IODP Proposal Cover Sheet

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Tyrrhenian Continent-Ocean Transition

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Title	Tyrrhenian Magmatism & Mantle Exhumation
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Abstract

The objective of The “TyrrhenIan Magmatism & Mantle Exhumation” (TIME) project aims at studying the 3D time and space evolution of a continent-ocean transition (COT), from breakup to robust magmatism and subsequent mantle exhumation with closely time-related magmatism. The objectives include the kinematics of the opening, the crust and mantle deformation mechanisms, and the relationship of melting products to the exhumed mantle.

The database available to design the drilling project is possibly one of the best from a basin. The basement of the Tyrrhenian basin has been dredged at highs, and the stratigraphy is reasonably well known from three drilling expeditions, DSDP leg 13, DSPD leg 42 and the ODP leg 107 (Fig.1). In addition, a full-coverage high-resolution multibeam bathymetry of the basin helps the 3D interpretation of a large data set of vintage and modern 2D MCS reflection profiles.

The TIME project focuses in the youngest basin of the Western Mediterranean, formed from Upper Tortonian to recent by continental extension related to rollback of the ESE-SE migrating Apennine subduction system. Recent geophysics with coincident wide-angle seismic (WAS), gravity and multichannel seismic (MCS) reflection data support the presence of magmatic rocks formed during early COT phase, and of presumably subsequently exhumed mantle. The youth of the basin results in a modest sediment cover, facilitating sampling, with unprecedented spatial resolution, the peridotitic and magmatic basement across the conjugated COT of the basin.

Scientific Objectives

1) to determine the kinematics and geometry in space and time of the extensional deformation in the basin;
2) to establish the timing and origin of the associated magmatism;
3) to establish the rheology, deformation patterns and timing of mantle exhumation;
4) to determine the compositional evolution and heterogeneity of the mantle source;
5) to test current models of continental lithosphere rifting and of COT formation.

Non-standard measurements technology needed to achieve the proposed scientific objectives

Proposed Sites (Total proposed sites: 12; pri: 6; alt: 6; N/S: 0)

Site Name	Position (Lat, Lon)	Water Depth (m)	Penetration (m)			Brief Site-specific Objectives
			Sed	Bsm	Total	
TYR-01A (Primary)	40.0025 10.9984	2675	286	70	356	The basement of the Cornaglia Terrace
TYR-02A (Primary)	40.00036 13.40327	2813	652	70	722	The basement of the Campania Terrace
TYR-03A (Primary)	40.18388 12.6413	3533	356	140	496	The serpentinized mantle peridotite
TYR-04A (Primary)	40.18402 12.72801	3546	773	70	843	The serpentinized mantle peridotites
TYR-05A (Primary)	40.26609 12.69432	3530	142	140	282	The serpentinized mantle peridotite
TYR-06A (Primary)	40.41593 12.72474	3592	902	70	972	The serpentinized mantle peridotite
TYR-07A (Alternate)	40.00097 10.98619	2700	286	70	356	Same target of TYR-01A, the basement of Cornaglia Terrace
TYR-08A (Alternate)	40.00036 13.39599	2837	548	70	618	Same target of TYR-02A, the Campania Terrace basement rocks
TYR-09A (Alternate)	40.18388 12.63243	3533	450	140	590	Same target of TYR-03A, the serpentinized mantle peridotite.
TYR-10A (Alternate)	40.18398 12.70826	3544	591	70	661	Same target of TYR-04A, serpentinized mantle peridotite.
TYR-11A (Alternate)	40.26614 12.70529	3538	327	140	467	Same target of TYR-05A, serpentinized mantle peridotites
TYR-12A (Alternate)	40.4159 12.7076	3590	1057	70	1127	Same target of TYR-06A, serpentinized mantle peridotites

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César	R. Ranero	ICREA at CSIC, Barcelona	Spain	Data Lead	Marine Geopphysics, Tectonics, Geopdynamics
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Daniele	Brunelli	Dipartimento di Scienze Chimiche e Geologiche Università di Modena e Reggio Emilia	Italy	Other Lead	Mantle and MORB petrology and geochemistry
Valenti	Sallares	Institute of Marine Sciences, CSIC, Barcelona	Spain	Other Lead	Marine Geophysics
Ingo	Grevemeyer	GEOMAR Helmholtz Centre of Ocean Research, Kiel	Germany	Other Lead	marine geophysics, crustal & lithosphere structure
Manel	Prada	Dublin Institute for Advanced Studies, School of Cosmic Physics, Dublin	Ireland	Other Lead	Seismic refraction, mantle exhumation, back-arcs
Isabella	Raffi	Dipartimento di Ingegneria e Geologia, Università "G. d'Annunzio" di Chieti-Pescara	Italy	Other Proponent	micropaleontology
Marco	Ligi	Istituto di Scienze Marine, Consiglio Nazionale delle Ricerche, Bologna	Italy	Other Proponent	Marine Geology, Marine Geophysics
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Christopher	MacLeod	School of Earth & Ocean Sciences, Cardiff University	United Kingdom	Other Proponent	Marine Geology, structural geology from cores
Tim	Minshull	National Oceanography Centre Southampton, University of Southampton	United Kingdom	Other Proponent	Marine Geophysics
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Introduction

A tenet of plate tectonics is that divergent plates cause asthenospheric mantle to ascent, decompress and melt, producing new crust. However, drilling west of Iberia discovered a Continental to Ocean Transition (COT) made of exposed mantle (Boillot and Winterer, 1988; Sawyer et al., 1994), causing the revision of models of lithospheric thinning and melt generation, leading to the definition of magma-poor margins. A long-standing argument about mantle of COTs concerns its nature as either *sub-continental* or formed by *ultraslow seafloor spreading*. Additionaly, two models discuss the apparent lack of melts invoking either slow extension resulting in low ascension rates with enhanced asthenospheric cooling and reduced melt production, or upwelling mantle originally too depleted to significantly further melt. Additionally, the debate extends on the significance of COT models, currently based on a few drilled sites at basement highs, due to limitations for ultra-deep-water drilling. Consequently, 30 years after its discovery, we still debate on the very nature and genesis of COTs. The "Tyrrhenian Magmatism and Mantle Exhumation" (**TIME**) proposal tackles all those issues.

The young Tyrrhenian basin formed by rifting during eastward migration of the Calabrian Arc. It is bounded eastward by the Italian peninsula and westward by Corsica and Sardinia. Modern investigations support an abrupt Tyrrhenian continental break-up, giving birth first to a segment of new magmatic crust with the layered seismic structure of oceanic crust, abutted by younger segments of exhumed mantle with discrete basaltic intrusions, at odds with conventional COT models.

Our main **hypothesis** is that the spatial variability of tectonic and magmatic structures in the Tyrrhenian may be present elsewhere, but that scarcity of both basement sampling and modern geophysical work has squinted conventional wisdom. This hypothesis can be tested only by drilling to determine rock nature and quantify extension rates.

To test the hypothesis, **TIME** proposes two perpendicular drill transects (Fig. 1). The E-W transect targets the progression from magmatic crust to exhumed mantle; the N-S transect maps the fault zone exhuming mantle. Drilling will sample the sediment cover, mantle, the associated magmas, and the products of syntectonic, and possibly ongoing, fluid-rock interaction to evaluate the hydrosphere-lithosphere geochemical exchange and potential related ecosystems.

TIME goals directly address topics that are central to the IODP Science Plan (2013-2023) including **Challenge 8** "What are the composition, structure and dynamics of Earth's upper mantle", **Challenge 9** "How are seafloor spreading and mantle melting linked to ocean crustal architecture?" **Challenge 10** "What are the mechanisms, magnitude and history of chemical exchanges between the oceanic crust and seawater" **Challenge 13** "What properties and processes govern the flow and storage of carbon in the subseafloor?" and **Challenge 14** "How do fluids link subseafloor tectonic, thermal, and biogeochemical processes?" as developed in the scientific objectives below.

Why the Tyrrhenian?

Deformation style, kinematics and the relationship of melts to mantle are key to understand lithospheric extension, breakup and mantle exhumation, associated magmatism and quantitatively constrain the hydrosphere-lithosphere interaction.

The deep water and thick sediment hindering COT research elsewhere do not occur in the Tyrrhenian, where comparatively shallow water and thin sediment (Fig.3) provide an optimal initial framework to test COT formation models by drilling.

High-resolution seafloor maps (Fig.1) and 2D seismic (Figs. 4d, 5) integrated with available drilling information of Tyrrhenian stratigraphy provide one of the best databases available in any basin studied by academia (Fig.2). However, a quantitative understanding of the processes requires the 3D fault kinematics, rate of mantle exhumation and age and nature of the magmatism (Fig.2): within **TIME** we aim at tightly constrain them.

The Tyrrhenian basin is the only example where extensive modern geophysical data has accurately mapped basement domains of <u>an unambiguously conjugate pair of COTs. The entire system can be characterized with unprecedented detail in a single drilling expedition to study its 3D time and space evolution</u> (Fig.1).

Summary of Tyrrhenian geology

The Tyrrhenian was surveyed in the 70-80's with thousands of kilometers of seismic reflection lines (Fig.2, inset), gravity and magnetic field measurements, heat flow measurements, dredge samplings (Fig.3), and drilling (DSDP leg 13, site 132; DSPD leg 42, site 373; and ODP leg 107, sites 650-656, Kastens & Mascle, 1990). The CROP program acquired in the 90's high-quality seismic reflection data and multibeam bathymetry (Fig. 1). In 2010 our cruise MEDOC acquired 5 geophysical transects across the basin with coincident wide-angle seismic (WAS), gravity and multichannel seismic (MCS) reflection data and additional MCS lines across basin center (Fig.1). In 2015 our CHIANTI campaign collected 2 WAS lines across the central-eastern basin (Fig.1). We summarize relevant results below.

The Tyrrhenian opened by extending the ~300 Ma Variscan continental lithosphere exposed in Corsica and Sardinia, driven by slab rollback of the ESE migrating Apennine subduction (Faccenna et al., 2001). Significant stretching started in Late Miocene (~10 Ma), leading to continental break up, a first phase of magmatism, and subsequent mantle exhumation in the Magnaghi-Vavilov Basin after Messinian ~5.3 Ma and terminating by ~2.0 Ma (Prada et al., 2016).

The amount of extension in the Basin increases from north to south, mirrored by seafloor morphology. The Tyrrhenian seafloor has 3 relief sectors (Figs.1, 2): north of ~40º45'N displays shallow rough seafloor; a central sector between ~40º45'N to ~39º30'N with deeper seafloor and smooth plains with volcanoes like Magnaghi and Vavilov and non-volcanic basement seamounts like Secchi, Farfalle, Flavio Gioia and De Marchi

(Fig.2), and South Tyrrhenian between 39º30'N to 38ºN with the Marsili Basin and volcano, and Aeolian volcanic arc.

The Northern Tyrrhenian sector exhibits N–S-trending normal faults thinning the continental crust to 20-25 km thick (Mauffret and Contrucci, 1999, Moeller et al., 2013, 2014). Central and South Tyrrhenian sectors display increased extension (Figs.4cd) with sub-basins originally interpreted as continental (Cornaglia Terrace) or oceanic (Magnaghi, Vavilov and Marsili basins; Duschenes et al., 1986; Kastens and Mascle, 1990; Sartori, 1990) with several-km-tall volcanoes of upper Pliocene to present-day age (Argnani and Savelli, 1990; Savelli, 1988, 2002; Lustrino et al., 2011) (Fig.3f).

However, MEDOC Vp models from WAS data show that the basement of the conjugate Cornaglia and Campania Terraces has a layer 2/3 classical oceanic seismic structure, supporting magmatic accretion (Prada et al., 2014, 2015). Thus, continental break-up was followed (in Tortonian/Messinian) by some 100-150-km-wide magmatic construction forming the Cornaglia and Campanian Terraces. This basement might resemble MORB drilled at DSDP site 373, but the significance of site 373 is unclear (see below) because it is at the edge of the Campania Terrace (Figs.2, 4c).

Further, MEDOC & CHIANTI Vp models, supported by gravity modeling, seismic reflection images and Leg 107 basement drilling indicate that the Magnaghi, Vavilov and Marsili basins are floored by exhumed mantle (Figs.4abc) intruded by MOR-type fissural volcanism (Prada et al., 2014, 2015), and later intraplate back-arc volcanism (Fig.4e) (Prada et al., 2016).

The basement of the Magnaghi - Vavilov basin was drilled in ODP Leg 107 sites 651 and 655, and DSDP site 373 (Fig.2). All three sites recovered basalts with major-element compositions similar to Mid-Ocean Ridge Basalts (MORB) and an enriched trace element pattern typical of Enriched MORB (E-MORB) (Beccaluva et al., 1990). MORB at site 651 is overlain by a basaltic unit with back-arc signature (BAB-like) (Bertrand et al., 1990). The upper basaltic unit in site 651 has major calc-alkaline affinity and shows enrichment in light ion lithophile element (LILE) and negative anomalies of high field strength element (HFSE; particularly Nb; Bertrand et al., 1990). The high LILE/HFSE ratio of the youngest unit indicates contamination from slab fluids during the last volcanic phase. This BAB-like volcanics may relate to the growth of the nearby Marsili Seamount, likely formed after extension ceased (Fig.4e) (Prada et al., 2016).

In the Vavilov basin, site 651 drilled a 30-m section of partially serpentinized peridotite under sediment containing altered peridotite clasts, which are sandwiched between two layers of basalt and basalt breccia (Fig.2) (Bonatti et al., 1990, Kasten & Mascle, 1990). MEDOC and CHIANTI Vp models support that site-651 peridotite is not an anomaly in a basaltic crust, rather it represents the ground-truthing of exhumed mantle in Vavilov and Magnaghi basins (Figs. 4abc, 5). The CHIANTI cruise has found evidence of mantle exhumation also in Marsili Basin, shown by high velocities in shallow basement, similarly to Magnaghi and Vavilov Basins, and the lack of PmP Moho reflections (compare Vavilov Basin OBH 83 to Marsili Basin OBS 28, Fig.7). Pliocene mantle exhumation in Vavilov (Fig. 4e) was fast and overlapped or was followed soon after (Phase 2) by fissural MORB volcanism (sites 655 and bottom basaltic unit of 651). Later, extension stopped or dramatically slowed down during the growth of the several-km-tall Vavilov Seamount of calc-alkaline affinity (Phase 3), possibly sampled in the shallowest basaltic unit of site 651. The sequence of events differs from conventional models of lithospheric extension where mantle exhumation follows breakup and subsequent oceanic spreading.

Rationale and scientific hypothesis

The discovery of COT formed of exposed mantle west of Iberia (Boillot & Winterer, 1988; Sawyer et al., 1994) initiated the ongoing debate on the mechanisms of lithospheric extension and mantle exhumation, the definition of break-up and initial seafloor spreading, and the nature of the COT and first oceanic crust. Our imperfect understanding of COT processes and onset of seafloor spreading is largely caused by the worldwide limitation to drill deeply-buried COT basement under deep water. Current COT models are based on few submarine examples and extrapolation from regionally-restricted land analogs in highly-deformed outcrops in mountain belts.

The process of magma-poor COT formation has been described by a suite of changes: following break up, mantle exhumation gradually exposes deeper lithospheric levels until eventually a shoaling asthenosphere produces melt (e.g. Perez-Gussinye et al., 2006, Davis and Lavier, 2017; Gillard et al., 2017). However, that idealized sequence has not been convincingly found by sampling in any COT, and remains a conceptual model based on fragmentary sampling and seismic reflection imaging, and without a detailed Vp constraints.

Growing evidence supports that conventional COT models are end members inadequately constrained by drill information. During the last ~15 years improving geophysical observational quality calls for a revision of COT models. Regional geophysical data in Woodlark basin (Goodliffe and Taylor, 2007) and the NW South China Sea basin (Cameselle et al., 2017) support magma-poor rifting, however break up was shortly followed by seafloor spreading, with no mantle exhumation. Similarly, intense magmatism followed abrupt breakup in the Gulf of California (Lizarralde et al., 2007) while the Black Sea basin displays abrupt lateral changes from magma-poor to magma-rich COT (Shillington et al., 2009). Woodlark basement ODP drilling studied continental faulting, but not the COT, and the Black Sea and Gulf of California basement are deep and unsampled. Only recent IODP drilling confirmed the abrupt COT at the NW South China Sea (Larsen et al., 2018).

Those studies highlight the end-member character of current COT models based on a few Atlantic-type margins, with their structure mapped with vintage relative low-resolution geophysics. For instance, the boundary between exhumed mantle and oceanic crust West of Galicia is still undefined after >40 years of work. Similarly, the structure of the best to-date sampled conjugate pair of COT (West-Iberia/Newfoundland) is inconclusively known. Interpretations of drilling results of Iberia Abyssal Plain originally proposed >100-km exhumation of a-magmatic *continental mantle* with no melt production (Sawyer et al., 1994), driving conceptual models. In contrast, the only modern wide-angle seismic profile (but away from drilling transects) with higher spatial resolution (OBS separation ~15 km) than previous results (OBS spacing ~30 km) across the COT of the Deep Galicia Margin appears to detect patches 0.5-1.5 km thick of magmatic crust overlaying partially exhumed mantle (Davy et al., 2016). However, it is unclear whether it represents regional variability or that existing drilling does not represent regionally COT structure because drilling sampled only basement highs, where no oceanic crust occurs. Drilling the conjugate sector of Newfoundland margin (with plate reconstruction uncertainty ~100 km) found limited synrift magmatism (Tucholke et al., 2007) supported by geophysical data (Hooper et al., 2004).

Therefore, growing evidence of modern studies of COT structure support the interplay between magmatic and tectonic processes, which indicates that end-member magma-poor models in literature may be oversimplifications due to scare drilling information. Further, the process of mantle unroofing is debated, differenciating between exhumation of continental lithosphere by depth-dependent differential stretching of the crust and mantle, a process that might involve little or no magmatism, or exhumation during slow-ultraslow seafloor spreading.

The structure of the comparatively better mapped Tyrrhenian basement (7 wide-angle seismic profiles, thousands of km of seismic images, and drilling and dredge sampling) confronts the idealized COT view and shows that oceanic crust formation was followed by mantle exhumation, even though opening rates remained rather constant (Prada et al., 2016).

<u>Our main hypothesis</u> is that the COT variability observed in the Tyrrhenian basement was created by regular processes that may have occurred at COTs worldwide. In particular, we interpret that the sequence of events forming the Tyrrhenian COT is related to vertical and/or horizontal

mantle heterogeneities during the segmented opening of the basin. We propose that the 3D structural COT configuration may represent a regular process rather than the 2D a-magmatic mantle exhumation inferred from comparatively lower resolution studies.

The hypothesis, challenging current conventional wisdom, will be tested through 5 scientific objectives, only achievable by drilling the basement in several locations.

Scientific Objectives

1) To determine the kinematics and geometry of the extensional deformation in space and time in the basin.

2) To determine the heterogeneity of the mantle source and establish the timing and origin of the associated magmatism.

3) To establish the rheology, deformation patterns and timing of mantle exhumation.

4) To determine the fluid-rock interactions in peridotite basement.

5) To test models of rifting and COT formation.

To achieve the scientific objectives, **TIME** proposes two main drilling transects:

A **W-E Transect** to determine the nature of the basement, and define the timing and relationships of mantle deformation, melting, and magmatic events. These goals will be accomplished by a transect of 4 drill sites (TYR-1A, TYR-2A, TYR-3A and TYR-4A; Figs.1, 5, 6) located one in Cornaglia Terrace, two in the exhumed mantle domain, and one in the Campanian Terrace.

A **N-S Transect** to establish the mechanisms and kinematics of mantle exhumation, which appears to mimic, the general southward increasing rate of crustal extension, i.e. limited in the northernmost Vavilov basin while showing ~100 km wide unroofing at 40° N. The roughly N-S transect has 4 sites (TYR-5A, TYR-6A, with TYR-3A and TYR-4A also in the W-E transect, Figs.1, 6) to map the spatial extension of the peridotite body that appears continuous in North-South direction (Figs.4, 6).

Objective 1: To determine the kinematics and geometry of the extensional deformation in space and time in the basin.

Determining the age of the extensional processes is key to understand the kinematics of deformation and constrain numerical simulations of the interplay between deformation and melting. To achieve a full understanding of the process it is important to determine the age of faulting, mantle deformation and melting.

The calibration of synrift strata helps to define the kinematics of extensional faulting and thus the opening of the basins. Although it appears straightforward, in reality ultra-deep-water environments and relatively thick post-rift sediment covering most COTs worldwide have prevented detailed dating, and indirect estimations vary greatly for any one basin. The example of West Iberia, with DSDP and ODP drilling in the Deep Galicia Margin and Iberia Abyssal Plain, shows that the exceeding total drill-string length restrained drilling to shallow portions of basement highs, penetrating only the youngest synrift. The results provide a general idea of the age progression of faulting (e.g. Ranero and Perez-Gussinye, 2010), but total rift duration estimations range between 5-25 m.y. (Whitmarsh et al., 2001). Furthermore, those ages only refer to continental extension, because alteration of the mantle exhumed in Mesozoic times prevents detailed study of the mechanisms and age of the deformation, let alone the relation to melt products. There is currently no observational data that collectively constrain the timing of faulting, mantle deformation, and melting of any basin. **TIME** will provide the first robust and integrated data set from an entire system.

ODP Leg 107 established the basic Tyrrhenian stratigraphy (Kastens & Mascle, 1990) providing the framework to interpret seismic images. The basin has several stratigraphic markers including 3 Messinian salinity crisis sediment units (>5.33 to 5.96 Ma), a local top Messinian erosional unconformity (5.33 Ma), and a lower Pliocene intra Zanclean unconformity (<5.33 to 3.60 Ma) used to define the sequence of events. Those markers provide excellent general constrains on timing of the opening of the basin.

