ECORD/ICDP

MagellanPlus Workshop Series Program

Tyrrhen**I**an **M**agmatism & Mantle **E**xhumation

Summary:
The Institute of Marine Science (ISMAR) of the National Council of the Italian Research (CNR) of Bologna hold the MagellanPlus Workshop "**T**yrrhen**I**an **M**agmatism & Mantle **E**xhumation" (TIME) on June 5-7, 2017, gathering 36 scientist from 7 countries.

The workshop was the follow up of the SSEP recommendation to the pre-proposal TIME (899-pre) submitted to IODP in March 2016 to study the process of continental lithospheric rifting and formation of the continent-ocean transition (COT), including magmatism and mantle exhumation occurred in the Tyrrhenian basin.

Since the discovery by drilling that the COT of the West Iberia Margin is characterized by large exposures of exhumed mantle peridotite forming the basement next to the continental crust, the model has been applied to interpret many other continental margins in the absence of sampling of the crystalline crust. However the processes that govern peridotite exhumation without significant magmatism are not well understood. To explain it, two main hypotheses have been proposed: (1) Slow extension rates, so that the asthenosphere cools during ascent and no melting occurs; and (2) The mantle was originally too depleted to significantly further melt. There is also an ongoing debate on whether mantle exhumation in West Iberia (and elsewhere) may actually be related to slow or ultraslow seafloor spreading, rather than representing rifting. Additionally, the transition to normal seafloor spreading after mantle exhumation, as in Atlantic non-volcanic type of margins, is not well constrained. A fundamental issue to understand the suite of processes is the scarcity of basement samples in this type of rift systems, and the limited number of modern, highly-spatially sampled seismic experiments.

Recent geophysical surveys carried out in the Tyrrhenian basin combining wide-angle seismic (WAS), gravity and multichannel seismic (MCS) reflection data is challenging this conceptual model which assumes the presence of a classical-type continental margin with thinned continental crust in the margin juxtaposed to oceanic crust in the deep central basins. Conversely, the new data support the presence of oceanic-type magmatic rocks where crust was previously assumed to be continental, and of partially serpentinized peridotites where crust was previously inferred to be oceanic crust. The exhumed mantle occupies the center of the basin, and was later intruded by renewed basaltic fissural magmatism. This interpretation is consistent with early drilling results, but an appropriate conceptual model that explains the early magmatic phase and the later amagmatic mantle exhumation, apparently at fast opening rates, is at odds with current conventional wisdom.

Drilling the Tyrrhenian is a unique opportunity to assess the validity of current end-member models. The basin is young and covered by a relatively thin sediment layer, which facilitates reaching basement in multiple locations. The database available to design the drilling project is possibly one of the best from any rifted basin. The basement here has been dredged at highs and drilled in several campaigns, and the stratigraphy is reasonably well known from three drilling expeditions, DSDP leg 13, DSPD leg 42 and the ODP leg 107. In addition, a full-coverage high-resolution multibeam bathymetry helps the 3D interpretation of a large data set of vintage and modern 2D MCS reflection profiles and seven regional wide-angle seismic transects of the basin.

The workshop gathered an interdisciplinary group of scientists including experts in the Tyrrhenian Basin, on continental rifting, basalt and mantle petrology and geochemistry, and researchers with broad experience studying mantle exhumation processes at both margins and

mid ocean ridges, and experts in Alpine-type ophiolites, potentially analogous to some of the western Mediterranean basins.

The first part of the Workshop was organized in a series of scientific oral sessions to illustrate the data set available and the geodynamics of the region accompanied by exhibition of posters and data. It followed a series of talks given by forefront specialists on mantle exhumation processes occurring in various geodynamic setting. Then it was opened the discussion to identify and agree on the KEY scientific questions, resulting in a strong support and consensus to proceed toward a submission of a revised version of proposal 899-pre. The final part of the workshop was organized in breakout groups discussion based on scientific goals to define the drilling, sampling and logging strategy and subsequent presentations and consensus.

