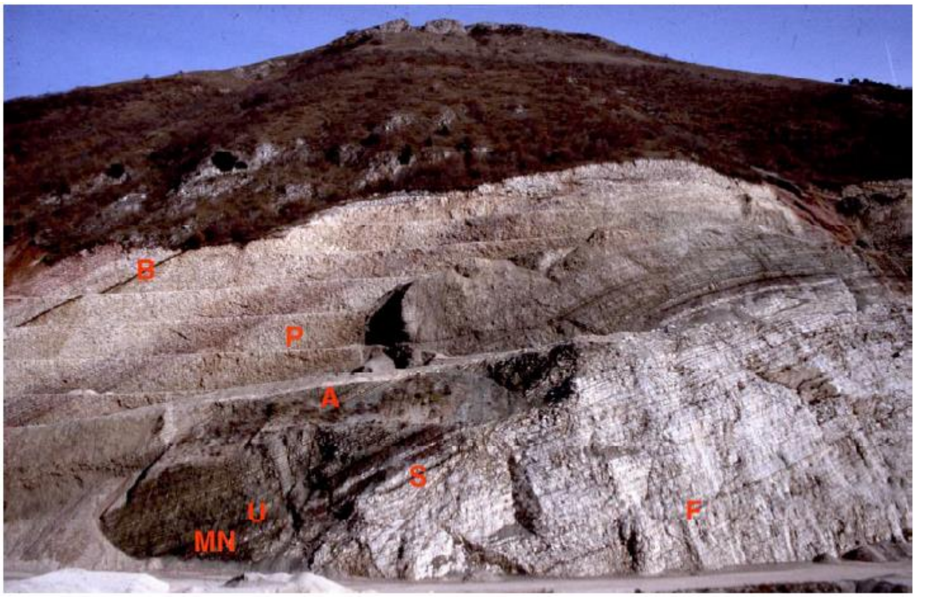

Figure 2. Organic-rich horizons are well recognizable: F = Faraoni Level (uppermost Hauterivian); S = Selli Level (OAE 1a, early Aptian) MN = Monte Nerone Level and U = Urbino Level (OAE 1b, early Albian); A = Amadeus Segment (OAE 1c, late Albian); P = Pialli Level (OAE 1d, latest Albian); B = Bonarelli Level (OAE 2, latest Cenomanian)

We also visited the Bottaccione section, located a few km from the town of Gubbio, is vitally important for the study of Paleogene stratigraphy. This section has been proposed as the magnetostratigraphic standard for the Cretaceous-Tertiary interval. The Bottaccione and the Contessa Valley sections, has been the focus of a large number of detailed studies in lithostratigraphy, integrated biostratigraphy, evolutionary paleontology, sedimentology, magnetostratigraphy, and chemostratigraphy which has led to a better knowledge of the Cretaceous-Paleogene interval. For this reason, the Gubbio sections (Bottaccione and Contessa Valleys) have become classical Tethyan settings where the most complete deep marine sequence of Cretaceous sediments can be found on land.

4. Future collaboration with host institution (if applicable)

The Urbino Summer School in Paleoclimatology has been organized and coordinated by three scientists from different Universities: Simone Galeotti from the University of Urbino, Stephen Schellenberg from San Diego State University, and Appy Sluijs from the Utretch University. For the moment, there is no intention of collaboration between the University of Graz and any of the ones mentioned above.

5. Projected publications / articles resulting or to result from the grant (ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)

Due to my recent incorporation to the Institute for Earth Sciences in the University of Graz as a PhD student, I am still working on the pickng and identification of foraminifera from the IODP Site 1387C (Figure 1). It is intended to make approaches on velocity and intensity of the MOW based on the foraminiferal assemblages, since the presence/absence of species is indicative of specific conditions. For the moment, some results at low resolution exist for this site. Future work will consist on the analyses of Mg/Ca ratio in order to find out water temperatures and salinity, as well as carbon isotopes, TOC, S and $CaCO_3$ which will reveal changes in bottom productivity and ventilation. An XRF scanning for a sediment core from the IODP Site 1389 (Figure 1) is already scheduled for this year at MARUM (Bremen). These results will be published and the ESF will be acknowledged for the support provided by the short visit grant for the assistance to the USSP 2014.

6. Other comments (if any)

I would like to thank the ESF for awarding me with this short visit grant.

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