However, existing stratigraphy constrains the opening of the continental crust, but not the rates of mantle exhumation because it occurred during Pliocene where available stratigraphic control is limited. TIME will refine the Pliocene stratigraphy by dating the sediment column, particularly with a detailed analysis of sediments on-lapping top basement. We will calibrate strata resting on the fault planes that exhumed mantle to determine, in time and space, the slip rate of the large domal faults – resembling core complexes- in seismic images (Fig. 6).

Age dating of sediment resting on basement will be achieved using calcareous nannofossils, which provide reliable biostratigraphy and biochronology in the Neogene-Pleistocene interval. The biozone resolution ranges from 0.15 to 2.2 Myr in the interval 7.4-2.4 Ma, and ~0.52 Myr in the interval 2.4-0 Ma. The biochronologic framework provided by nannofossils, combined with the easy processing of samples, the generally excellent preservation of assemblages, and the small quantity of material needed for analysis, make the approach suited for obtaining high-resolution biostratigraphy and precise dating. The age calibration will be about one order of magnitude superior, and better constrained by stratigraphic correlation and smaller uncertainty in age determination, that at any other conjugate COT system. Biozones can be further calibrated by tephrochronology and magnetostratigraphy if core recovery is of enough quality.

Dating fault activity will be crucial to understand the kinematics of mantle exhumation, the mechanisms of coeval peridotite deformation (Objective 3), and melt products (Objective 2, see below). Thus, we will analyze lithospheric rheological evolution in time and space, a key to quantitatively understand the system.

Magmatic events will be dated based on radiogenic decay series. Ar/Ar and K/Ar geochronology will be applied respectively on lava glasses and basalt groundmasses. Leg 107 cores (Fig. 9) present widespread mantle impregnation by amph-bearing gabbroic patches and veins. These lithologies are excellent for dating and will help defining the age of the impregnation events by K/Ar on amphiboles and feldspars and U/Th on zircon and xenotime.

Objective 1 addresses the *IODP SP Challenge 9: "How are seafloor spreading and mantle melting linked to ocean crustal architecture?"* by tackling the mechanisms that "with little volcanism but widespread tectonism results in exposure, weakening, and alteration of mantle rocks".

Objective 2: To determine the heterogeneity of the mantle source and establish the timing and origin of the associated magmatism.

A primary aim is to characterize the spatial and temporal variations of the mantle source through the coupled study of melting products and mantle residua. Structural, microstructural, petrological, geochemical and geochronological studies of the exhumed mantle peridotites will establish the ductile mantle deformation, the mantle history of melting and melt-extraction, melt retention and intrusion, and its three-dimensional variability. This work establishes the critical link between *Challenge 8 (What are the composition, structure, and dynamics of Earth's upper mantle*) and *Challenge 9* (*How are seafloor spreading and mantle melting linked to ocean crustal architecture?*).

Exhumed mantle peridotites drilled at Site 651 (Fig.2) are spinel harzburgite and dunite with significant veining of amphibole gabbro. These peridotites record a protracted history of high-temperature ductile deformation, metasomatism, serpentinization and brittle deformation (Bonatti et al., 1990). Our pilot microstructural study of Site 651 peridotites shows the existence of high-T (proto-)granular harzburgite (Fig. 9 a-b) —characteristic of asthenospheric flow— that contain rare metasomatic/secondary clinopyroxene similarly to that observed in slow-spreading MOR (Brunelli et al., 2006; Seyler et al., 2007; Warren, 2016). Locally, granular peridotites of Site 651 display pervasive amphibole-gabbro veins and patches (Fig. 9c; Bonatti et al., 1990). Granular peridotites are cross-cut by relatively sharp shear bands expressed as proto-mylonitic domains (Fig. 9d). Protomylonites are seldom observed in drilled abyssal peridotites from slow-spreading MOR (e.g. Jaroslow et al., 1996; Cipriani et al., 2009) but have been described in submersible surveys and sampling from the Iberian COT (Beslier et al., 1990). In both cases, they attest for retrograde non-magmatic strain localization at high-deviatoric stress during mantle exhumation pointing to high-T shear zones extending into unaltered mantle rocks (Jaroslow et al., 1996).

Late syn-kinematic gabbroic veins (Fig. 9d) indicate long-lived faulting and uplift from ductile deformation to brittle-plastic transition and further strain location, coeval with melt impregnation and high-T hydrothermal activity. The latter feature is characteristic of detachment formation and evolution of ocean core complexes in slow-spreading MOR (e.g., Escartín et al., 2017) and COTs, at slower spreading rates than the allegedly fast mantle exhumation at Tyrrhenian Sea basin. **TIME** samples will be used for microstructural (combining EBSD in fresher samples) and geothermometry studies in pyroxene and spinel, to reveal the mechanism of strain localization and the P-T-t cooling path, constraining the onset of mantle exhumation.

Analyses of bulk chemistry and geochemistry (major and trace elements and Re-Os isotopes), along with analyses of ortho/clinopyroxene couples for in-situ major and trace elements, and Sr-Nd (and Hf-Pb in less depleted and refertilized peridotites) isotopes on mineral separates, will provide information on the provenance and shed light into the exhumation process and the lateral extent of mantle heterogeneities.

Site 651 peridotites are mostly devoid of clinopyroxene, and have an extremely residual composition characterized by high Cr/Al in spinel and very low Al_2O_3 content (<1.0 wt.%). This compositional character is markedly different from the subcontinental and oceanic mantle peridotites exposed in the circum-Tyrrhenian ophiolites and the Iberian COT, which are more fertile than Tyrrhenian samples (Bonatti et al., 1990; Bodinier and Godard, 2003, Gonzalez-Jimenez et al., 2013). Site 651 mineral chemistry indicates high degrees of partial melting and melt extraction, with a composition similar to the most depleted peridotites found in slow-spreading to ultraslow spreading MOR such as the MAR and Gakkel Ridge (Warren, 2016) or those affected by fluid-flux melting in supra-subduction settings (Marchesi et al., 2006). It is unlikely that the residual character of site 651 peridotite is due to decompression partial melting leading to the early Tyrrhenian N-MORB magmatic crust, as such depletion in peridotite requires extremely high mantle potential temperatures and a long vertical decompression path (Herzberg, 2004). Neither fluid-flux melting would explain the composition of MOR composition of basaltic crust in the Tyrrhenian extended margins. Such depletion more likely represents an unusually actively convecting mantle recording multiple episodes of (ancient) melting (Warren, 2016), or the presence of domains of old and buoyant Archean subcontinental mantle.

Our <u>preliminary trace element chemistry</u> of site 651 peridotite minerals (Fig. 10a,b) unveils a complex metasomatic and mantle melting history. Trace elements in granular peridotite orthopyroxenes (Fig. 10b) show a highly heterogeneously distributed depleted mantle domains overprinted by late metasomatism events leading to enrichment in LREEs (Fig. 10b). These data highlight the high potential of **TIME** core samples to unravel the melting and melt-extraction history of the Tyrrhenian mantle through detailed trace element analyses of (relic) peridotite orthopyroxene, clinopyroxene, and olivine, addressing fundamental aspects of the IODP *Challenge 8: What are the composition, structure, and dynamics of Earth's upper mantle.* We will also use Re-Os analyses — whole rock and, if available, sulfides— to decipher the protracted history of past melting and compare it to that of other circum-Mediterranean mantle peridotites (González-Jiménez et al., 2013). These data will not constrain the age of young melting events but they will decode their ancient melt-extraction history that will be used to evaluate the potential role of inherited ancient mantle depletion (e.g., Harvey et al.,2006) as a potential factor controlling the switch from magmatic to magma-poor mantle exhumation during COT formation.

The Tyrrhenian region is characterized by igneous activity during the Cenozoic showing an extreme compositional variability in space and time, highlighting a complex evolutionary history for magmas and their sources (Peccerillo 2017; Fig. 10d). The Tyrrhenian basin hosts Miocene to Quaternary volcanoes ranging in composition from MORB- to BAB and OIB. MORB-type rocks occur in the Vavilov Basin (Fig. 1), but also in other Tyrrhenian volcanoes. Components with OIB-fingerprint (Trua et al., 2003, 2007; Peccerillo, 2017) have been sampled at the Marsili, Vavilov and Prometeo seamounts and from the Ustica Island (Fig. 2). A melt inclusion study of the Marsili lavas (Trua et al., 2010) showed that the OIB component may derive from scattered blobs of African-type mantle instead of a well-developed asthenospheric flow as previously suggested (Trua et al., 2003). Defining the nature of different mantle components is a major goal of the project.

The first magmatic pulse, preceding mantle exhumation, has been inferred from seismic velocities in the conjugate Cornaglia and Campanian terraces, but it has not been sampled because it does not outcrop and was undetected until recently (Prada et al., 2014, 2015, 2016). **TIME** sites will sample the volcanic layer associated with the first stages of magmatic spreading (Figs. 1, 5, 6). Site 651 basalts recovered fresh glassy rims suggesting these new drilled samples will provide enough glassy volcanic samples suitable for standard radiogenic isotopic study (Sr-Nd-Hf-Pb) as well as high-precision Ar-Ar dating, that is largely unavailable for volcanic rocks from the Tyrrhenian seafloor. These results will allow investigating the temporal evolution of magmatism from N-MOR to back-arc and OIB, through the compositional evolution of basalts for major REE, LILE and HFSE and they source (Sr-Nd-Hf-Pb isotopes), constraining the temporal evolution of the melts involved in crustal accretion, and addressing fundamental aspects of *Challenge 9 of the Science Plan*. Data from volcanic rockss will be compared with those of gabbroic inclusions in mantle peridotites to establish a potential link between mantle exhumation and volcanism.

Furthermore, we will establish the relationship between mantle source and Tyrrhenian volcanism. Our preliminary trace element investigation, although on a very small sample set, reveals a clear disequilibrium between the residual character of the rocks almost devoid of clinopyroxene and the extreme enrichment in incompatible elements in ortho and clinopyroxenes (Fig 10b). LREE enriched secondary clinopyroxenes in site 651 peridotites (Fig. 10b) are likely precipitated from the same melts that crystallized the amphibole-gabbroic impregnations in some peridotites (Fig. 10a). These enriched patterns are rarely found in MOR and COT settings (Warren, 2016), but present in Tyrrhenian OIB and arc-related volcanism (Fig 10c,d). Further characterization requires additional analyses of large clinopyroxenes in peridotite with variable depletion allowing reconstructing the primary composition of clinopyroxenes for reliable computation of the trace element composition of equilibrium melts (particularly HFSE). Constraining the source equilibrium melts will reveal the nature of the lateral heterogeneities dispersed in the deep source and their genetic link with Tyrrhenian volcanism. For that, we will analyze trace element (LA-ICP-MS) and, if sufficient fresh material is recovered, Sr-Nd-Pb-Hf isotopes of mineral separates from gabbroic impregnations. Amphiboles from gabbroic veins and patches (Fig. 10a) reveal different degrees of differentiation of the magmas involved, suggesting the presence of deep reservoirs or en-route reactive differentiation. State-of-the-art high-precision U-Pb N-TIMS dating of zircon, xenotime and apatite in amphibole-gabbros patches will provide robust age constraints for mantle impregnation processes (e.g., Schärer et al., 1995). A coupled Ar/Ar and K/Ar geochronology of the associated basalts will constrain the different magmatic phases. Our work will address Challenge 9; *How are seafloor spreading and mantle melting linked to ocean crustal architecture?*

Objective 3: To establish the rheology, deformation patterns and timing of mantle exhumation.

Mantle exhumation in the Tyrrhenian resembles the process occurring at MOR, either at slow or ultra-slow spreading centers. In those contexts it is accommodated by two types of faulting, respectively: 1) asymmetric detachment faulting associated with non-negligible amount of magmatism (~50% of the extension; Tucholke et al., 2008). This allows the formation under greenschist facies of a weak metasomatic assemblage made of talc-chlorite-amphibole that localizes deformation in a ≤~100-meter thick fault (e.g. McLeod et al., 2002; Escartin et al., 2003, 2017); 2) successive polarity change of detachment faulting (symmetric system) associated with very limited magmatic supply (Sauter et al., 2013) and a less characterized deformation style, most probably localized in serpentinites. The latter mechanism of exhumation has been inferred at COT with poor magma supply, but it usually occurs at slower spreading rates than that estimated in the Tyrrhenian, where magmatic impregnation also testifies of non-negligible magmatic activity (see Objective 2). By analogy with mid-ocean ridges systems (e.g. Cannat et al., 2008), temporal variations of the extensional style are also possible, depending on the evolution of the extension rate and magmatic supply in the Tyrrhenian basin (see Objective 1).

The current limited sampling does not allow the identification of exhumation mechanisms and deformation modes in Tyrrhenian peridotites, since no clear fault plane material was drilled. High-temperature fabrics in peridotites, shown by plastically deformed pyroxene, are the only deformation structures clearly described so far (Bonatti & al., 1990). However, the fabrics cannot account for the whole history of massive mantle exhumation to the surface, which implies lower T conditions. The available samples suggest that HT deformation was actually localized in impregnated areas of peridotites samples, subsequently altered in talc-chlorite-amphibole, highlighting the role of magmatism in early localization of deformation *(part of IODP SP challenge 9: How are seafloor* *spreading and mantle melting linked to ocean crustal architecture).* Talc, having one of the lowest friction coefficients, is key in localizing deformation thanks to its weak (001) plane over a wide range of T conditions (Escartin et al., 2008). Such a weak assemblage, locally foliated, can reinforce the localization of deformation at lower T conditions (greenschist facies), also attested by broken pyroxene and amphiboles, and contribute to exhumation by faulting (Fig. 11a-b). The capability of the tectono-magmatic interplay to create such an assemblage is similar to conditions of asymmetric detachment at MOR, but real fault schists attesting of high strain zones have not been collected yet.

Drilling peridotites at 3 sites will increase the likelihood to sample fault material from the main slip surface and the damage zone associated to the detachment. Detachment faults are ~75-100 meter thick at MOR (Escartin et al., 2017), and secondary shearing areas are locally observed down to 300 m into the footwall (Bonnemains et al., 2016). A fully silicified brecciated diabase occurs in the upper 70 m under a MOR detachment fault (Bonnemains et al., 2016). Drilling two holes of ~140m depth into the Tyrrhenian peridotite will help understanding deformation partitioning with depth, to be later used in numerical thermal models (Objective 5).

MOR observations show that deformation mechanisms at exhumed mantle areas are heterogeneous, and associated to variable intensity and type of hydrothermalism. This highlights the complex interplay between hydrothermal fluid circulation, magmatism, and faulting, and broadens the possible exhumation mechanisms and deformation modes in this kind of setting, so that new Tyrrhenian samples may display unexpected processes.

Objective 4: To determine fluid-rock interactions in peridotite basement

Available peridotite samples from Leg 107 (hole 651) are largely hydrated but some samples show pyroxene and olivine relicts allowing their use for magmatic studies (Objective 2). Peridotites show different stages of alteration, ranging from amphibolite to greenschist facies, and also some low-T processes (<100°C) marked by clays and hydroxides formation (Bonatti et al., 1990). Superficial alteration of peridotites by colder seawater during long exposition at the seafloor (i.e. leaching) can considerably modify the geochemical record of magmatic and hydrothermal processes but it is usually limited to the uppermost section. Static serpentinization is the dominant alteration process in peridotites (Figs. 11c-d) away from melt impregnation; otherwise, the metasomatic assemblage talc-chlorite-amphibole is observed.

Serpentinization textures (mesh and bastite) are very similar to those observed at MOR with abundant magnetite veins suggesting a formation T near 300-350°C concomitant with exhumation tectonics (Bach et al., 2004; Andreani et al., 2007, 2013; Klein et al., 2014). From a geochemical point of view, serpentinites act as sponges for fluid mobile elements (Deschamps et al., 2011; Debret et al., 2013a, 2013b) and may have recorded a contribution from upward subducted fluids, which has to be investigated. A comprehensive geochemical study will provide a unique dataset to be compared with other settings (forearc, MOR, subduction: e.g. Debret et al., 2019; Deschamps et al., 2013) and address the specificity of the water-rock exchanges at COT. The search for fluid inclusions, more direct markers of fluid circulating at depth, requires fresher samples that may be recovered in the proposed deepest holes.

A second stage of serpentinization also occurs, forming serpentine textures poorer in magnetite. Such textures are usually more abundant in ophiolites and continental rifted margins where they are associated with very low magnetic susceptibility and lower T of serpentinization (<150-200°C; Figs. 11e-g) (Oufi et al., 2002; Seyfried et al., 2007; Klein et al., 2014; Bonnemains et al., 2016). More abundant sampling for oxygen isotopes and magnetic measurements is required to test whether Tyrrhenian serpentinites differ from those at other COTs (Klein et al., 2014) where serpentinization T seems lower (Fig. 11g).

The search for low T (past or active) serpentinization or alteration in general in such systems is determinant to better constrain the seawater-lithosphere chemical exchange through time away from spreading centers, after tectono-magmatic processes ceased. This is still missing for the global budget, central to *IODP SP challenge 10: What are the mechanisms, magnitude, and history of chemical exchanges between the oceanic crust and seawater*. While evidence of active serpentinization/alteration at T <200°C below inactive faults exists near MOR (e.g. Lost City at Atlantis massif, MAR; Clamstone and Ghost City at Rainbow massif, MAR), its extent through time has not been addressed by drilling because of the thick sediment cover away from the ridge. In particular, it is an unquantified contributor to H_2 production, carbon conversion and storage, and ecosystem development in oceanic lithosphere. H_2 and abiotic reduced carbon species, both volatiles and condensed (Fig. 4: see review in Andreani & Ménez, 2019), can be produced during serpentinization and thrive ecosystem development at shallow levels. Drilling Tyrrhenian peridotite provides the opportunity to quantify long-term alteration processes and test whether serpentinization is still active at the upper section of a peridotite exhumed 2-5 Ma covered by sediment.

The deepest holes will allow exploring the T and fluid composition with depth, and especially relate the distribution of H_2, organic volatiles, and ecosystems with rock properties. Different locations will allow addressing the lateral heterogeneity of possible outflow, complementing similar investigations of recent IODP Exp. IODP 357 at Atlantis Massif, and ICDP Oman Drilling project, but in a different geological setting. Investigating redox-sensitive elements such as metals, S and C will help to decipher the evolution of redox conditions and possible biogeochemical processes notably at the basement-sediment interface where the strongest geochemical gradient are expected (e.g. Andreani et al., 2013; Debret et al., 2017; Ménez et al., 2018). This objective addresses *IODP SP challenges 13 (What properties and processes govern the flow and* *storage of carbon in the subseafloor?) and 14 (How do fluids link subseafloor tectonic, thermal, and biogeochemical processes?).*

Objective 5: To test models of rifting and COT formation.

Results from Objectives 1-4 will provide a unique dataset of the main parameters governing COT formation, not available at other systems in the world, which will allow evaluating conceptual models of COT formation. The parameters, will provide the framework for model testing through *quantitative* numerical modelling, rather than the more common *qualitative* descriptions of models.

Objectives 1, 2 and 3 will provide the kinematics and geometry, in space and time, of the extensional deformation of the brittle layer, and the transition from ductile to brittle deformation in the mantle as exhumation progressed.

Integration of the timing and spatial evolution of the deformation with estimation of PT conditions for mantle mineral, and a melting evolutionary model resulting from Objectives 2 and 3, will provide the information to define the 3D rheological evolution of the system.

The study of fluid-rock interaction of Objective 4, integrated with the information of Objectives 1-3, will help constrain the depth of penetration and strength of the hydrothermal system active during extension and after tectonism stopped.

The model predictions will be compared to P-wave velocity of the basin, obtained from the 7 WAS profiles discussed above. P-wave velocity models were produced with state-of-the-art travel time tomography and can be interpreted in terms of distribution of porosity and rock type for basalts and degree of serpentinization for mantle peridotite. This information will further constrain the thermal and rheological structure of the extension system.

The holistic quantitative database of the system will be used to constrain numerical models of lithospheric deformation, melt production and mantle exhumation reproducing the conditions of the Tyrrhenian system. The parameter space of the numerical code will be tested to investigate the range of changes necessary to produce other COT scenarios in literature and evaluate the feasibility of producing them using physically realistic conditions.

Numerical models predict that serpentinized mantle exhumation at the COT occurs either related to slow extension velocity or due to originally depleted mantle (e.g. Pérez-Gussinyé et al. 2006, Ros et al., 2017). This applies particularly for strong rheologies. In contrast, weak initial lithospheric rheologies lead to ultra-wide margins and no mantle exhumation, but produce an abrupt transition to magmatic oceanic crust, as observed in the South China Sea (Ros et al., 2017, Davis and Lavier, 2017).

Numerical models using constant mantle potential temperature and composition indicate that in cases where mantle exhumation and serpentinization first occur, melting progressively increases until formation of a normal oceanic crust. In space, the continental crust is adjacent to the exhumed serpentinised mantle, and this is followed by magmatic oceanic spreading. The Tyrrhenian, however, challenges these view because continental crust abruptly abuts magmatic oceanic crust, which itself abuts younger exhumed mantle. The data collected during IODP in combination with state-of-the-art numerical modeling techniques will allow us to understand the conditions necessary to produce such an assemblage of basement domains, and whether this might be a common process. The fact is that oceanic ridges show significant lateral and temporal variations along and among ridge segments, from magmatic to non-magmatic spreading. This alternation projected in time, may lead to structure configurations similar to that of the Tyrrhenian. Numerical models constrained with the **TIME** data will allow testing and mapping of the parameters controlling these changes. Two potential candidates may be lateral mantle heterogeneities or changes in velocity.