Objectives:
The purpose of the TIME workshop was to open the opportunities offered by the recently revised geology of the Tyrrhenian basin to a broad group of interdisciplinary experts for the discussion of a series of fundamental questions on rifting of continental lithosphere, the formation of the COT, synrift magmatism and seafloor spreading, and mantle exhumation by tectonic extensional processes. These events occurred during the last ~11 m.y. in the relatively small Tyrrhenian Basin and hence the area provides a natural laboratory to study in one single iODP expedition a suite of processes interpreted to exist in a variety of margins and basins. The geological domains formed by these processes have been mapped with modern active-source wide-angle data with Ocean Bottom Seismometers and near-vertical deep penetrating multichannel data collected in two cruises in 2010 and 2015. Also, 3 previous DSDP/iODP expeditions and dredging of the abundant basement outcrops, and full multibeam coverage of the basin provide a unique database to carefully plan the drilling.

This database was used to prepare the TIME iODP pre-proposal 899-pre that has been positively reviewed with the recommendation of organizing a meeting to open the discussion to the broader community and clarify some of the proposal goals and drilling strategies, which has been the main goal of this Magellan Workshop

Following the recommendations of the SSEPs for proposal 899-pre, the major tasks of the workshop participants was to identify the key scientific question that could be addressed by drilling the Tyrrhenian basin, to define the locations for drilling to achieve the largest number of scientific goals, and to define the strategy in terms of drilling, sampling and logging.

The workshop helped not only to refine the scientific goals, and drilling strategy to prepare a pre/full iODP proposal for the October 2017 deadline, but also to define work that can be done with existing materials and to identify the researchers that will take responsibility to carry out the work. Further, it was also discussed the strategy to collect additional site survey data.

Program:

DAY I –June 5: The Tyrrhenian knowledge and past work

Overview of the Geology of the Tyrrhenian Basin (Nevio Zitellini)	14:00
Nature of the basement in the Tyrrhenian (Manel Prada)	14:20
Tyrrhenian tectonics (Cesar Ranero)	14:40
Petrology and ages of igneous rocks of the Tyrrhenian (Daniele Brunelli)	15:00
Drilling peridotite in the Tyrrhenian at site 651 (Enrico Bonatti)	15:20
D/V JOIDES Resolution facility and board capabilities (Philippe Pezard)	15:40
ODP proposal and key scientific questions (Nevio Zitellini)	16:00
Coffe Break	16:20

Seismic expression of exhumed mantle around the world (Ingo Grevemeyer)	17:00
Overview of ocean-continent transition off West Iberia (Tim Minshull)	17:20
Day wrap up (Cesar Ranero)	17:40

DAY II - June 6: State of the art of rifting and COT studies

Impact of melt supply on slow-spread oceanic crust (Mathilde Cannat)	09:00
Mantle exhumation at MOR (Chris MacLeod)	09:20
Fluid-rock interactions and deformation at OCC (Muriel Andreani)	09:40
Subcontinental Mantle in back arcs (Carlos Garrido)	10:00
Numerical modelling of continental lithosphere extension (Marta Perez)	10:20
Geodynamic Modelling of back arc opening and mantle processes (Taras Gerya)	10:40
Evaluation process of IODP Panels (Watchdog Johan Lissenberg)	11:00
Coffe Break	11:20
Calcareous nannofossil biostratigraphy and biochronology in the Pliocene-Pleistocene: potential for accurate dating of marine sediments (Isabella Raffi)	12:00
Open discussion: Identify and agree on the KEY scientific questions (Cesar Ranero Moderator)	12:10
Lunch	13:30
How can drilling in the Tyrrhenian solve them?	14:30
Coffe Break	16:30
Where to drill to achieve the goals? Choose the drill sites areas!	17:00
Day wrap up (N.Zitellini/C.Ranero)	18:00

DAY III - June 7: Drilling strategy

What drilling strategy: cores required (break out in groups based on scientific goals)	09:00
What drilling strategy: logging required (break out in groups)	10:00
Coffe Break	11:00
What drilling strategy: presentations of groups	11:30
The new ODP proposal: topics and proposal structure	12:30
Lunch	13:30
The new ODP proposal: work distribution and deadlines	14:30
AOB and meeting end	15:30

Open discussion outcome:
The open discussion started after one full day of oral session illustrating the geology of the Tyrrhenian basin and the state of the art on the mantle exhumation process (half day on day one, first half of day two). This part of the workshop was then integrated with exhibition of posters, geophysical data, in particular the most representative MCS lines, and geological maps summarizing the stratigraphic information available in the basin.