State-of-the-art modeling techniques solve for the momentum, heat and mass conservations equations of a visco-elasto-plastic lithosphere-asthenosphere system, allowing to simulate deformation, sedimentation, melting, serpentinisation and the dynamic interactions between them (Ros et al., 2017, Andrés-Martínez et al., 2019). These fully dynamic models can be adapted to simulate deformation along a given cross sections (or seismic profile), in that the location of brittle faults is given as inputs to the fully dynamic model. Figure 12 shows a simulation with Kinedyn, which allows not only to analyze the response of the model to input parameter variations, e.g. to rheologies, temperature, extension velocity, etc., but also to simulate deformation mapped on a seismic profile. This approach will be used to integrate kinematics with rheological and temperature evolution derived from objectives 1 to 4 into detailed structural sections.

Numerical models will also incorporate hydrothermal circulation and the thermodynamics of fluid-rock interactions. The study of fluid-rock interaction of Objective 4, integrated with the information of Objectives 1-3, will provide strong constraints on the depth of penetration and strength of the hydrothermal system active during extension and after tectonism stopped. Thus the combination of modeling and observations will permit to analyze the influence of fluids in the mode of deformation and also the role of fluid-rock interaction in element exchange.

Finally, the petrology in numerical simulations will be transformed to P-wave velocities and compared to measured P-wave velocities from the WAS lines, and analyzed in light of petrological drilling results.

Objective 5 addresses essential aspects of *IODP SP challenges 8: "What are the composition, structure and dynamics of Earth's upper mantle?" and 9: "How are seafloor spreading and mantle melting linked to ocean crustal architecture?"*

Expected scientific impact of the drilling and analysis results

The ground-truth provided by drilling and the analysis of the cores described in objectives 1-4, with their integration into quantitative numerical modelling in Objective 5, will test <u>conventional wisdom models</u>

of COT formation. Our holistic approach will, for the first time, determine 3D crustal and mantle deformation style and rates, and will quantitatively relate them to melting models that will be linked to mantle processes.

Strategy for addressing the scientific objectives through drilling, logging or other downhole measurement:

1) Coring by APC of entire sediment column at Vavilov Basin (TYR-6A). RCB with recovery for the others. Recovery is particularly important in the tens of meters above basement to calibrate ages based on microfossils and evaluate rock-fluid interactions with possible biogeochemical evidence of active serpentinization at depth.

2) Basement coring with rotary drilling aimed at rock recovery. Pore water samples will be taken at least in 1 site on serpentinized mantle to study fluid-rock interaction and potential faunal communities.

3) Well logging is required for the project goals:

- All sites with triple combo: natural gamma, resistivity, magnetic susceptibility, litho-density for their interpretation.
- All sites, but particularly important in basement, should have Spectral natural gamma, acoustic velocity (sonic), shear anisotropy, and (oriented) electrical images. These measurements will provide correlation with seismic images, particularly important to understand rock nature, and orientation, extent, and mechanisms of deformation structures observed in cores.
- Logging temperature every 35 meters approaching basement to detect potential fluid flow or active (exothermic) serpentinization processes. In addition, we plan to acquire more geophysical data to further characterize structure and nature of the basement.
- Sites priority is: TYR-3A, TYR-1A, TYR-6A, TYR-4A, TYR-5A, TYR-2A.
- Site TYR-3A targets the mantle peridotites of the Vavilov Basin and represents the “core” of the W-E and N-S transects, it is one of the two deeper holes (140 m). TYR-1A is located in the Cornaglia Terrace, belongs to the W-E transect and targets the pre-exhumation basalts. TYR-6A

trargets the upper mantle peridotites in the northernmost portion of the Vavilov Basin and belongs to the N-S transect. TYR-4A completes the W-E transect in the Vavilov Basin and will provide the sediment log of this basin by the APC/XCB technique. TYR-5A completes the N-S transect drilling to 140 m in basement. TYR-1A completes the W-E transect.

A goal for at least 2 sites in exhumed mantle is crossing the exhumation fault zone, assumed to be ≤~100 meter thick (Escartin et al., 2017). TYR-3A and TYR-5A will penetrate 140 meters into the mantle to likely cross the fault zone and, two sites will penetrate 70 m, which might be enough to drill through the fault too. Sites in Cornaglia and Campania Terrances will penetrate 70 meters into basement basalt.

Justification for the time requested

To accomplish the goals, TIME needs to reach the Tyrrhenian basement at the six sites. Four sites in the Vavilov Basin target exhumed mantle (TYR-3A, TYR-4A, TYR-5A, TYR-6A) and sites at Cornaglia and Campania terraces (TYR-1A, TYR-2A) target magmatic basement.

To estimate the time needed for the four sites in Vavilov sites peridotite we use ODP leg 107 site 651 information, because they are at similar water depth and share the stratigraphy

To estimate the time required for holes TYR-1A, TYR-2A we use site 653 information located not far from TYR-1A (Cornaglia Terrace) and penetrated possibly similar lithologies above basement.

To compute basement penetration we estimated the maximun penetration in a 60-days leg duration considering the ≤~100 m inferred thickness of the detachment to be crossed at least by two holes. The penetration depth was addapted to the standard logging-tool string length of ~35 m . We obtained the statistics for wave height and period for the whole year (loaded in the SSDB), which gives 1% probability for waves higher 5 meters.

In total we estimate for 6 holes **4.9** (TYR-1A) + **8.8** (TYR-2A) + **8.0** (TYR-3A) + **11.9** (TYR-4A) + **6.3** (TYR-5A) + **11.6** (TYR-6A) = **51.5** days of operations and **2.3** days transit time assuming beginning/end of expedition in Naples/Marseille and transit at 10.5 knots plus **5.0** days of Port call. This computation is based on the operations/timing recommendations from the SEP operation office. This estimate includes **1.2** days time for weather delays notwithstanding the favourable meteo condition of the region for any season.

The **TIME** drill plan fits into a 60 days iODP leg. Leg 107 achieved a total penetration of **2954** meters in 45 days leg. TIME plans **3275** meters (311 meters more than leg 107) in 60 days leg. Alternate sites TYR-7A to TYR-12A require similar operational times.

Site characterization

The Tyrrhenian basin has had three drilling expedition: DSDP leg 13, site 132; DSPD leg 42, site 373 and ODP leg 107, sites 650-656. These data provide excellent information on the stratigraphy. Leg 107 drilled the basement of Vavilov basin target of **TIME**.

In the Vavilov basin (TYR-3A, TYR-4A, TYR-5A, TYR-6A) sediment thickness ranges from ~142 (TYR-5A) to ~902 meters (TYR-6A). The oldest sediment drilled lapping on basement is Early Pliocene (3.6 Ma, Kastens et al., 1987). This sediment is made of volcanoclastics interbedded with marly muds, pumice sandy layers and cemented volcanic breccia. Basement **TIME** sites in Vavilov are chosen to drill partly-serpentinized peridotite, but might contain a few meters of basalt and/or basalt breccia in the shallow-most section.

Cornaglia (TYR-1A) and Campania Terraces (TYR-2A) Plio-Quaternary to Messinian stratigraphy was sampled at site 653. Plio-Quaternary strata are nannofossil ooze, clastics and ash layers. Messinian evaporites in the Mediterranean have the so-called "trilogy" of -from bottom to top- gypsum, halite, and gypsum units, clearly seismically imaged (Roveri et al., 2014). In the Tyrrhenian the trilogy is restricted to the deepest portion of the basin during the Messinian crisis i.e. part of Cornaglia basin and possibly south of Magnaghi seamount (Fig. 1). Site TYR-1A in

Cornaglia is away from salt deposit, but will drill upper gypsum evaporites. Campania Terrace site TYR-2A will drill upper gypsum.

Relation with other projects

The objectives of TIME are directly related to the objectives of the US-GeoPrism program and the international Interridge community, in addition to several EU-national programs.

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Figures captions:

Figure 1. Bathymetric and topographic map of the Tyrrhenian region located in the western Mediterranean (see inset). Bathymetric data are downloaded from EMODnet portal (http://portal.emodnet-bathymetry.eu/gebco-bathymetry-basemap), while topographic data are part of 90m-SRTM dataset freely downloaded by web. Black thick and red lines depict respectively the WAS and MCS transects acquired during the

MEDOC and CHIANTI experiment. The most relevant profiles for this study are MEDOC4/WAS EF Line (Prada et al., 2015) and MEDOC6/WAS GH Line (Prada et al. ,2014) in the Central Tyrrhenian. Locations of OBS, and OBHs used to acquire WAS data are indicated by yellow circles while land stations are shown in red. Green polygons show the location of ODP and DSDP sites sampled in the seventies and eighties (Dietrich et al., 1977; Kastens and Mascle, 1990), while pink polygons depict the location of the proposed IODP sites TYR-1A to TYR-6A. The location of OBH 83 along line MEDOC6/WAS GH and OBS 28 along CHIANTI-WAS2 line, shown in Figure 7, are also included in the map. Bottom: cartoon showing the kimematic of the Tyrrhenian from rifting to mantle exhumation based on the amount of crustal thinning derived for the four W-E refraction lines.

Figure 2. Bathymetric map of the Tyrrhenian basin, produced by using middle resolution data downloaded from EMODnet portal, including the location of ODP and DSDP sites and respective synthetized stratigraphic columns of the recovery (Kastens and Mascle et al., 1990).

Figure 3. **(a)** Bouguer anomaly from satellite-derived free air anomaly (Sandwell et al., 2014). Bouguer anomalies are obtained by subtracting from free air anomalies the attraction of seafloor topography and of unconsolidated sediments using a density contrast of 1630 Kg/m^3 and of 770Kg/m^3, respectively. **(b**) Reduced to Pole (RTP) magnetic anomaly of the aeromagnetic field (AGIP and SGN, 1994) from Caratori Tontini et al. (2004). **(c)** Heat Flow Map of the Tyrrhenian region modified after Della Vedova et al. (2001). **(d)** Plio-Quaternary Isopach Map of the Tyrrhenian Basin derived from a dense network of high-resolution, single-channel, seismic reflection profiles (Fig.1, inset). **(e)** Map of the pre-Tortonian rocks distribution in the Tyrrhenian region with their radiometric ages (From Sartori, 2005), **1** Variscan rocks, **2** Metamorphic units of Alpine Corsica, **3** Calabride-Peloritanian-Kabilide units, **4** Oligocene to Middle-Late Miocene sedimentary rocks, **5** Ophiolite of the Tethyan domain, **6**

Apenninic-Maghrebian units, **7** Carbonate sequence of Apenninic-Maghrebian units, **8** Central Tyrrhenian metamorphic rock of uncertain paleogeographic attribution, **9** Tyrrhenian mantle sertpentinites **(f)** distribution of Oligocene to Recent magmatic rocks with rock ages reported only at sea (From Sartori, 2005), **1** Oligocene to Middle Miocene island arc basal, **2** Tortonian to Recent rocks either with mantle sources contaminated by crustal materials, or derived from upper crustal sources, or derived by mixing between crustal and mantle sources (Tuscany and Latium on land), **3** Pleistocene to recent rocks with ocean island basalt mantle sources enriched by subduction-related sources (Campania), **4** Pliocene to Recent rocks with island arc basalt type mantle sources, **5** Pliocene to Recent rocks derived from ocean island basalt (OIB) type and from mid-oceanic ridge basalt (MORB) mantle sources, **6** Rocks from undefined magma sources.

Figure 4. (**a**) 2D P-wave velocity (Vp) models of transects EF (Prada et al., 2015) and (**b**) GH (Prada et al., 2014). Yellow circles display location of land-stations, and OBS/H along both profiles. Blue lines represent the PmP-inverted Moho geometry (modified from Prada et al., 2015). Along transect EF (a) and GH (b), velocity changes laterally abruptly in basement, indicating crustal thinning toward the center of the basin. The serpentinized mantle extends in W-E direction for more than 100 km along model GH (b). The absence of PmP wide-angle reflections indicate the lack of a sharp Moho discontinuity under Vavilov and Magnaghi basins. Additionally, recent analysis of converted S-waves from MEDOC OBHs deployed in the area of mantle exhumation, reported Vp/Vs and Poisson's ratios within the range of partially serpentinized peridotite, rather than oceanic gabbro/diabase (Prada et al., 2016), further supporting the presence of exhumed mantle. (**c**) Bathymetric and topographic map of the Central Tyrrhenian with the interpretation of the spatial distribution of the main basement domains. The interpretation of this map is based on geophysical information of both WAS and MCS transects, rock sampling

(colored triangles) (Colantoni et al., 1981; Kastens and Mascle, 1990), and from geomorphological observations. Based on P-wave velocity models three domains can be identified: continental crust (light yellow), magmatic crust (light brown) and serpentinized mantle (green). P-wave velocity models and particularly vertical velocity gradients support the existence of a large expanse of exhumed mantle (Fig. 3a-b). **(d)** Tectonic map of the Cornaglia-Magnaghi-Vavilov-Campania region showing the location of faults active during Messinian and Early-Middle Pliocene (courtesy from M.F. Loreto, ISMAR-CNR). **(e)** Cartoon showing the three stage of formation of the Magnaghi-Vavilov basin as discussed in Prada et al (2016) and inferred from radiometric ages and stratigraphic data information (Prada et al., 2016 and references therein).

Figure 5. Time migrated MCS profile MEDOC 6 showing a consistent lack of Moho reflections under Vavilov and Magnaghi basins, as observed for wide-angle seismic data in Fig. 4b. In these profiles, Moho reflections, indicated by the dashed black lines, terminate abruptly at the location where WAS derived reflections also stop.

Figure 6. From bottom to top, close ups of the time-migrated MCS MEDOC lines 6, 9, 8, 11. Colored triangles indicate the nature of the basement imaged by MCS lines as in Fig.4c. Locations of drill sites TYR-1-2-3-4-5-6A are shown in pink displaying the depth of penetration, and hence, the target of the proposed IODP site. Locations of the alternate drill sites are shown in black. Inset: Bathymetric map with the location of WAS and MCS MEDOC transects used in this proposal, thick yellow lines depict the location of seismic lines shown in this figure together with the location of the proposed drill sites.

Figure 7.(a) Record section of OBH 83, and **(b)** OBS 28 used to acquire respectively WAS data along MEDOC line G-H and CHIANTI line WAS2 respectively. Both record sections are corrected using a velocity of 8 km/s.

The flat geometry of travel-time curves defined by first arrivals implies that the average P-wave velocity of the subsurface is close to the reduction velocity applied, that is ~8 km/s. This apparent velocity is anomalously high for oceanic crust (i.e. 6.5-7.0 km/s), but not for exhumed mantle rocks. The location along the line of the receivers is shown in Figure 1. **(c)** Characteristics of the drilling sites proposed in the TIME pre-proposal.

Figure 8. Close ups of time migrated MCS MEDOC sections 6, 8, 9 and 11 at the area of IODP drilling sites proposed here. In dark pink is shown the location of the proposed wells and in black the location of the alternate wells with the estimated depth of penetration (see map in Fig.1 for the location of wells and MCS lines).

Figure 9. Pictures of ODP Leg 107 cores at site 651 (651A-58R) illustrating different lithologies and structures of residual peridotites with variable degrees of late magmatic veining. **(a) Top**: Dunite patches in highly depleted granular harzburgite with late veining (651A-58R1-50-65). **Bottom**: Thin section micrograph of the same core showing coarse orthopyroxene-spinel aggregates (blueish) of typical of protogranular harzburgite in a matrix of heavily serpentinized olivine (black-dark brown background) (crossed-polarized; field of view 2x3.5 cm). **(b) Top**: Typical granular harzburgite in site 651 (651A-58R1-94-102); **Bottom**: Thin section micrograph of the same core showing rounded clusters (whitish areas with blueish-red and yellow grains) of granular orthopyroxene-spinel with late magmatic clinopyroxene in a matrix of heavily serpentinized olivine (dark brown) (crossed-polarized; field of view 2x3 cm). **(c) Top**: Highly depleted granular harzburgite with pervasive intrusion of late amphibole gabbroic veining, heavily transformed to talc-chlorite and rodingite (651A-58R3-20-37). **Bottom**: Thin section micrograph (crossed-polarized; field of view 1x1.5 cm). Below: Thin section micrograph of gabbroic patches with plagioclase transformed to rodingite assemblages

(white and brownish areas) preserving grains of amphibole-clinopyroxene (red-green and yellow) (crossed-polarized; field of view 1.5x2.5 cm) **(d) Top**: Picture of core section with a cm-scale protomylonite harzburgite attesting for high-temperature ductile strain localization in shear zones in site 651A; the ductile deformation is overprinted by late synkinematic gabbroic and talc-chlorite veins attesting for late synkinematic melt impregnation (651A-58R3-110-129). **Bottom**: Thin section of the same core showing harzburgites with a porphyroclastic textures characteristic of high-T protomylonite (800-900 ^{o}C) showing rounded orthopyroxene porphyroclast and highly stretched spinels (black elongated grains) in a heavily serpentinized fine-grained olivine matrix.

Figure 10. Chondrite-normalized extended trace element patterns of minerals from Leg107 site 651R peridotite and gabbroic rocks, analysed by LA-ICP-MS analyses (***unpublished preliminary results***): **(a)** amphibole in gabbroic veins and patches (651A-58R3-28-36); **(b)** clinopyroxene and orthopyroxene in protogranular harzburgites in core sections 651A-58R1-50-65 and 651A-58R1-94-102. See Figure 1 for textures. **(c and d)**: Primitive mantle-normalized incompatible element patterns of submarine mafic volcanics (MgO>4.0 %) from the southern Tyrrhenian Sea (Fig. 12.4 of Peccerillo, 2017).

Figure 11. **a**) Deformation textures observed in sample 651A-68-1-86 from Leg 107 (hole 651). **b**) Typical serpentinization textures of peridotites recovered at ODP Leg 107 (sample 651A-58-4-99) displaying both magnetite-rich and magnetite-poor areas. **c)** Compilation of existing data for serpentinites susceptibility versus grain density and corresponding serpentinization degree from different oceanic settings (Bonnemains et al., 2016). **d)** Histogram showing serpentinization temperatures from oxygen isotope thermometer showing a bimodal distribution of magnetite-poor samples from Iberia margin and magnetite-rich samples from mid-ocean ridge settings (Klein et al., 2014). MAR—

Mid-Atlantic Ridge; MARK—Mid-Atlantic Ridge Kane Transform. At Bottom, examples of occurrences of organic carbon in serpentinized oceanic rocks: **(e)** SEM image of O-bearing condensed carbonaceous matter abiotically formed jointly with hematite (Hem) and saponite (Sap) during the low-T alteration (T<150°C) of oceanic serpentinites of the Ligurian Tethyan ophiolites (Sforna et al., 2018); **(f)** Associated elemental distributions of carbon (red) and iron (green) within the white square area in (e); **(g)** Transmission electron microscope (TEM) image showing polyhedral serpentine (pol-spt) sections wet by a jelly film of organic carbon interfacing between the pol-spt and an andraditic hydrogarnet (H-adr) in serpentinites from the MAR (4-6°N) (Ménez et al., 2018).

Figure 12. **Top**: Seismic section along the West Iberia margin. **center**: Modelled section with Kinedyn, which fits the pattern of crustal thinning and faulting observed along the seismic line. Shown are the crust in brownish colours, the mantle in olive green. The Moho in blue dashed line and the plastic and viscous strain rates for that time step during the model run. The area shaded in yellow corresponds to the sediment. **Bottom**: temperature field for that time step during the model run.

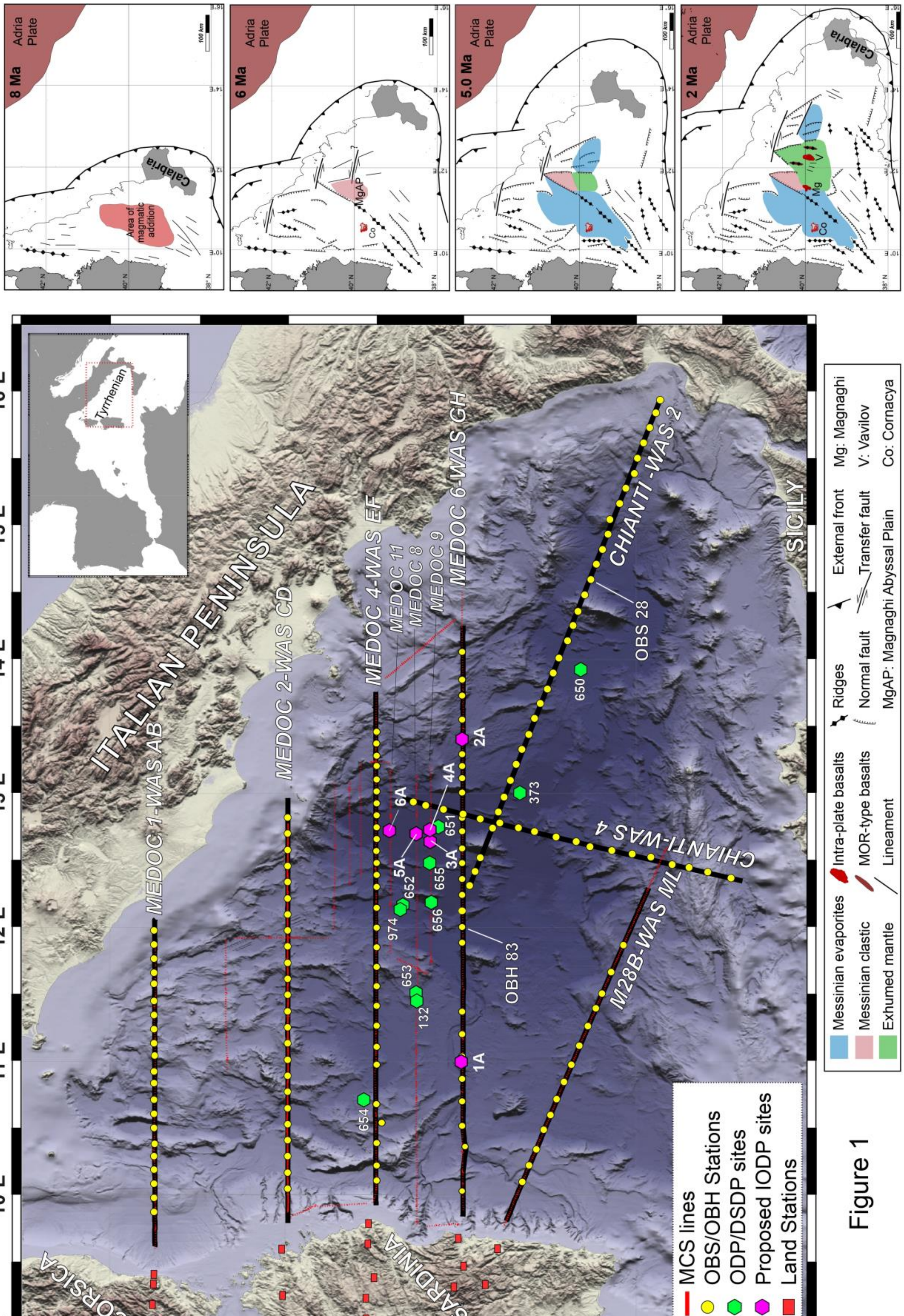

ITALIAN PENINSULA
MEDOC 1-WAS AB
MEDOC 2-WAS CD
MEDOC 4-WAS EF
MEDOC 11
MEDOC 8
MEDOC 9
MEDOC 6-WAS GH
CHIANTI-WAS 2
CHIANTI-WAS 4
M28B-WAS ML
CORSICA
SARDINIA
SICILY
Tyrrhenian
OBS 28
OBH 83
1A
2A
3A
4A
5A
6A
132
373
650
651
652
653
654
655
656
974
MCS lines
OBS/OBH Stations
ODP/DSDP sites
Proposed IODP sites
Land Stations
9°E
10°E
11°E
12°E
13°E
14°E
15°E
16°E
38°N
39°N
40°N
41°N
42°N
8 Ma
6 Ma
5.0 Ma
2 Ma
Adria Plate
Calabria
Area of magmatic addition
MgAP
Co
Mg
V
100 km
Messinian evaporites
Messinian clastic
Exhumed mantle
Intra-plate basalts
MOR-type basalts
Lineament
Ridges
Normal fault
MgAP: Magnaghi Abyssal Plain
External front
Transfer fault
Mg: Magnaghi
V: Vavilov
Co: Cornacya

Figure 1

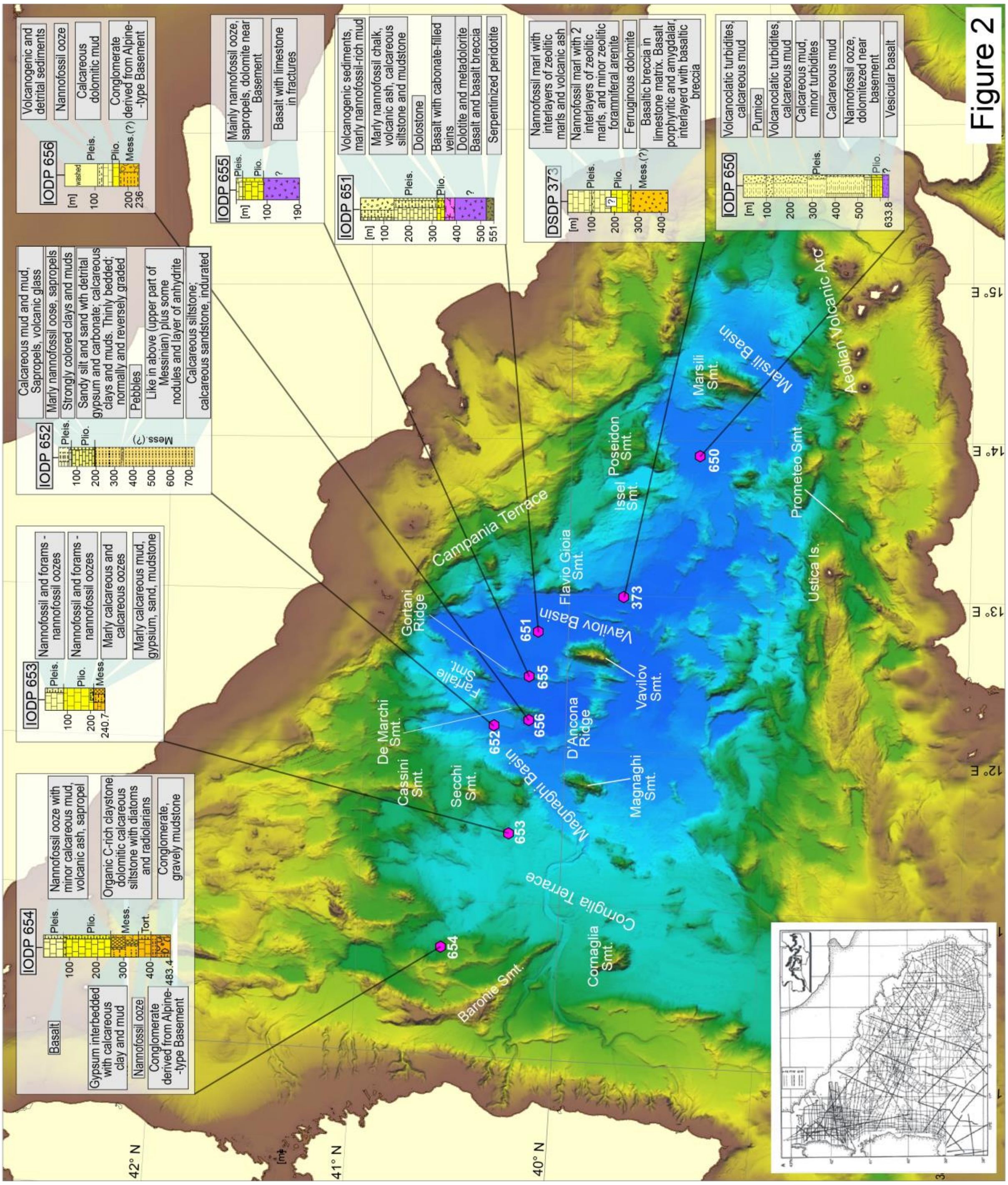


Figure 2
IODP 656
Volcanogenic and detrital sediments
Nannofossil ooze
Calcareous dolomitic mud
Conglomerate derived from Alpine-type Basement
IODP 655
Mainly nannofossil ooze, sapropels, dolomite near Basement
Basalt with limestone in fractures
IODP 651
Volcanogenic sediments, marly nannofossil-rich mud
Marly nannofossil chalk, volcanic ash, calcareous siltstone and mudstone
Dolostone
Basalt with cabonate-filled veins
Dolotite and metadolorite
Basalt and basalt breccia
Serpentinized peridotite
DSDP 373
Nannofossil marl with interlayers of zeolitic marls and volcanic ash
Nannofossil marl with 2 interlayers of zeolitic marls, and minor zeolitic foraminiferal arenite
Ferruginous dolomite
Basaltic breccia in limestone matrix. Basalt porphyritic and amygdalar, interlayerd with basaltic breccia
IODP 650
Volcanoclatic turbidites, calcareous mud
Pumice
Volcanoclatic turbidites, calcareous mud
Calcareous mud, minor turbidites
Calcareous mud
Nannofossil ooze, dolomitezed near basement
Vesicular basalt
IODP 652
Calcareous mud and mud, Sapropels, volcanic glass
Marly nannofossil oose, sapropels
Strongly colored clays and muds
Sandy silt and sand with detrital gypsum and carbonate; calcareous clays and muds. Thinly bedded; normally and reversely graded
Pebbles
Like in above (upper part of Messinian) plus some nodules and layer of anhydrite
Calcareous siltstone; calcareous sandstone, indurated
IODP 653
Nannofossil and forams - nannofossil oozes
Nannofossil and forams - nannofossil oozes
Marly calcareous and calcareous oozes
Marly calcareous mud, gypsium, sand, mudstone
IODP 654
Nannofossil ooze with minor calcareous mud, volcanic ash, sapropel
Organic C-rich claystone dolomitic calcareous siltstone with diatoms and radiolarians
Conglomerate, gravely mudstone
Basalt
Gypsum interbedded with calcareous clay and mud
Nannofossil ooze
Conglomerate derived from Alpine-type Basement
Pleis.
Plio.
Mess.
Mess.(?)
Tort.
[m]
Campania Terrace
Gortani Ridge
Flavio Gioia Smt.
Vavilov Basin
Vavilov Smt.
Issel Smt.
Poseidon Smt.
Marsili Smt.
Marsili Basin
Aeolian Volcanic Arc
Prometeo Smt.
Ustica Is.
Farfalle Smt.
De Marchi Smt.
Cassini Smt.
Secchi Smt.
D'Ancona Ridge
Magnaghi Basin
Magnaghi Smt.
Cornaglia Terrace
Cornaglia Smt.
Baronie Smt.
650
651
652
653
654
655
656
373
42° N
41° N
40° N
12° E
13° E
14° E
15° E

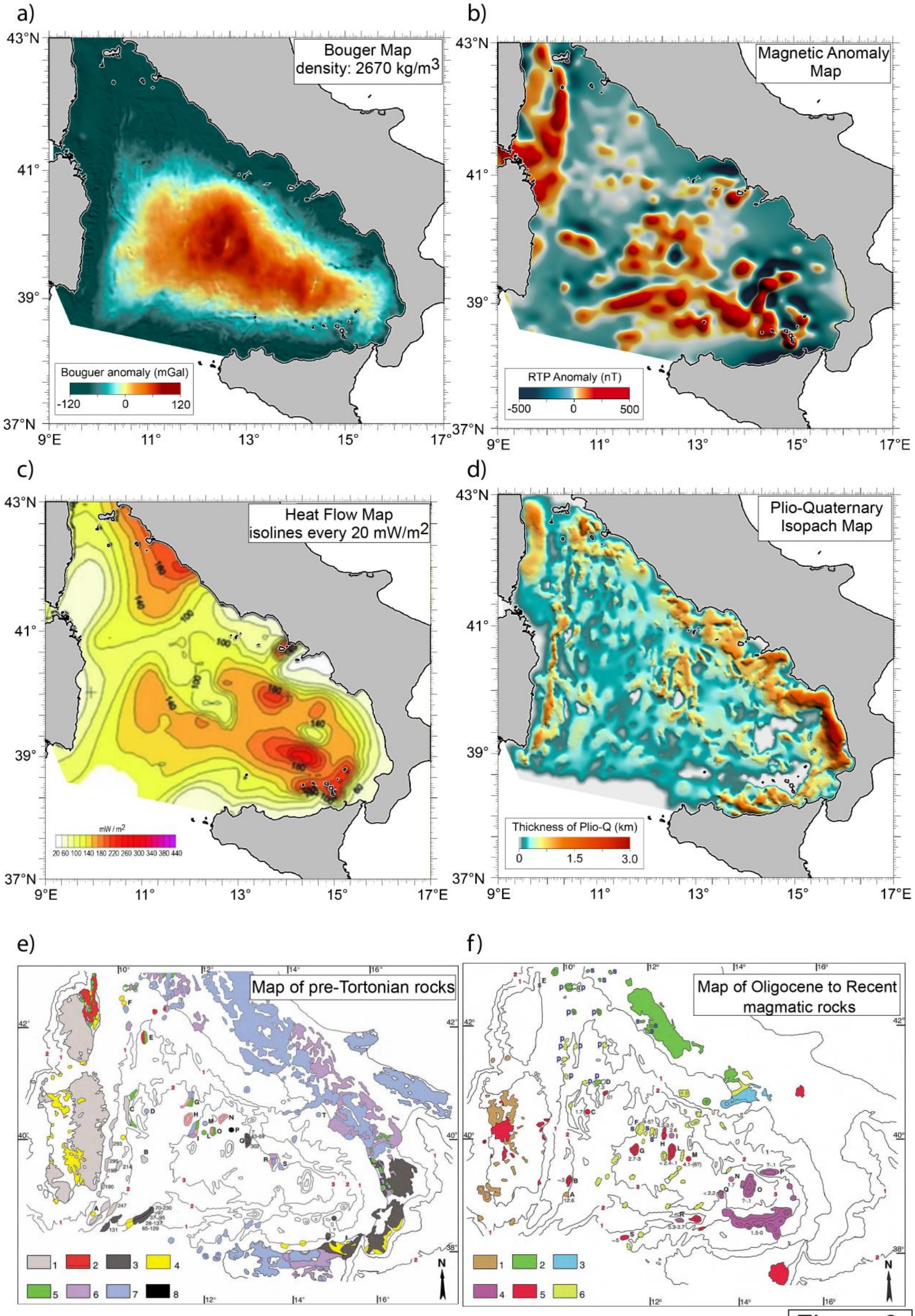

a)
Bouger Map
density: 2670 kg/m3
Bouguer anomaly (mGal)
-120
0
120
b)
Magnetic Anomaly Map
RTP Anomaly (nT)
-500
0
500
c)
Heat Flow Map
isolines every 20 mW/m2
d)
Plio-Quaternary Isopach Map
Thickness of Plio-Q (km)
0
1.5
3.0
e)
Map of pre-Tortonian rocks
f)
Map of Oligocene to Recent magmatic rocks

Figure 3

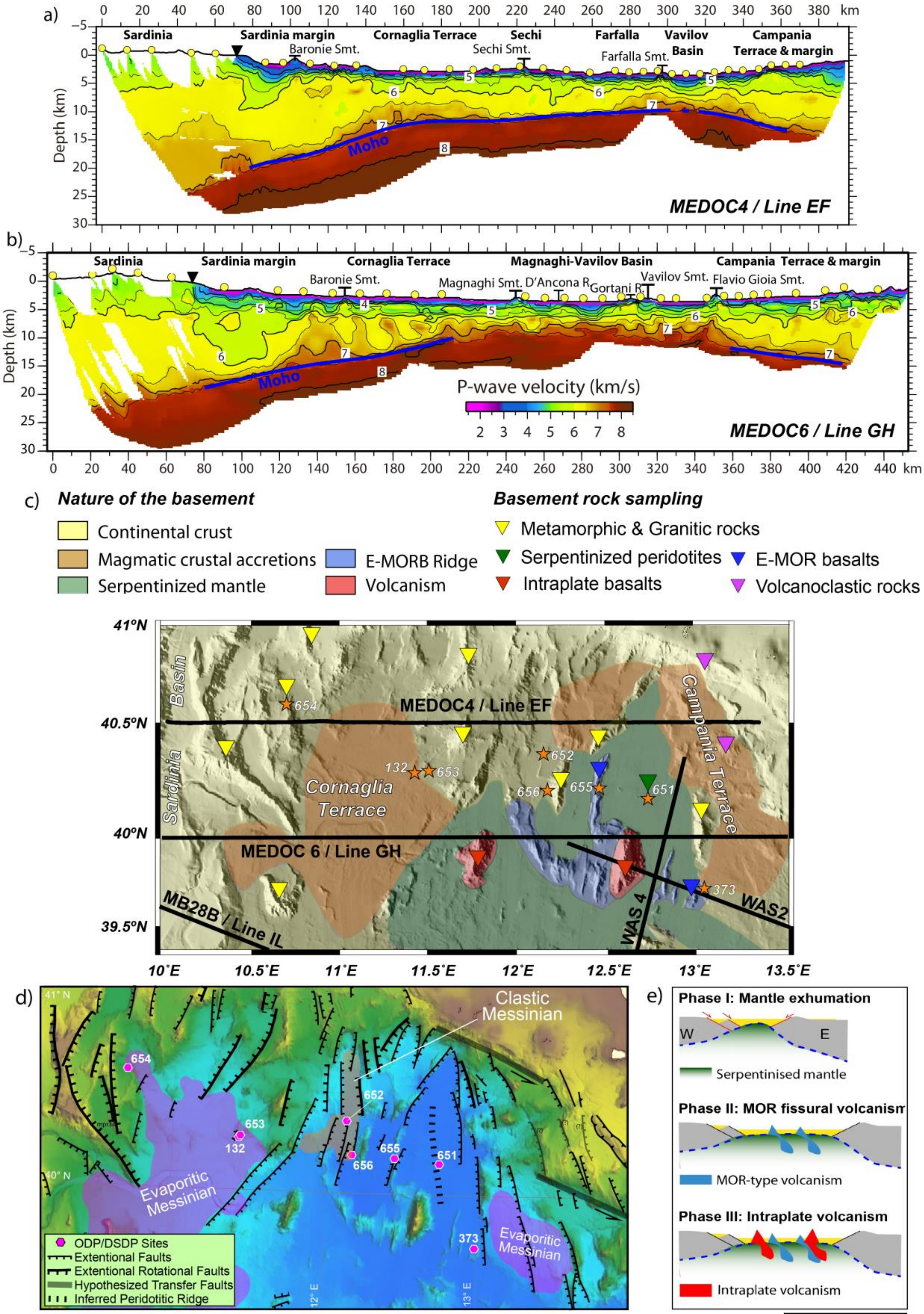

a)
Sardinia
Sardinia margin
Baronie Smt.
Cornaglia Terrace
Sechi
Sechi Smt.
Farfalla
Farfalla Smt.
Vavilov
Basin
Campania
Terrace & margin
Depth (km)
Moho
MEDOC4 / Line EF
b)
Sardinia
Sardinia margin
Cornaglia Terrace
Baronie Smt.
Magnaghi-Vavilov Basin
Magnaghi Smt.
D'Ancona R.
Gortani R.
Vavilov Smt.
Campania Terrace & margin
Flavio Gioia Smt.
Depth (km)
Moho
P-wave velocity (km/s)
MEDOC6 / Line GH
c)
Nature of the basement
Continental crust
Magmatic crustal accretions
Serpentinized mantle
E-MORB Ridge
Volcanism
Basement rock sampling
Metamorphic & Granitic rocks
Serpentinized peridotites
Intraplate basalts
E-MOR basalts
Volcanoclastic rocks
Sardinia Basin
MEDOC4 / Line EF
Cornaglia Terrace
MEDOC 6 / Line GH
Campania Terrace
MB28B / Line IL
WAS 4
WAS2
d)
Clastic Messinian
Evaporitic Messinian
ODP/DSDP Sites
Extentional Faults
Extentional Rotational Faults
Hypothesized Transfer Faults
Inferred Peridotitic Ridge
e)
Phase I: Mantle exhumation
W
E
Serpentinised mantle
Phase II: MOR fissural volcanism
MOR-type volcanism
Phase III: Intraplate volcanism
Intraplate volcanism