The open discussion was focused on the KEY scientific questions to be addressed in the Tyrrhenian Basin and occupied the second half of day two. The discussion was driven by the geophysical and geological evidences of exhumed mantle occurring in the center of the basin, which led to a review of the significance of the data set available. The discussion embraced a variety of topic as the petrologic meaning of the basalts recovered in the previous ODP expedition, the kinematic of basin opening, the stratigraphy and the sequence of events in relation to the mantle exhumation.

A the end of the discussion the group acknowledged that drilling the basement in the Tyrrhenian is comparatively easier than other margins given the thin sedimentary cover. The site logistics is very favorable being the basin small and accessible. The basin has good chronological constraints with a control on opening rates much better known than at any other COT in the Atlantic margin. A general agreement was reached on the need to focus the proposal on the hypothesized strong magmatic episode preceding the mantle exhumation and on the mantle exhumation process, which seem to have been anomalously fast and short lived. It was also decided to proceed toward a resubmission of a pre-proposal for the 2017 fall call.

Summarizing the consensus obtained during the discussion it was decided to proceed to draft a pre-proposal entitled "Tyrrhenian Magmatism and Mantle Exhumation (TIME) for a new paradigm for COT" aimed at addressing the following leading-edge scientific questions that can not be tested at any other –to date- known site in the world:

1) To define the processes that control mantle exhumation at fast rates;
2) To determine the type and intensity of the first magmatism preceding mantle exhumation inferred from seismic velocities but not yet tested by sampling;
3) To resolve the temporal and genetic relation between the second and third basaltic pulses emplaced during and/or soon after the mantle exhumation process.
4) To study potential relations of serpentinization to ecosystems and mineral byproducts.

Some issues were raised during the review processed and were discussed for integration in the proposal:

1) How representative is the Tyrrhenian for continent-ocean transitions (COT) globally considering the back arc setting of the Tyrrhenian basin? It was remarked that continental rifting occurs in a suite of geodynamic settings including well-studied back arcs like Woodlark basin, and Black Sea and trans-tensional settings like Gulf of California. Woodlark was the goal of IODP drilling of a fault system at the tip of a propagator. Black Sea and Gulf of California, even though targets of oil&gas industry, their basement have not been drilled because it is too deep and the opening process remains poorly documented. In this respect, previous studies highlight the differences of distinct geodynamic setting with end-members of Atlantic-type margins;
2) The degree of depletion of site 651 is typical of extensional settings implying an exhumation of more than 10 km which consequently should accompany considerable amounts of decompression melting, which is expected to be associated to thinning of the crust, but does not occur coeval to mantle exhumation;
3) Integrate in the proposal available geological samples.

Below are summarized the recommendations received from the assembly as input for the successive discussion regarding the drilling strategy that are taken into account for the new pre-proposal:

1) Full coring of sediment to basement for each site is mandatory and needs to be accounted;
2) Determine regional extent of exhumed mantle across the Vavilov Basin by drilling;
3) Prioritize as many sites as possible to study original mantle properties and the reactions during melt ascent;
4) Maximize the number sites for testing basement even if they are shallow. One site should penetrate at least 200 m deep in the mantle;

A general agreement was also reached about the number and the location of the drills to be proposed: 2 holes in Cornaglia, 1 hole in Campania Terrace, 5 holes in the Vavilov and if possible 1 in the Marsili Basin.