Figure 4

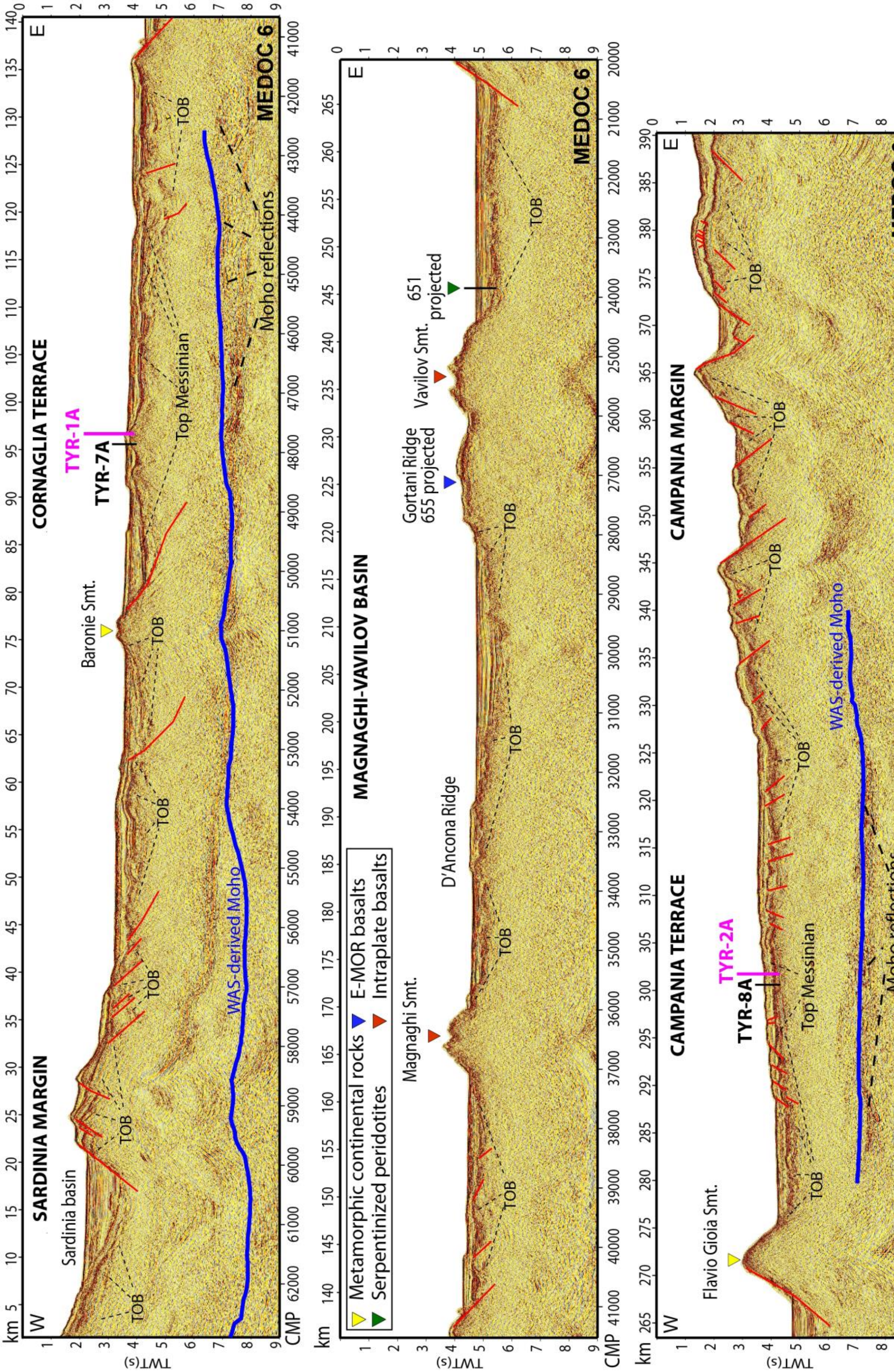
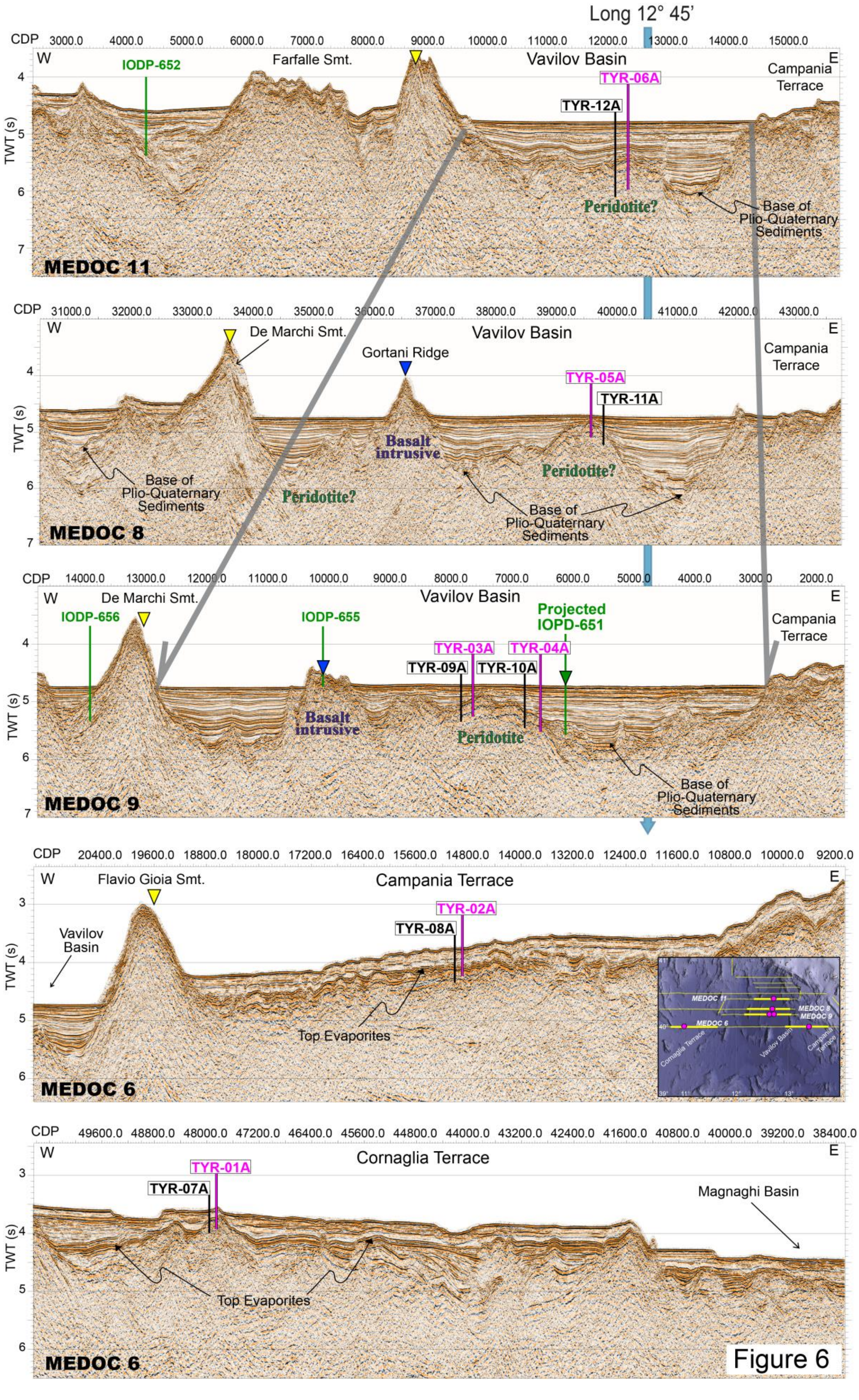
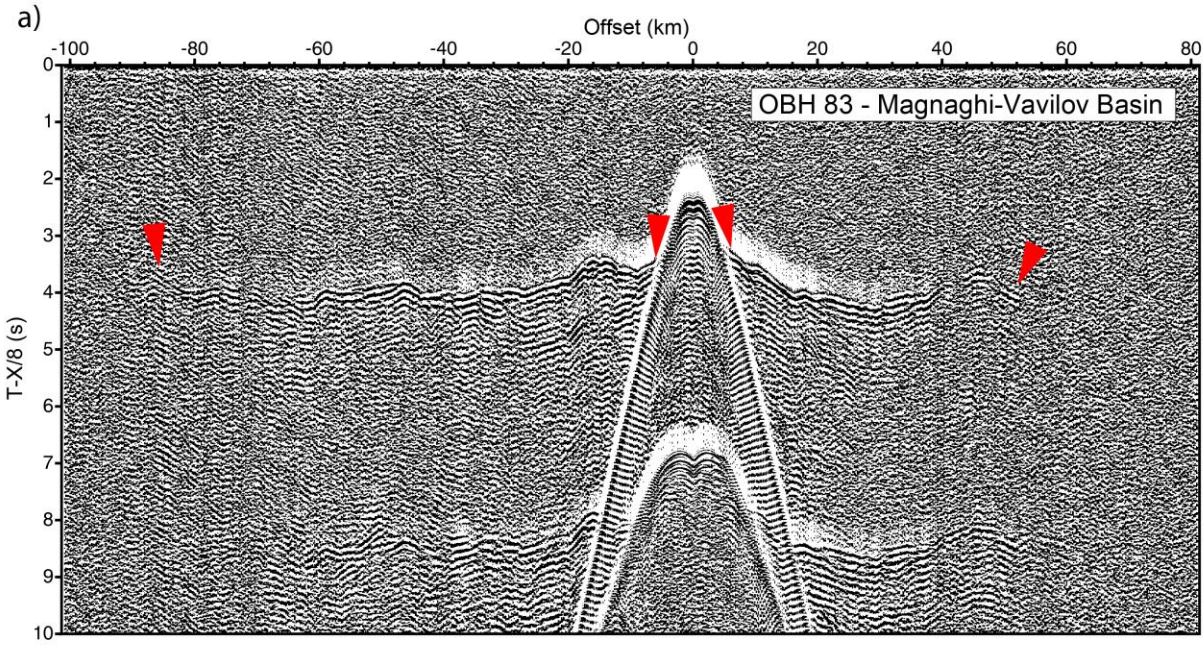

SARDINIA MARGIN
CORNAGLIA TERRACE
Sardinia basin
Baronie Smt.
TYR-1A
TYR-7A
Top Messinian
TOB
WAS-derived Moho
Moho reflections
MEDOC 6
MAGNAGHI-VAVILOV BASIN
Metamorphic continental rocks
Serpentinized peridotites
E-MOR basalts
Intraplate basalts
Magnaghi Smt.
D'Ancona Ridge
Gortani Ridge 655 projected
Vavilov Smt.
651 projected
CAMPANIA TERRACE
CAMPANIA MARGIN
Flavio Gioia Smt.
TYR-2A
TYR-8A
W
E
km
CMP
TWT(s)

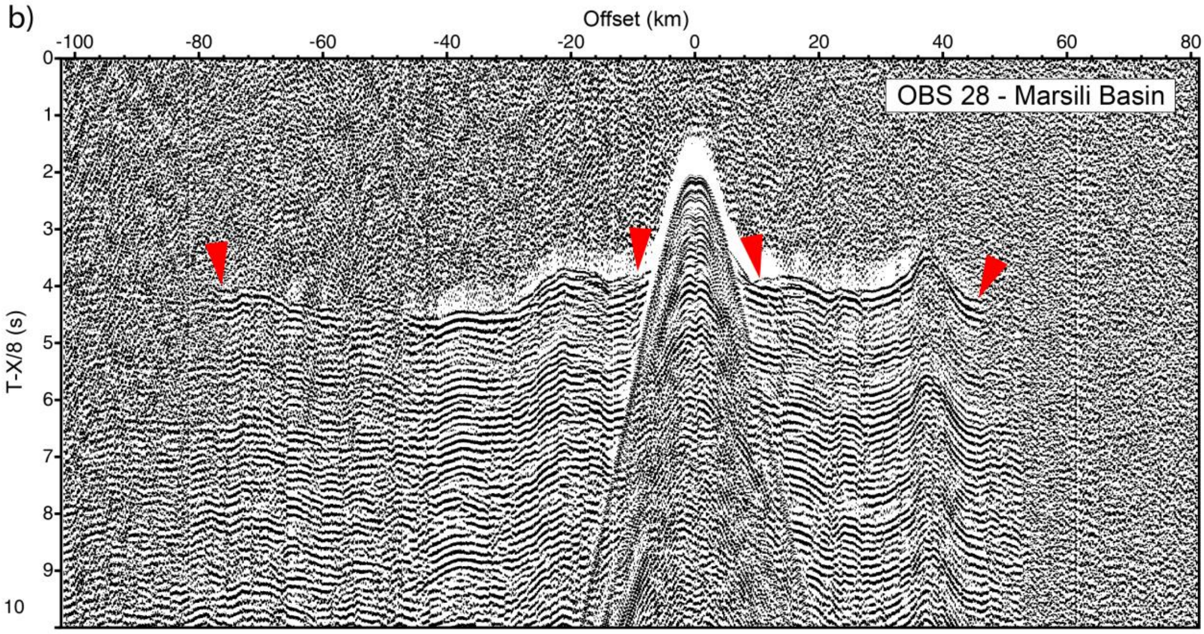
Figure 5


Long 12° 45'
MEDOC 11
W
E
IODP-652
Farfalle Smt.
Vavilov Basin
Campania Terrace
TYR-06A
TYR-12A
Peridotite?
Base of Plio-Quaternary Sediments
MEDOC 8
De Marchi Smt.
Gortani Ridge
TYR-05A
TYR-11A
Basalt intrusive
Peridotite?
MEDOC 9
IODP-656
IODP-655
Projected IOPD-651
TYR-03A
TYR-04A
TYR-09A
TYR-10A
Peridotite
MEDOC 6
Flavio Gioia Smt.
TYR-02A
TYR-08A
Top Evaporites
Cornaglia Terrace
TYR-01A
TYR-07A
Magnaghi Basin
TWT (s)
CDP
Figure 6

a)



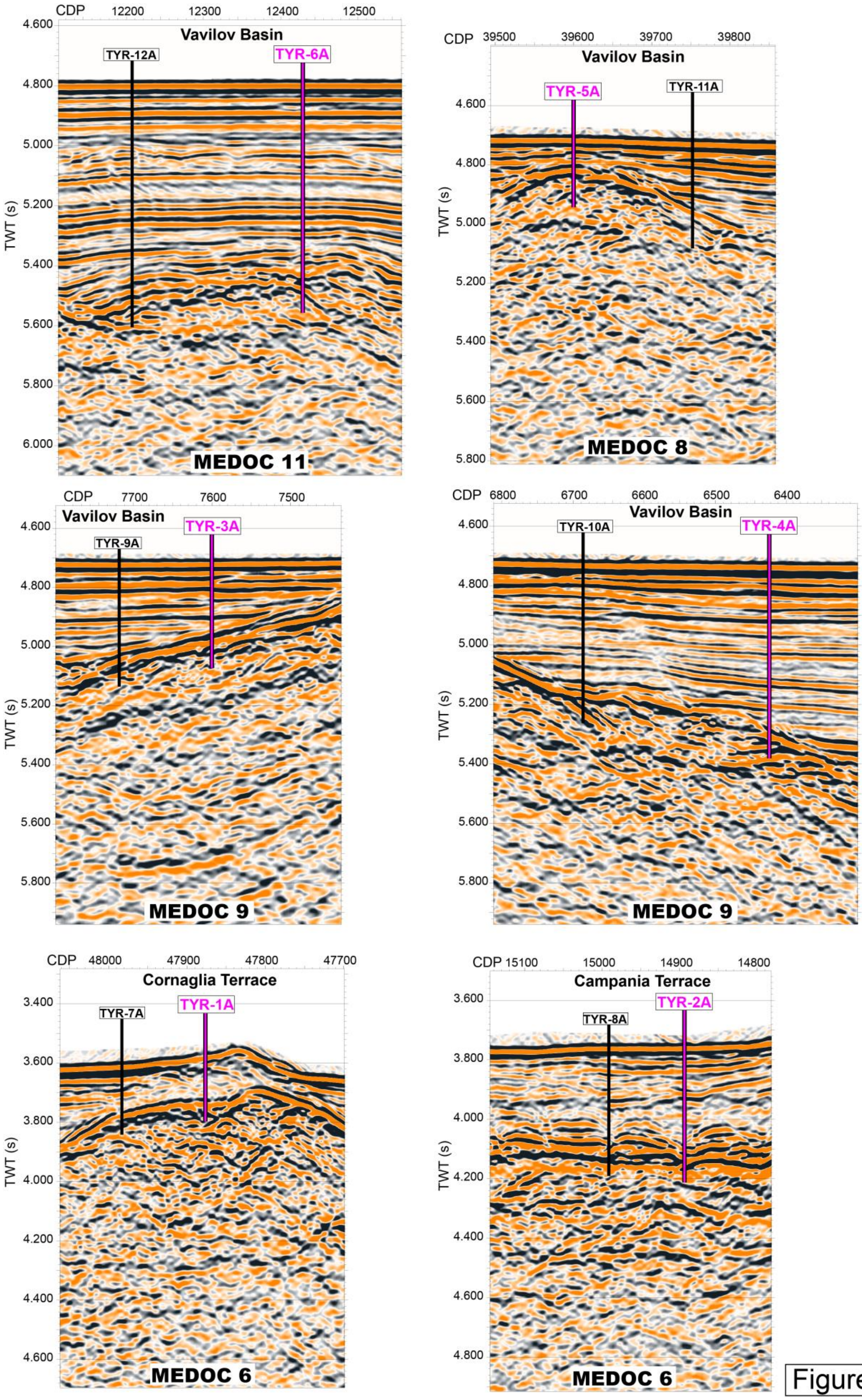
b)



c)

Site name		TYR-1A	TYR-2A	TYR-3A	TYR-4A	TYR-5A	TYR-6A	TYR-7A	TYR-8A	TYR-9A	TYR-10A	TYR-11A	TYR-12A
Latitude		40,0025	40,00036	40,18388	40,18402	40,26609	40,41593	40,00097	40,00036	40,18388	40,18398	40,26614	40,4159
Longitude		10,9984	13,40327	12,6413	12,72801	12,69432	12,72474	10,98619	13,39599	12,63243	12,70826	12,70529	12,7076
Seafloor (m bsl)		2675	2813	3533	3546	3530	3592	2700	2837	3533	3544	3538	3590
Total depth (m bsl)		3031	3535	4029	4389	3812	4564	3056	3455	4123	4205	4005	4717
Drilled unit thickness (m)	Plio-Quat. (2750 m/s)	216	419	356	773	142	902	238	363	450	591	327	1057
	Messinian (4800 m/s)	70	233					48	185				
	Continental basement (5750 m/s)	70	70					70	70				
	Serpentinized mantle rocks (5000 m/s)			140	70	140	70			140	70	140	70
Total Recovery		356	722	496	843	282	972	356	618	590	661	467	1127

Figure 7



CDP 12200 12300 12400 12500
Vavilov Basin
TYR-12A
TYR-6A
TWT (s)
4.600 4.800 5.000 5.200 5.400 5.600 5.800 6.000
MEDOC 11
CDP 39500 39600 39700 39800
Vavilov Basin
TYR-5A
TYR-11A
TWT (s)
4.600 4.800 5.000 5.200 5.400 5.600 5.800
MEDOC 8
CDP 7700 7600 7500
Vavilov Basin
TYR-9A
TYR-3A
TWT (s)
4.600 4.800 5.000 5.200 5.400 5.600 5.800
MEDOC 9
CDP 6800 6700 6600 6500 6400
Vavilov Basin
TYR-10A
TYR-4A
TWT (s)
4.600 4.800 5.000 5.200 5.400 5.600 5.800
MEDOC 9
CDP 48000 47900 47800 47700
Cornaglia Terrace
TYR-7A
TYR-1A
TWT (s)
3.400 3.600 3.800 4.000 4.200 4.400 4.600
MEDOC 6
CDP 15100 15000 14900 14800
Campania Terrace
TYR-8A
TYR-2A
TWT (s)
3.600 3.800 4.000 4.200 4.400 4.600 4.800
MEDOC 6

Figure 8

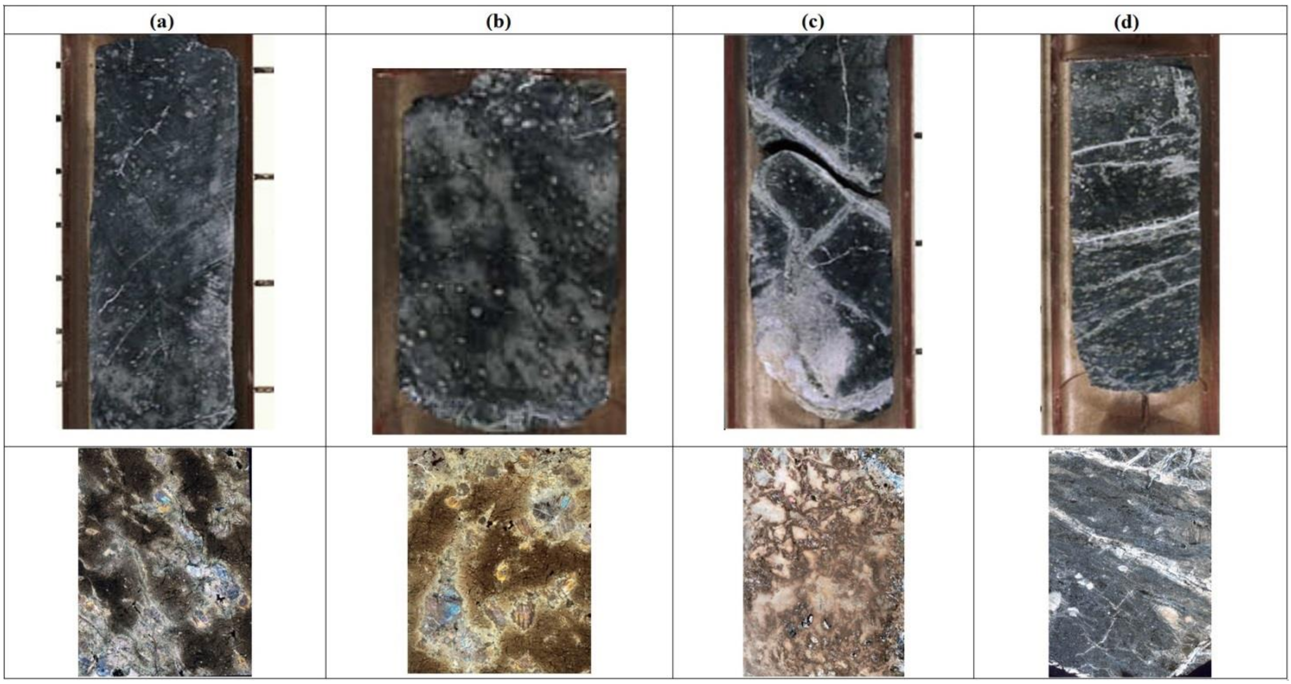
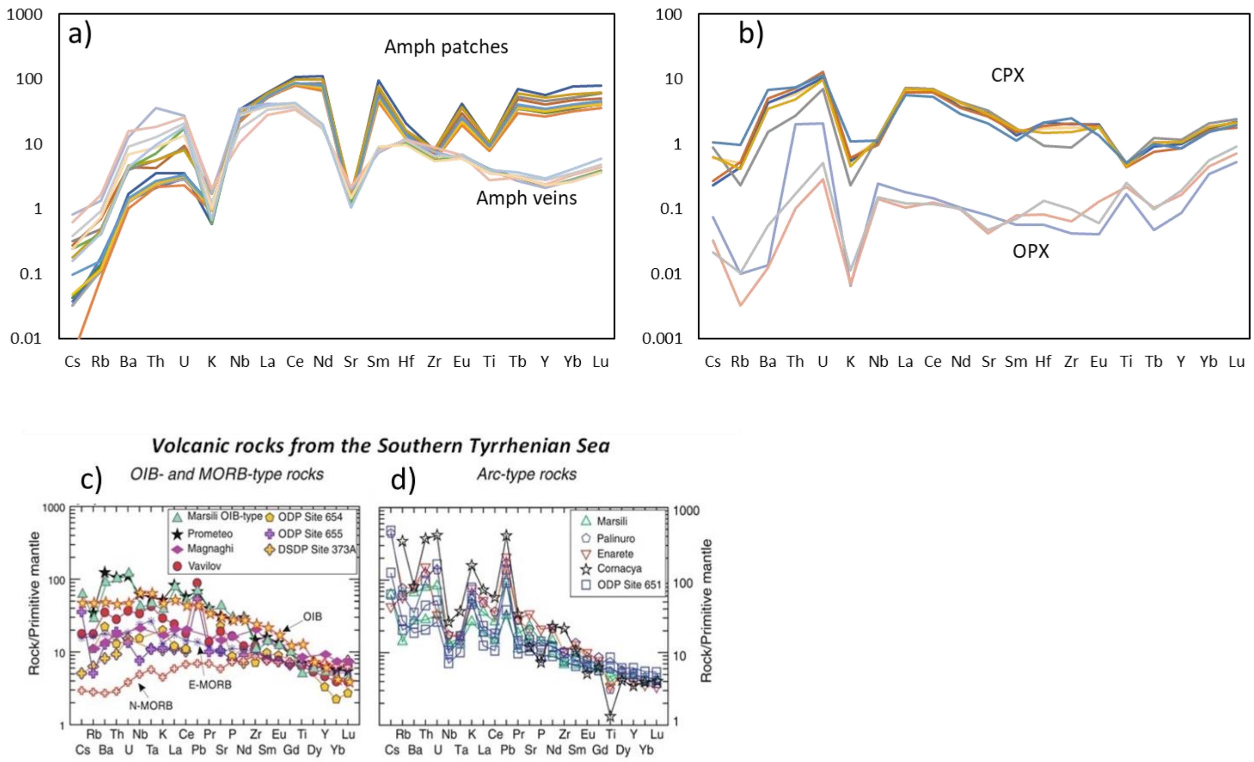


Figure 9



a)
Amph patches
Amph veins
1000
100
10
1
0.1
0.01
Cs Rb Ba Th U K Nb La Ce Nd Sr Sm Hf Zr Eu Ti Tb Y Yb Lu
b)
CPX
OPX
100
10
1
0.1
0.01
0.001
Cs Rb Ba Th U K Nb La Ce Nd Sr Sm Hf Zr Eu Ti Tb Y Yb Lu
Volcanic rocks from the Southern Tyrrhenian Sea
c)
OIB- and MORB-type rocks
Marsili OIB-type
ODP Site 654
Prometeo
ODP Site 655
Magnaghi
DSDP Site 373A
Vavilov
OIB
E-MORB
N-MORB
Rock/Primitive mantle
d)
Arc-type rocks
Marsili
Palinuro
Enarete
Cornacya
ODP Site 651
Rock/Primitive mantle

Figure 10

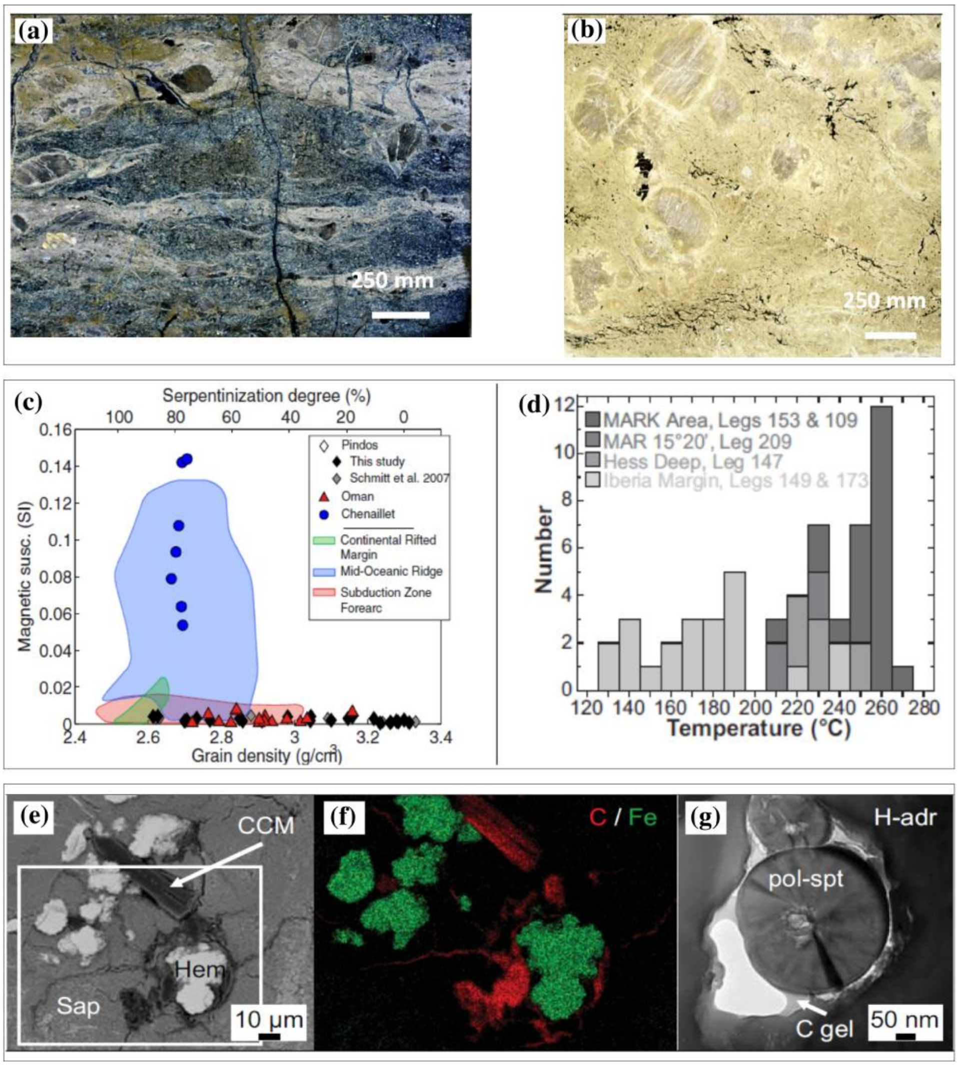

(a)
250 mm
(b)
250 mm
(c)
Serpentinization degree (%)
Magnetic susc. (SI)
Grain density (g/cm3)
Pindos
This study
Schmitt et al. 2007
Oman
Chenaillet
Continental Rifted Margin
Mid-Oceanic Ridge
Subduction Zone Forearc
(d)
MARK Area, Legs 153 & 109
MAR 15°20', Leg 209
Hess Deep, Leg 147
Iberia Margin, Legs 149 & 173
Number
Temperature (°C)
(e)
CCM
Hem
Sap
10 µm
(f)
C / Fe
(g)
H-adr
pol-spt
C gel
50 nm

Figure 11

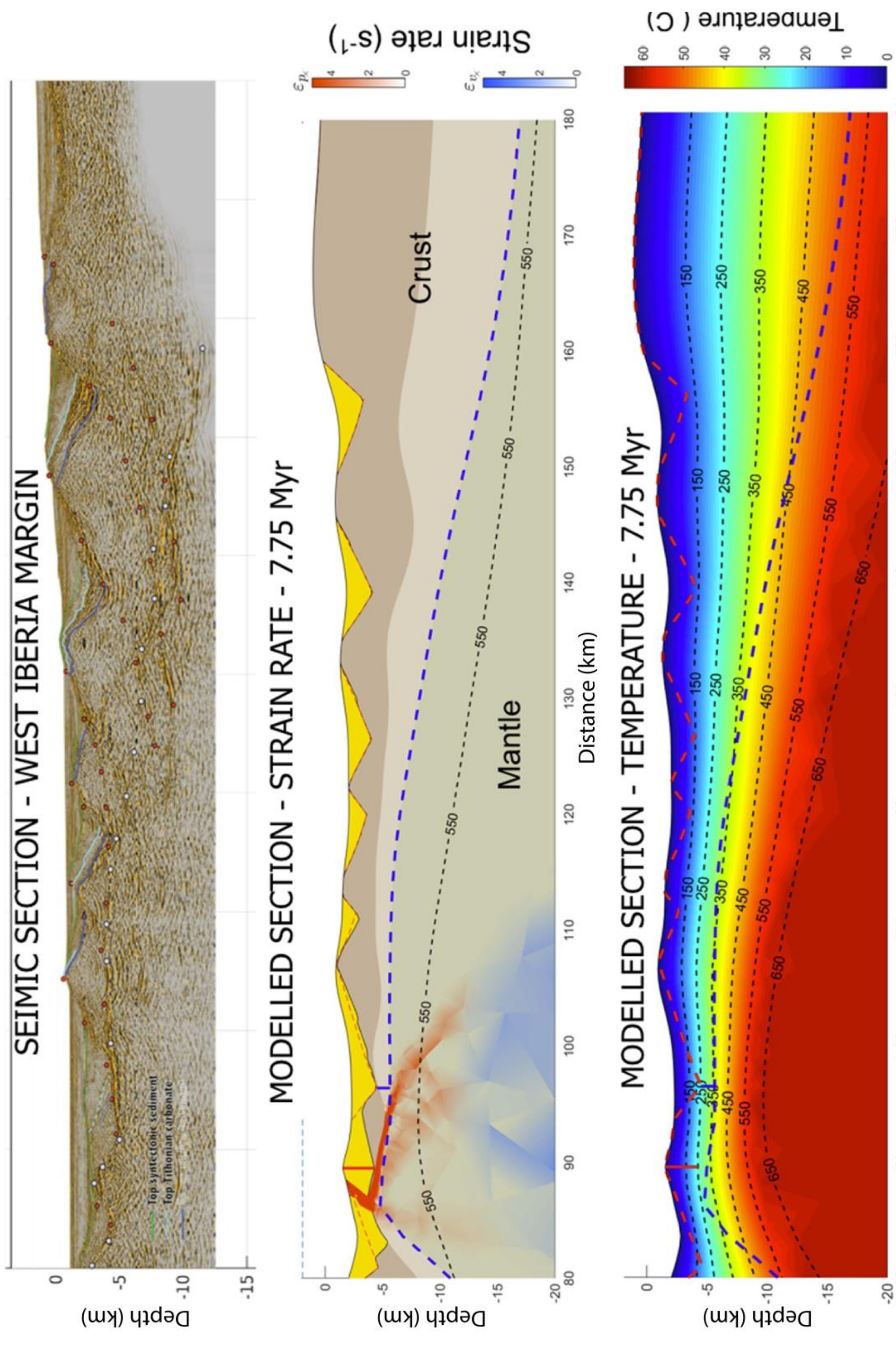

SEIMIC SECTION - WEST IBERIA MARGIN
Top syntectonic sediment
Top Tithonian carbonate
Depth (km)
MODELLED SECTION - STRAIN RATE - 7.75 Myr
Strain rate (s-1)
Crust
Mantle
Distance (km)
Depth (km)
MODELLED SECTION - TEMPERATURE - 7.75 Myr
Temperature (C)
Distance (km)
Depth (km)

Figure 12

IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	The basement of the Cornaglia Terrace
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-01A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.0025	Jurisdiction:	italian
Longitude:	Deg: 10.9984	Distance to Land: (km)	112
Coordinate System:	WGS 84		
Priority of Site:	Primary: ✓ Alternate: ☐	Water Depth (m):	2675

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	286	70
	Total Sediment Thickness (m) 286	
		Total Penetration (m): 356
General Lithologies:	Terrigenous sand/silt/clay over about 70 meters of messinian gypsum	continental basement rocks

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
3.7	1.2	4.9

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					
Sensitive marine habitat (e.g., reefs, vents)						

Other:

Proposal #: 927 - Full 2	Site #: TYR-01A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_6 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocitty
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	yes	P-wave velocity from WAS data
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-01A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-01A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
2670 - 2680	basalts	8	5.750	basalt	oceanic	26	N/A

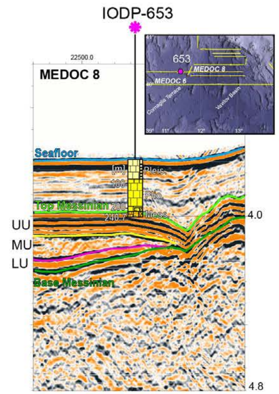
Site Figure IODP proposal P927 Site TYR-01A

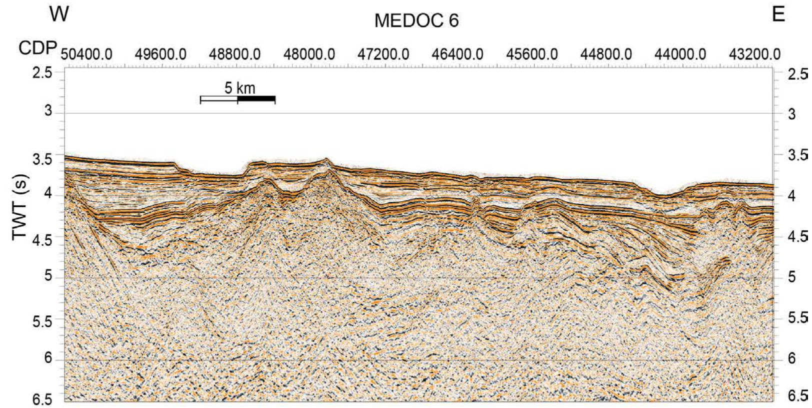
Coordinates: 40.0025 / 10.9984
Water depth: -2675 m
Penetration: 356 m

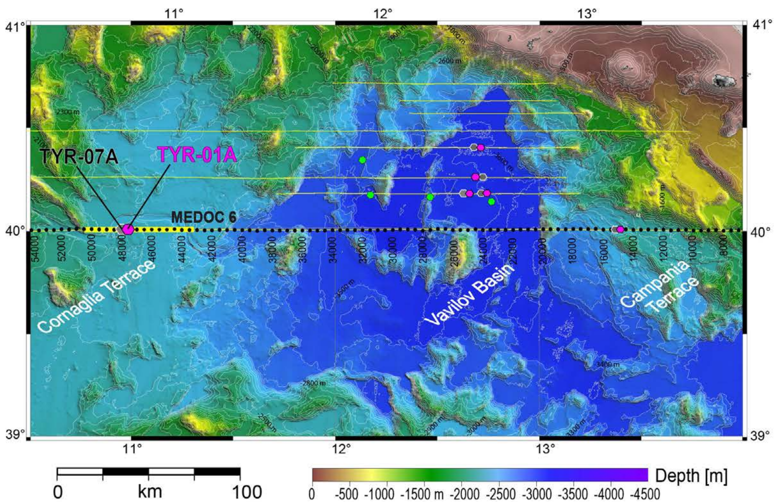
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

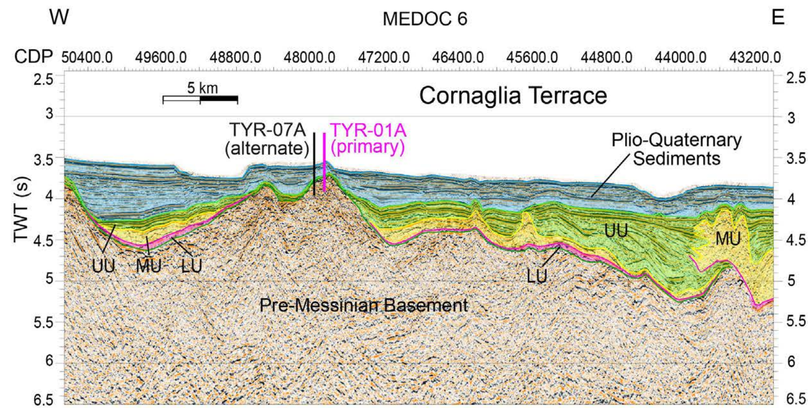
Data files in SSDB:
MEDOC_6.segy

Additional data available:
Multibeam, velocity information









IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	The basement of the Campania Terrace
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-02A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.00036	Jurisdiction:	Italian
Longitude:	Deg: 13.40327	Distance to Land: (km)	113
Coordinate System:	WGS 84		
Priority of Site:	Primary: ✓ Alternate: ☐	Water Depth (m):	2813

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	652	70
	Total Sediment Thickness (m) 652	
		Total Penetration (m): 722
General Lithologies:	Terrigenous sand/silt/clay in the first 419 m. and gypsum for 233 m.	continental basement rocks

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		Other tools:
WL	☑	Magnetic Susceptibility	☐	
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
7.2	1.6	8.8

Observatory Plan:

Longterm Borehole Observation Plan/Re-entry Plan

Potential Hazards/ Weather:

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

Sensitive marine habitat (e.g., reefs, vents)

Preferred weather window

Other:

Proposal #: 927 - Full 2	Site #: TYR-02A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_6 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	yes	P-wave velocity from WAS data
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-02A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-02A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

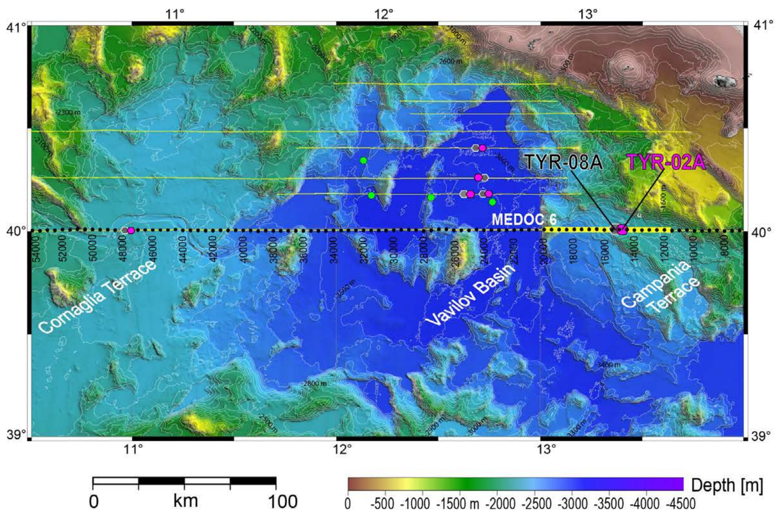
Site Figure IODP proposal P927 Site TYR-02A

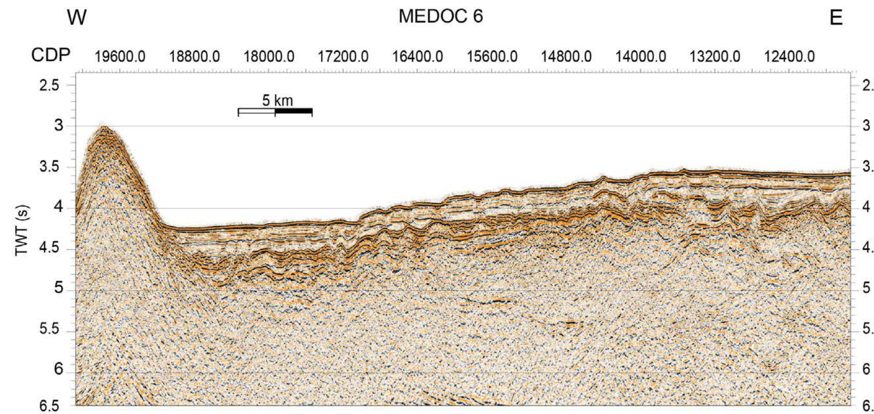
Coordinates: 40.00036 / 13.40327
Water depth: -2813 m
Penetration: 722 m

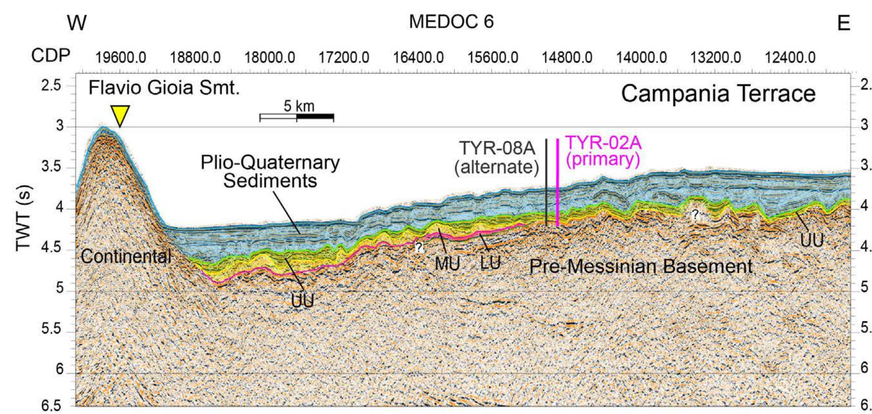
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_6.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	The serpentinized mantle peridotite
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-03A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.18388	Jurisdiction:	Italian
Longitude:	Deg: 12.6413	Distance to Land: (km)	157
Coordinate System:	WGS 84		
Priority of Site:	Primary: ✓ Alternate: ☐	Water Depth (m):	3533

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	356	140
	Total Sediment Thickness (m) 356	
		Total Penetration (m): 496
General Lithologies:	Terrigenous sand/silt/clay	serpentinized peridotite

Coring Plan:
(Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	6.6	Logging:	1.4	Total On-site:	8

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	Preferred weather window
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					
Sensitive marine habitat (e.g., reefs, vents)						

Other:

Generated: 2019-10-01T20:02:48+00:00

Proposal #: 927 - Full 2	Site #: TYR-03A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_9 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity		Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-03A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-03A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

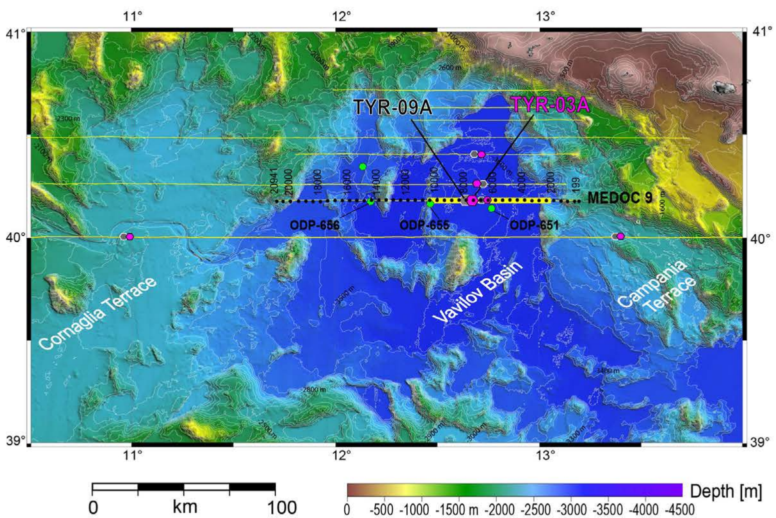
Site Figure IODP proposal P927 Site TYR-03A