Once terminated the open discussion, the assembly was split in 2 groups, the Geochemistry Group and Tectonic Group to define the drilling target and the drilling strategy.

Geochemistry/Tectonic Group recommendation outcome:

a) The core samples need to address:

1) Exhumation mechanisms: what are we drilling at the top of the basement? Is the fault zone preserved for drilling? It is suggested to integrate all available geophysical data by ISMAR;
2) The existing cores show: high temperature deformation accompanied by ductile shear zones with no evidence of brittle shallow deformation considering that brittle deformation may be associated to serpentine and talc;
3) Melt production: Why is melt absent during mantle exhumation? What controlled the degree of melting?

b) Drilling Strategy recommendation:

1) Number of sites: Agreed that ~5 km total penetration in 5-8 sites is maximum and a minimum of 3-4 sites in Peridotite with one going deeper to some 200 meter.
2) There must be a prioritization of sites, 5 sites are feasible and perhaps up to 8 sites if some are very shallow.
2 cores in Cornaglia if total is 8 or 1 if total is 5-6
1 core in Campania Terrace
5 Cores in Vavilov or 4 if total is 6
3) Cores need to go through the exhumed shear zone, implying >100 m up to 200 m. penetration in at least one site.
4) Rotary coring.

c) What needs to be done during drilling operations:

1) Take pore water samples in 1 serpentine site
2) Logging temperature every 50 meters approaching basement and in basement.

d) Missing expertise:

1) Microbiologist should be contacted.

e) Drilling strategy:

1) Logging is required
2) Every hole should have triple combo: natural gamma, resistivity, magnetic susceptibility, litho-density
3) Every hole should have Spectral natural gamma. Acoustic velocity (sonic), shear anisotropy. Electrical images (oriented).
4) Acoustic image. (slow to run) evaluate if needed.

5) VSP (very slow) technique will provide the critical information to link lithologies to regional seismic data. Possibly not needed and to be evaluated case by case.

Future plans:
There was a clear consensus from the workshop participants to proceed toward the development of a pre-proposal to be submitted to iODP by the end of September 2017. The new proposal should be based on the new finding not observed elsewhere in the world as the strong magmatism preceding the mantle exhumation, the occurrence of mantle exhumation at fast EPR rates within a very short time interval along with the relation between basalts emplacement and exhumation process. Within this frame the group suggested the following activities:

1) Make a kinematic reconstruction of the mantle exhumation based on the current data as stratigraphy, structure and morphology derived from swath bathymetry; (N.Zitellini, M.F.Loreto);
2) Acquire more geophysical data to further characterize the structure and the nature of the mantle. Three-component magnetic survey might help to evaluate nature and extent of magmatic crust in the Cornaglia Terrace (I.Grevemeyer, C.Ranero, V.Sallares, N.Zitellini);
3) Make a numerical simulation with the different hypotheses regarding the nature of the Cornaglia Terrace (M.Perez-Gussinye, T.Gerya);
4) Review constrains on the ages of basalts and sediment resting above the exhumed mantle (D.Brunelli, C.Garrido, E.Bonatti, I.Raffi). In particular, C.Garrido and D.Brunelli will look at ODP site 651 rocks and DSDP site 373 basalts. C.Garrido will carry out the geochemistry and will prepare site 373 glass for dating. U.Barkhausen and C.Ranero will approach Kaj Hoernle (Geomar) to do the re-dating of site 373;
5) Pilot study of the sediments above exhumed mantle to check if there is indications of interaction between seafloor serpentinization and ocean water. In particular M.Andreani will look at the oldest sediment at ODP site 651 for indications of fluid flow related to serpentinization. Moreover, M.Andreani and D.Brunelli will look at the products of serpentinization;
6) Submit the pre-proposal by the end of September;
9) In case of acceptance of the pre-proposal by the SSEP panel develop the full proposal to match the 30 September 2018 deadline;
10) Organize a half-day Workshop for proposal up-grading during the next EGU.

Participants during the Posters exhibition

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Enlighten in bold are the early career scientists