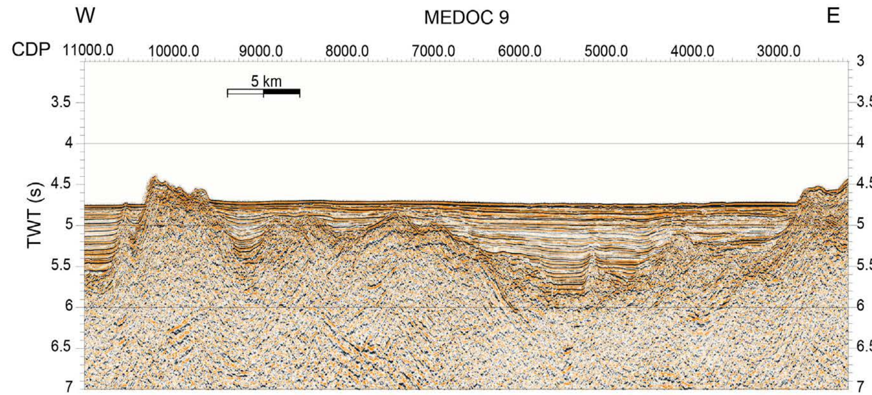
Coordinates: 40.18388 / 12.6413
Water depth: -3533 m
Penetration: 496 m

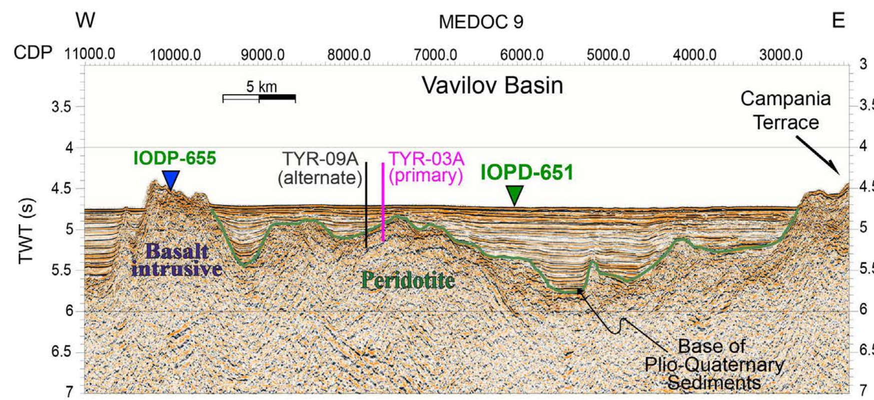
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_9.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	The serpentinized mantle peridotites
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-04A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.18402	Jurisdiction:	Italian
Longitude:	Deg: 12.72801	Distance to Land: (km)	151
Coordinate System:	WGS 84		
Priority of Site:	Primary: ✓ Alternate: ☐	Water Depth (m):	3546

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	773	70
	Total Sediment Thickness (m): 773	
		Total Penetration (m): 843
General Lithologies:	Terrigenous sand/silt/clay	Exumed mantle rocks

Coring Plan: (Specify or check)

APC ☑ XCB ☑ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		Other tools:
WL	☑	Magnetic Susceptibility	☐	
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
10.1	1.8	11.9

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					

Sensitive marine habitat (e.g., reefs, vents)

Other:

Proposal #: 927 - Full 2	Site #: TYR-04A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_9 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-04A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-04A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

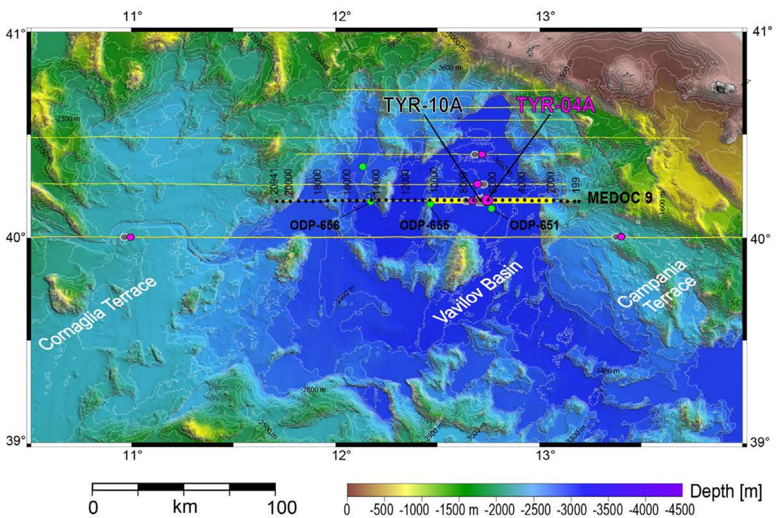
Site Figure IODP proposal P927 Site TYR-4A

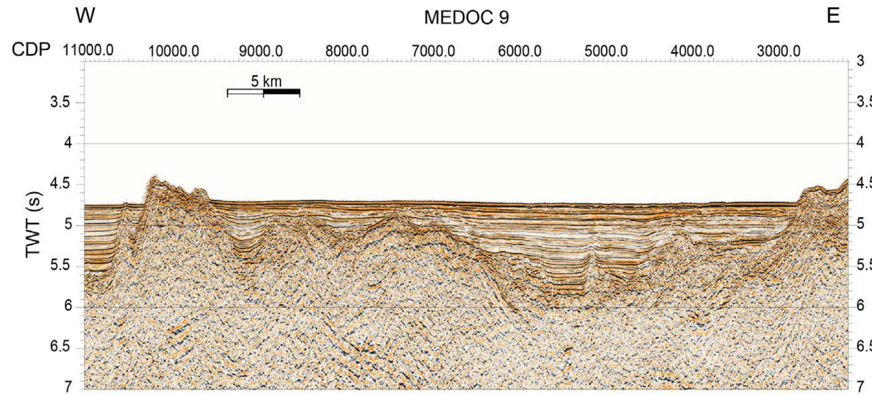
Coordinates: 40.18402 / 12.72801
Water depth: -3546 m
Penetration: 843 m

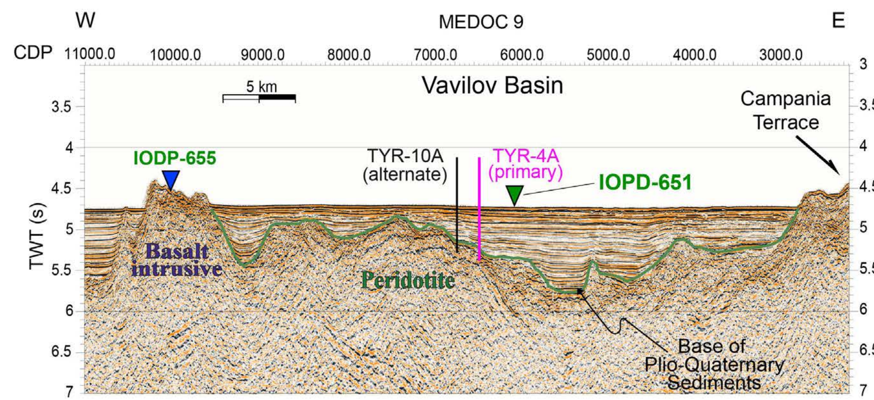
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_9.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	The serpentinized mantle peridotite
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-05A		Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#				
Latitude:	Deg: 40.26609		Jurisdiction:	Italian
Longitude:	Deg: 12.69432		Distance to Land: (km)	148
Coordinate System:	WGS 84			
Priority of Site:	Primary: ✓	Alternate: ☐	Water Depth (m):	3530

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	142	140
	Total Sediment Thickness (m): 142	
		Total Penetration (m): 282
General Lithologies:	Terrigenous sand/silt/clay	Serpentinized mantle rocks

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
5.1	1.2	6.3

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	Preferred weather window
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					
Sensitive marine habitat (e.g., reefs, vents)						

Other:

Generated: 2019-10-01T20:02:48+00:00

Proposal #: 927 - Full 2	Site #: TYR-05A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_8 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-05A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-05A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

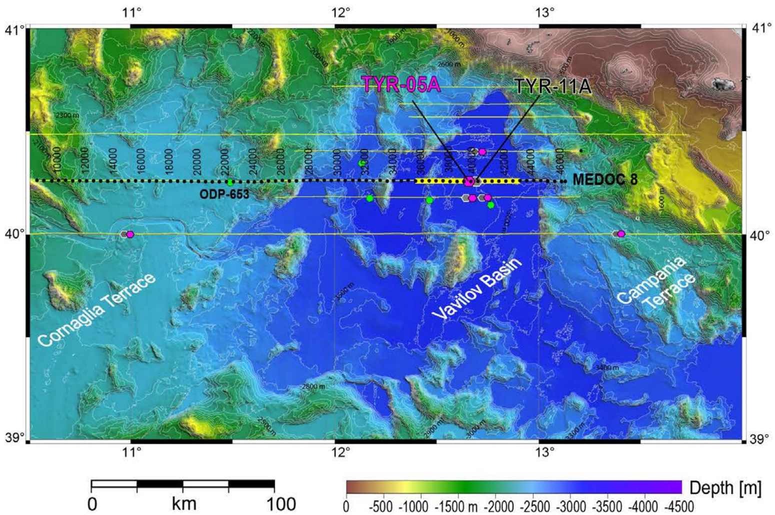
Site Figure **IODP proposal P927** **Site TYR-05A**

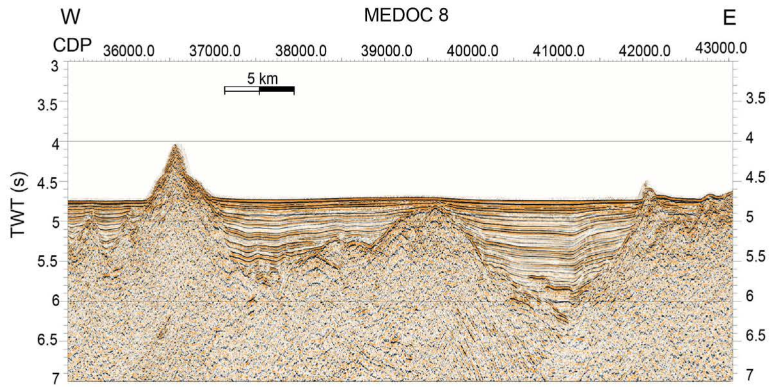
Coordinates: 40.26609 / 12.69432
Water depth: -3530 m
Penetration: 282 m

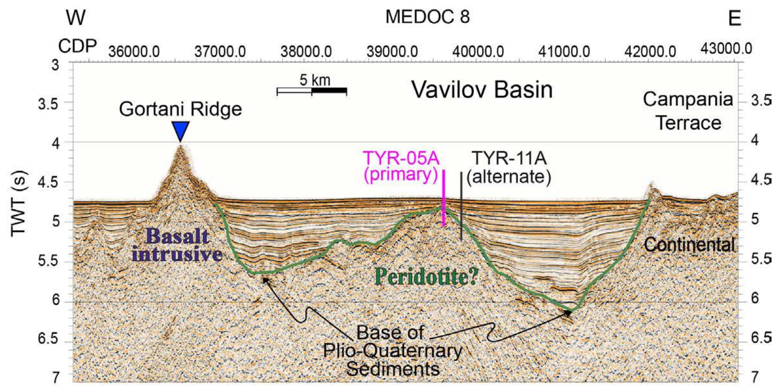
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_8.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	The serpentinized mantle peridotite
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-06A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.41593	Jurisdiction:	Italian
Longitude:	Deg: 12.72474	Distance to Land: (km)	138
Coordinate System:	WGS 84		
Priority of Site:	Primary: ✓ Alternate: ☐	Water Depth (m):	3592

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	902	70
	Total Sediment Thickness (m) 902	
		Total Penetration (m): 972
General Lithologies:	Terrigenous sand/silt/clay	serpentinized peridotite

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days: Drilling/Coring: 9.7 | Logging: 1.9 | Total On-site: 11.6

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					

Sensitive marine habitat (e.g., reefs, vents)

Other:

Proposal #: 927 - Full 2	Site #: TYR-06A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_11 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-06A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-06A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

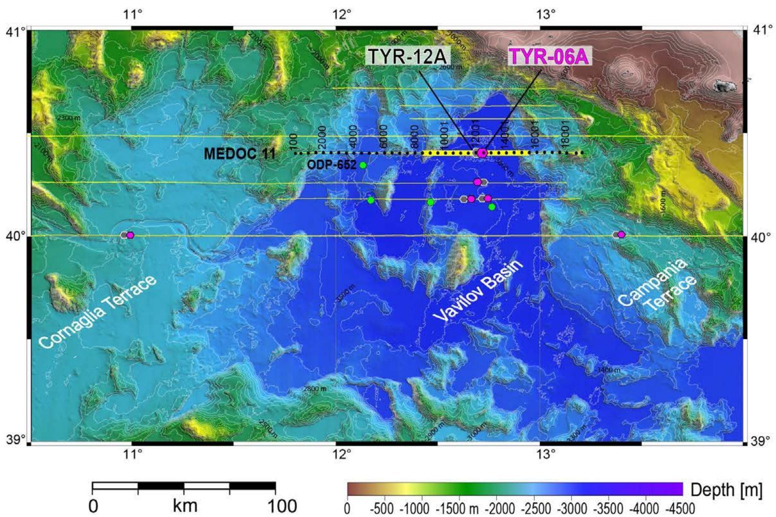
Site Figure IODP proposal P927 Site TYR-06A

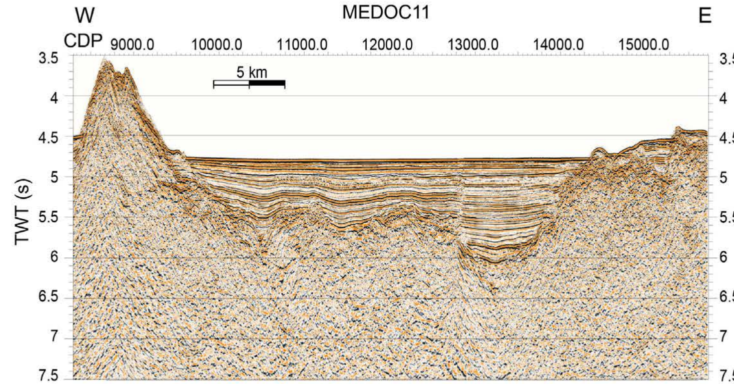
Coordinates: 40.41593 / 12.72474
Water depth: -3592 m
Penetration: 972 m

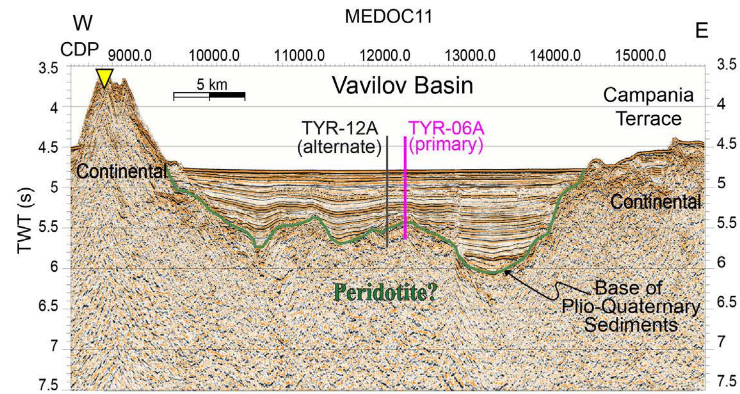
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_11.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	Same target of TYR-01A, the basement of Cornaglia Terrace
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-07A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.00097	Jurisdiction:	Italian
Longitude:	Deg: 10.98619	Distance to Land: (km)	110
Coordinate System:	WGS 84		
Priority of Site:	Primary: ☐ Alternate: ☑	Water Depth (m):	2700

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	286	70
	Total Sediment Thickness (m) 286	
		Total Penetration (m): 356
General Lithologies:	Terrigenous sand/silt/clay over about 48 meters of messinian gypsum	basement rocks

Coring Plan:
(Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
3.7	1.2	4.9

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					

Sensitive marine habitat (e.g., reefs, vents)

Other:

Proposal #: 927 - Full 2	Site #: TYR-07A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_6 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	yes	P-wave velocity from WAS data
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation		
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-07A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-07A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

Site Figure

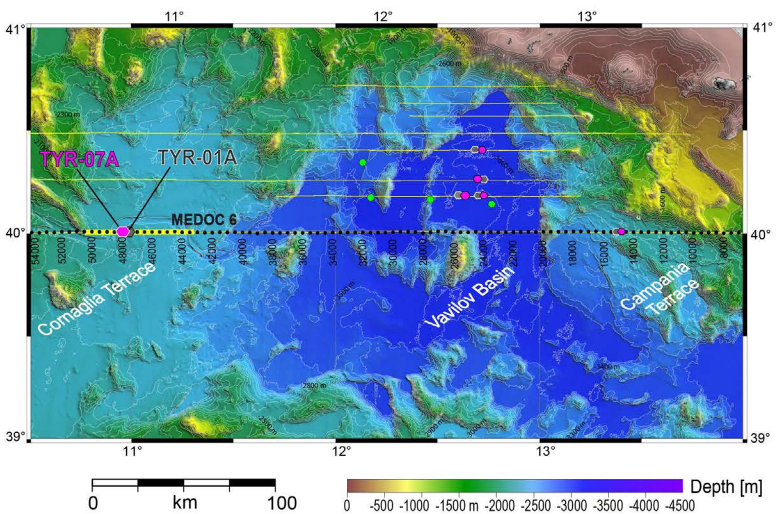
IODP proposal P927 Site TYR-07A

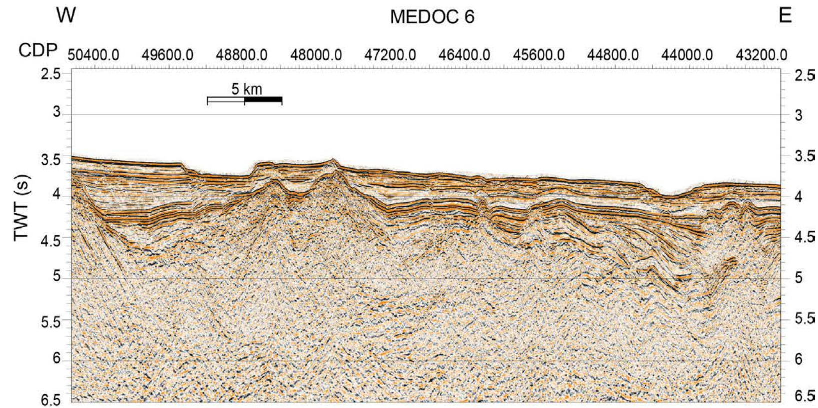
Coordinates: 40.00097 / 10.98619
Water depth: -2700 m
Penetration: 356 m

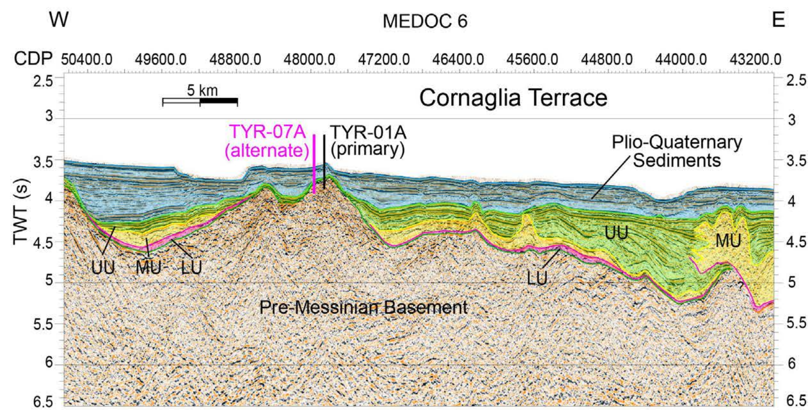
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_6.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

927	- Full	2

Form 1 – General Site Information

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	Same target of TYR-02A, the Campania Terrace basement rocks
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-08A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.00036	Jurisdiction:	Italian
Longitude:	Deg: 13.39599	Distance to Land: (km)	113
Coordinate System:	WGS 84		
Priority of Site:	Primary: ☐ Alternate: ☑	Water Depth (m):	2837

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	548	70
	Total Sediment Thickness (m) 548	
		Total Penetration (m): 618
General Lithologies:	Terrigenous sand/silt/clay over 185 meters of messinian gypsum	Continental basement rocks

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
7.2	1.6	8.8

Observatory Plan:

Longterm Borehole Observation Plan/Re-entry Plan

Potential Hazards/ Weather:

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐
CO_2	☐				

Preferred weather window

Sensitive marine habitat (e.g., reefs, vents)

Other:

Generated: 2019-10-01T20:02:49+00:00

Proposal #: 927 - Full 2	Site #: TYR-08A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_6 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	yes	P-wave velocity from WAS data
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-08A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-08A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

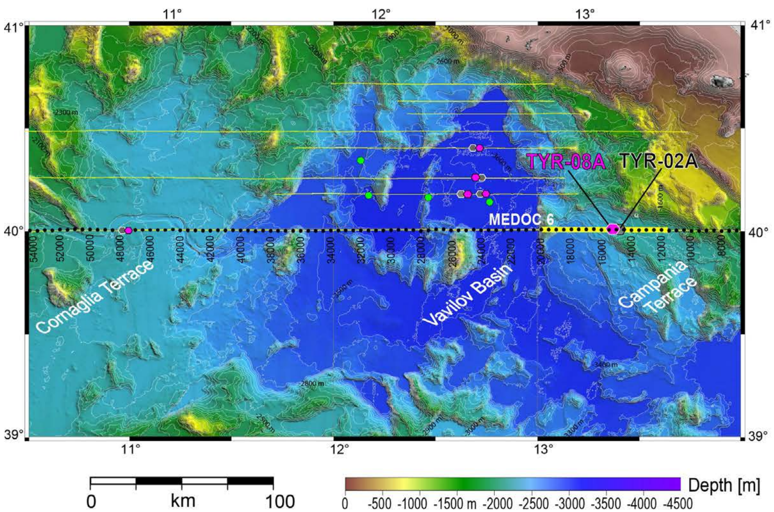
Site Figure **IODP proposal P927** **Site TYR-08A**

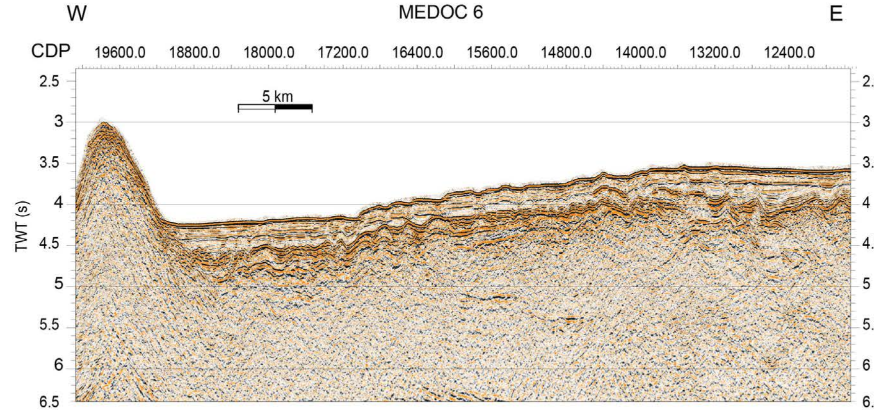
Coordinates: 40.00036 / 13.39599
Water depth: -2837 m
Penetration: 618 m

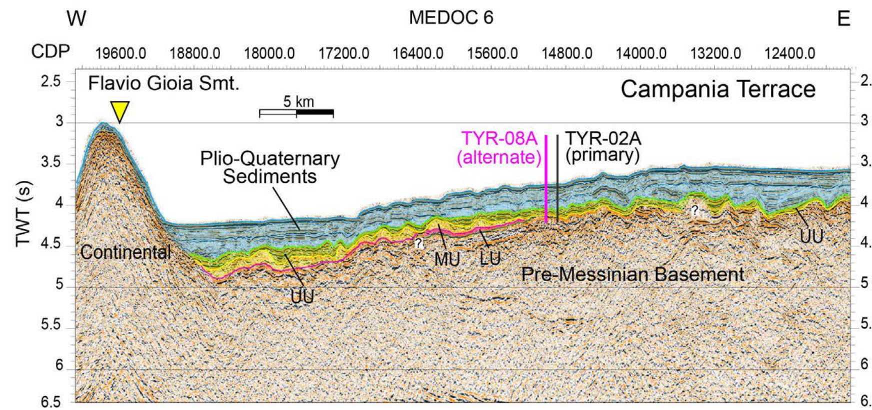
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_6.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	Same target of TYR-03A, the serpentinized mantle peridotite.
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-09A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.18388	Jurisdiction:	Italian
Longitude:	Deg: 12.63243	Distance to Land: (km)	157
Coordinate System:	WGS 84		
Priority of Site:	Primary: ☐ Alternate: ☑	Water Depth (m):	3533

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	450	140
	Total Sediment Thickness (m) 450	
		Total Penetration (m): 590
General Lithologies:	Terrigenous sand/silt/clay	serpentinized mantle peridotite

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		Other tools:
WL	☑	Magnetic Susceptibility	☐	
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☐			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
6.6	1.4	8

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					
Sensitive marine habitat (e.g., reefs, vents)						

Other:

Proposal #: 927 - Full 2	Site #: TYR-09A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_9 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-09A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-09A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

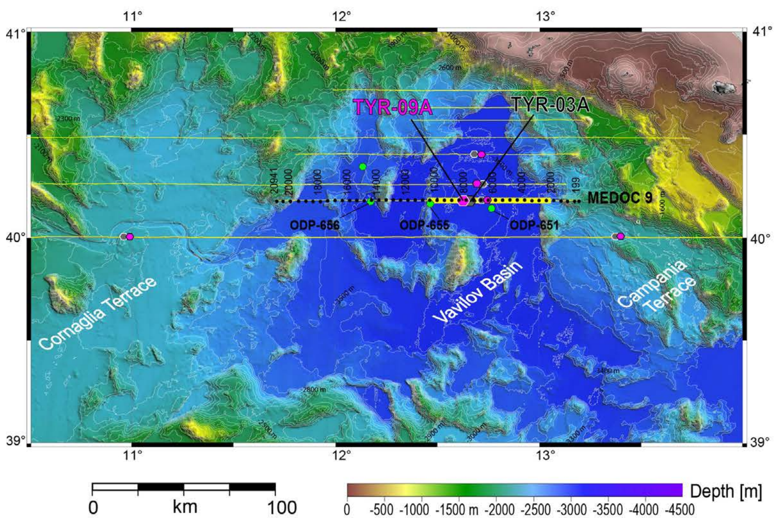
Site Figure IODP proposal P927 Site TYR-09A

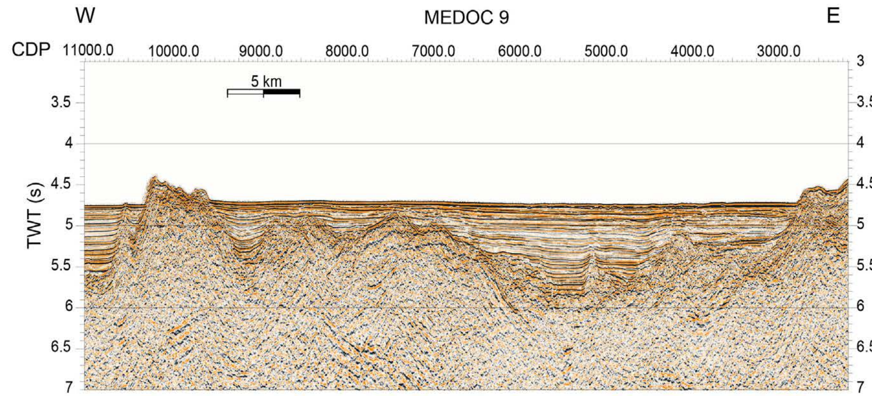
Coordinates: 40.18388 / 12.63243
Water depth: -3533 m
Penetration: 590 m

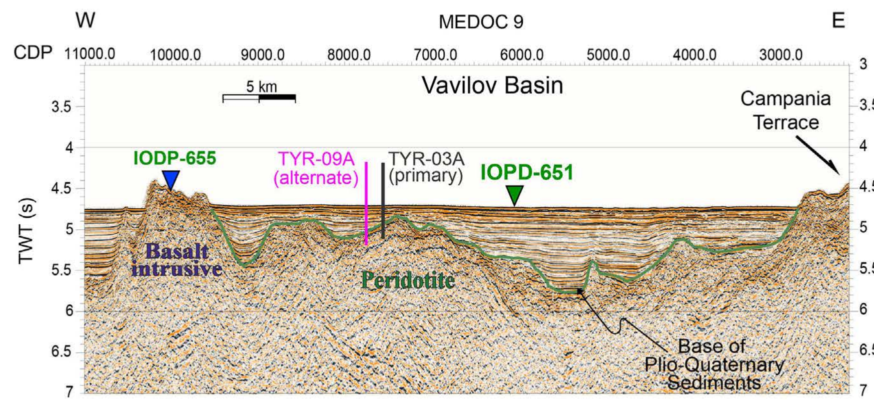
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_9.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	Same target of TYR-04A, serpentinized mantle peridotite.
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-10A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.18398	Jurisdiction:	Italian
Longitude:	Deg: 12.70826	Distance to Land: (km)	151
Coordinate System:	WGS 84		
Priority of Site:	Primary: ☐ Alternate: ☑	Water Depth (m):	3544

Generated: 2019-10-01T20:02:49+00:00

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	591	70
	Total Sediment Thickness (m) 591	
		Total Penetration (m): 661
General Lithologies:	Terrigenous sand/silt/clay	Serpentinized mantle rocks

Coring Plan:
(Specify or check)

APC ☑ XCB ☑ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
10.1	1.8	11.9

Observatory Plan:

Longterm Borehole Observation Plan/Re-entry Plan

Potential Hazards/ Weather:

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	Preferred weather window
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					
Sensitive marine habitat (e.g., reefs, vents)						

Other:

Proposal #: 927 - Full 2	Site #: TYR-10A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_9 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 m grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-10A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-10A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

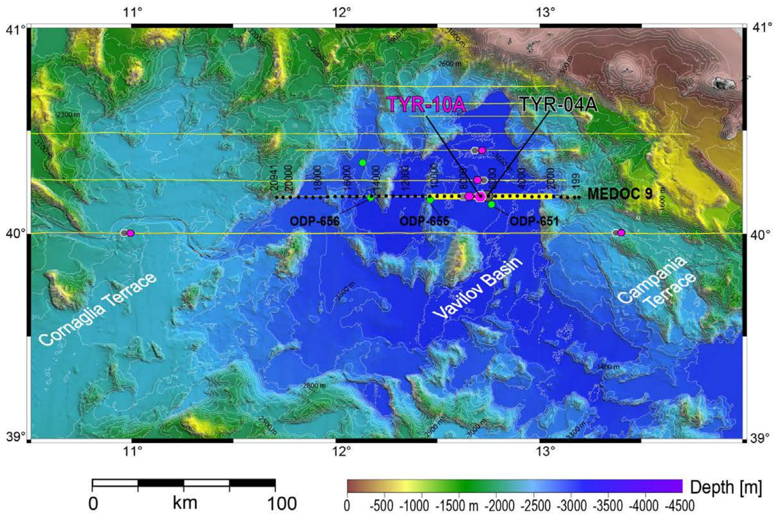
Site Figure IODP proposal P927 Site TYR-10A

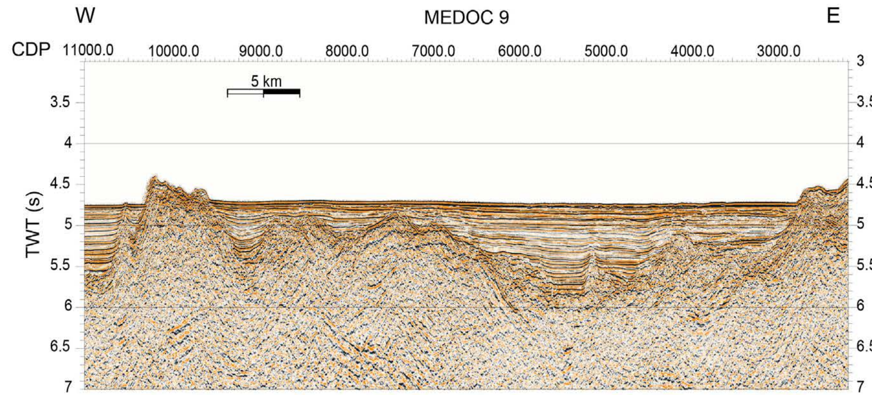
Coordinates: 40.18398 / 12.70826
Water depth: -3544 m
Penetration: 661 m

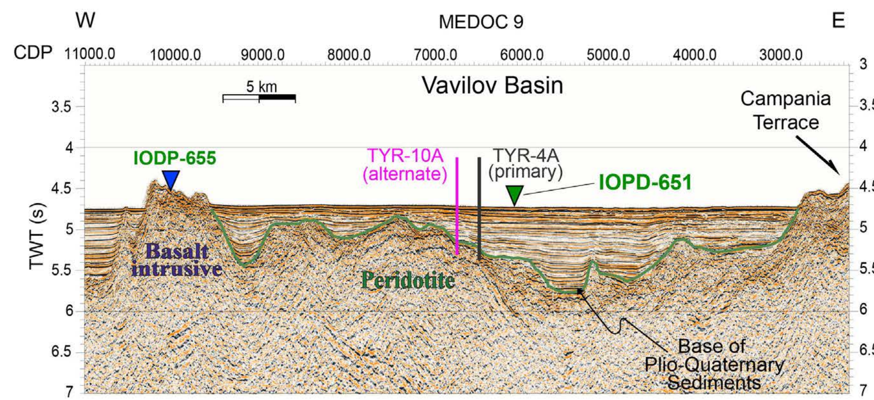
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_9.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	Same target of TYR-05A, serpentinized mantle peridotites
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-11A	Area or Location:	Tyrrhenian Sea
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.26614	Jurisdiction:	Italian
Longitude:	Deg: 12.70529	Distance to Land: (km)	148
Coordinate System:	WGS 84		
Priority of Site:	Primary: ☐ Alternate: ☑	Water Depth (m):	3538

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	327	140
	Total Sediment Thickness (m) 327	
		Total Penetration (m): 467
General Lithologies:	Terrigenous sand/silt/clay	serpentinized mantle peridotite

Coring Plan: (Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		Other tools:
WL	☑	Magnetic Susceptibility	☐	
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☐			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
5.1	1.2	6.3

Observatory Plan:

Longterm Borehole Observation Plan/Re-entry Plan

Potential Hazards/ Weather:

						Preferred weather window
Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					
Sensitive marine habitat (e.g., reefs, vents)						

Other:

Proposal #: 927 - Full 2	Site #: TYR-11A	Date Form Submitted: 2019-10-01 08:55:38

Data Type	In SSDB	Details of available data and data that are still to be collected
1a High resolution seismic reflection (primary)	no	
1b High resolution seismic seismic reflection (crossing)	no	
2a Deep penetration seismic reflection (primary)	yes	Line: MEDOC_8 Position: CDP
2b Deep penetration seismic reflection (crossing)	no	
3 Seismic Velocity	yes	Stack RMS velocity
4 Seismic Grid	no	
5a Refraction (surface)	no	
5b Refraction (bottom)	no	
6 3.5 kHz	no	
7 Swath bathymetry	yes	100 x 100 grid cell size
8a Side looking sonar (surface)	no	
8b Side looking sonar (bottom)	no	
9 Photography or video	no	
10 Heat Flow	yes	
11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-11A	Date Form Submitted: 2019-10-01 08:55:38

Pollution & Safety Hazard	Comment
1. Summary of operations at site	
2. All hydrocarbon occurrences based on previous DSDP/ODP/IODP drilling	
3. All commercial drilling in this area that produced or yielded significant hydrocarbon shows	
4. Indications of gas hydrates at this location	
5. Are there reasons to expect hydrocarbon accumulations at this site?	
6. What "special" precautions will be taken during drilling?	
7. What abandonment procedures need to be followed?	
8. Natural or manmade hazards which may affect ship's operations	
9. Summary: What do you consider the major risks in drilling at this site?	

Proposal #: 927 - Full 2	Site #: TYR-11A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

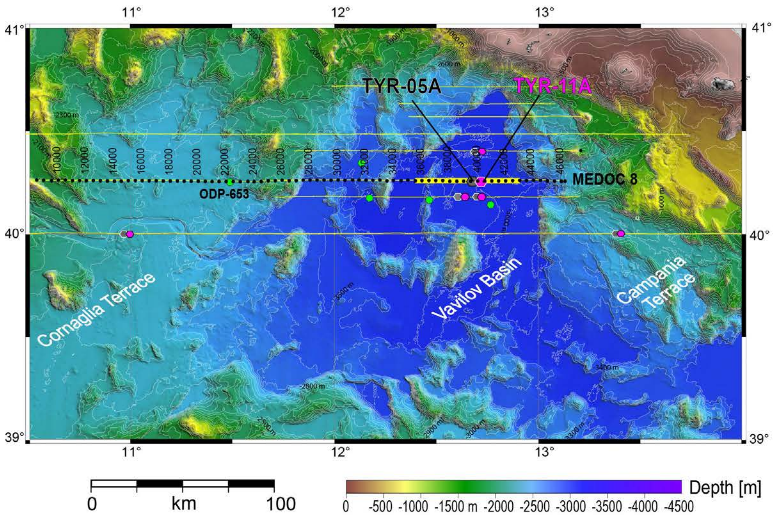
Site Figure **IODP proposal P927** **Site TYR-11A**

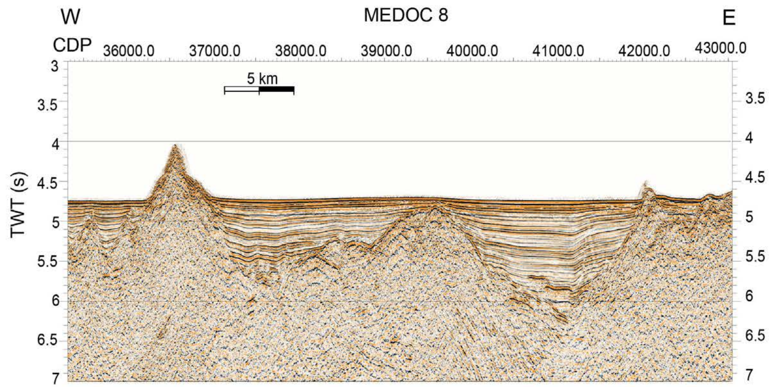
Coordinates: 40.26614 / 12.70529
Water depth: -3538 m
Penetration: 467 m

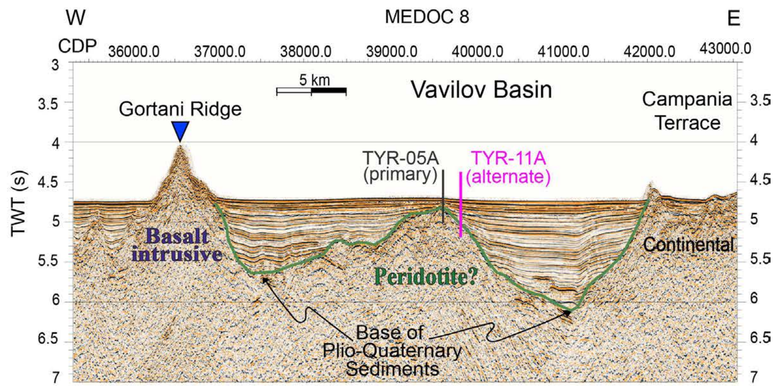
Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_8.segy

Additional data available:
Multibeam, velocity information







IODP Site Forms

Form 1 – General Site Information

927 - Full 2

Section A: Proposal Information

Proposal Title	Tyrrhenian Magmatism & Mantle Exhumation
Date Form Submitted	2019-10-01 08:55:38
Site-Specific Objectives with Priority (Must include general objectives in proposal)	Same target of TYR-06A, serpentinized mantle peridotites
List Previous Drilling in Area	DSDP 132, DSDP 373, ODP 650-656

Section B: General Site Information

Site Name:	TYR-12A	Area or Location:	Tyrrhenian
If site is a reoccupation of an old DSDP/ODP Site, Please include former Site#			
Latitude:	Deg: 40.4159	Jurisdiction:	Italian
Longitude:	Deg: 12.7076	Distance to Land: (km)	138
Coordinate System:	WGS 84		
Priority of Site:	Primary: ☐ Alternate: ☑	Water Depth (m):	3590

Section C: Operational Information

	Sediments	Basement
Proposed Penetration (m):	1057	70
	Total Sediment Thickness (m) 1057	
		Total Penetration (m): 1127
General Lithologies:	Terrigenous sand/silt/clay	serpentinized mantle rocks

Coring Plan:
(Specify or check)

APC ☐ XCB ☐ RCB ☑ Re-entry ☐ PCS ☐

Wireline Logging Plan:

Standard Measurements		Special Tools		
WL	☑	Magnetic Susceptibility	☐	Other tools:
Porosity	☑	Borehole Temperature	☐	
Density	☑	Formation Image (Acoustic)	☐	
Gamma Ray	☑	VSP (walkaway)	☐	
Resistivity	☑	LWD	☐	
Sonic (Δt)	☑			
Formation Image (Res)	☑			
VSP (zero offset)	☑			
Formation Temperature & Pressure	☑			

Other Measurements:

Estimated Days:

Drilling/Coring:	Logging:	Total On-site:
9.7	1.9	11.6

Observatory Plan: *Longterm Borehole Observation Plan/Re-entry Plan*

Potential Hazards/ Weather:

Shallow Gas	☐	Complicated Seabed Condition	☐	Hydrothermal Activity	☐	Preferred weather window
Hydrocarbon	☐	Soft Seabed	☐	Landslide and Turbidity Current	☐	
Shallow Water Flow	☐	Currents	☐	Gas Hydrate	☐	
Abnormal Pressure	☐	Fracture Zone	☐	Diapir and Mud Volcano	☐	
Man-made Objects (e.g., sea-floor cables, dump sites)	☐	Fault	☐	High Temperature	☐	
H_2S	☐	High Dip Angle	☐	Ice Conditions	☐	
CO_2	☐					

Sensitive marine habitat (e.g., reefs, vents)

Other:

Proposal #: 927 - Full 2	Site #: TYR-12A	Date Form Submitted: 2019-10-01 08:55:38

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5b Refraction (bottom)	no	
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11a Magnetics	yes	
11b Gravity	yes	
12 Sediment cores	no	
13 Rock sampling	no	
14a Water current data	no	
14b Ice Conditions	no	
15 OBS microseismicity	no	
16 Navigation	no	
17 Other	no	

Proposal #: 927 - Full 2	Site #: TYR-12A	Date Form Submitted: 2019-10-01 08:55:38

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Proposal #: 927 - Full 2	Site #: TYR-12A	Date Form Submitted: 2019-10-01 08:55:38

Subbottom depth (m)	Key reflectors, unconformities, faults, etc	Age (My)	Assumed velocity (km/s)	Lithology	Paleo-environment	Avg. accum. rate (m/My)	Comments
N/A							

Site Figure   IODP proposal P927   Site TYR-12A

Coordinates: 40.4159 / 12.7076
Water depth: -3590 m
Penetration: 1127 m

Remarks:
- Seismic images are time migrated stacks.
- Seismic data in CDP order.

Data files in SSDB:
MEDOC_11.segy

Additional data available:
Multibeam, velocity information