



SIRENE

Serpentine/mud diapIRs along Extensional faults in the Ionian sea

Technical Report

(August 26 – September 05, 2024)

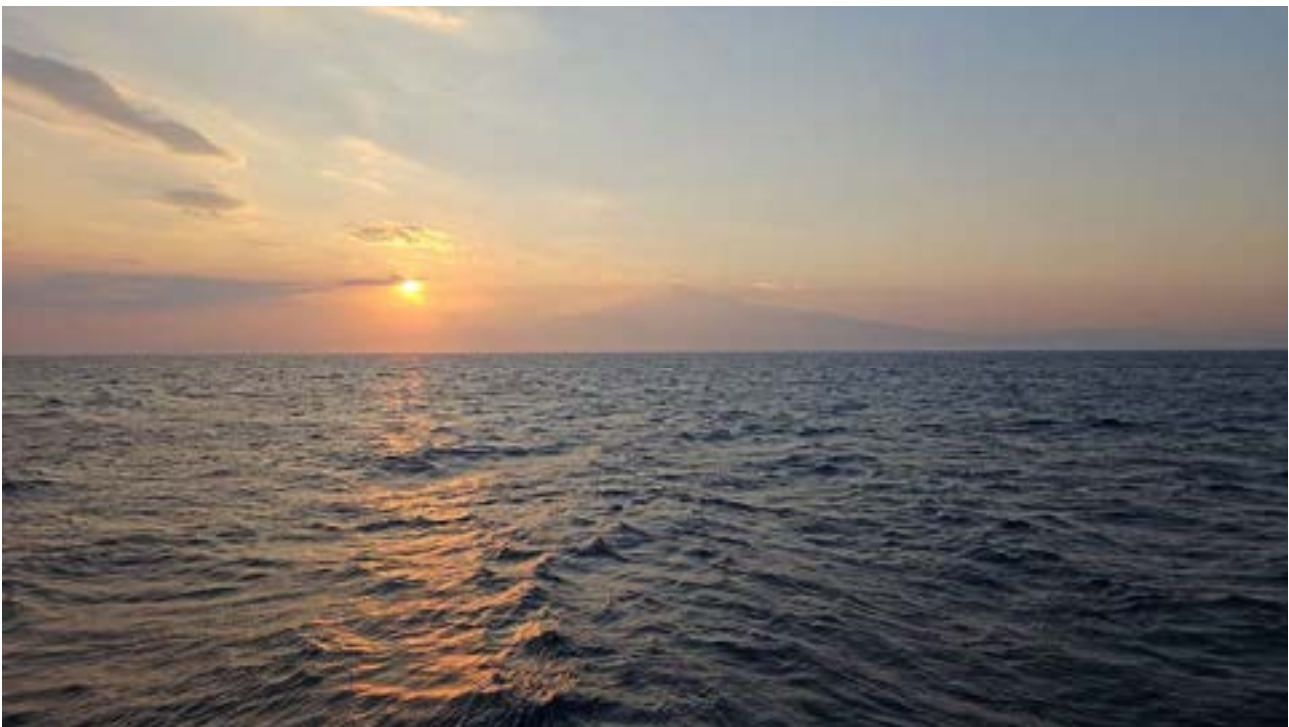
N/O GAIA BLU



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Alessio Nogarotto, Alessandro Santilano

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ACRONYMS OF ORGANIZATIONS, MANUFACTURERS AND PRODUCTS

- SIRENE – Serpentine mud diapirs along extensional faults in the Ionian Sea
- CNR - Consiglio Nazionale Delle Ricerche www.cnr.it
- ISMAR CNR - Istituto di Scienze Marine www.bo.ismar.cnr.it
- IGG CNR – Istituto di Geoscienze e Georisorse <https://www.igg.cnr.it/>
- ISP CNR – Istituto di Scienze Polari <https://www.isp.cnr.it/index.php/it/>
- CTD – Conductivity, Temperature, Depth
- SEG Soc. of Exploration Geophysicists www.seg.org
- XTF Extended Triton Format www.tritonelics.com
- GPS-DGPS Global Positioning System, Differential Global Positioning System
- DTM - Digital Terrain Model en.wikipedia.org
- MBES - MULTIBEAM ECHOSOUNDER SYSTEM
- SBP - Sub Bottom Profiling
- PSU Practical Salinity Scale ioc.unesco.org
- UTC Universal Time Coordinated
- WGS84 World Geodetic System 1984
- ARGO – Ship Management and Services Company Srl
- SBE Sea Bird Electronics www.seabird.com
- SIS Sea Floor Inf. System www.kongsberg.com
- GMT Generic Mapping Tool gmt.soest.hawaii.edu/gmt

HOW TO READ THIS REPORT

Section 1 gives the introductory and background information, including some technological and scientific issues of the organization and execution of tasks, whereas **Section 2** provides the technical aspects that were involved in the data acquisition and processing. **Section 3** summarizes the cruise operations. **Section 4** discusses the initial results, the on-going data processing and usage, and gives concluding remarks. The cruise logbook is presented in the **Appendix**.

ACKNOWLEDGEMENTS

We would like to thank Commander Andrea Scotto Di Perta, the officers, the onboard technicians Giovanni De Vita and Vito Romano, and the crew of the R/V Gaia Blu for their professionalism, collaborative spirit, and commitment demonstrated during the cruise. Their support and cooperation were invaluable throughout the SIRENE campaign. We also wish to thank the Hydrographic Institute of the Italian Navy, the Italian Navy (MARISTAT, MARINASUD Taranto, and MARISICILIA), the relevant Coast Guard Port Authorities, the Ministry of Economic Development and SPARKLE for their assistance and availability during the preparation and management of the at-sea activities.

RIASSUNTO

Questa relazione contiene il resoconto tecnico della campagna di Geologia Marina denominata "SIRENE-2024", effettuata tra il 26 agosto e il 5 settembre 2024 nel Mar Ionio meridionale. Durante la spedizione SIRENE-2024 sono stati acquisiti dati di morfo-batimetria, magnetometria, sismica a riflessione Chirp, campioni di sedimento con carotiere a gravità e CTD. Lo scopo del progetto era acquisire informazioni geologiche e geofisiche utili a caratterizzare i processi di risalita di materiale profondo in prossimità di strutture litosferiche che segmentano il margine continentale della Sicilia orientale. Tramite l'utilizzo della strumentazione a bordo della N/O Gaia Blu sono stati acquisiti profili sismici a riflessione, carte morfo-batimetriche, e profili magnetometrici attraverso i supposti diapiri di fango/serpentino. Sono state inoltre prelevate 13 carote di sedimento per un totale di 37 m di campioni che permetteranno di ricostruire litologia ed età del materiale che viene rimobilizzato all'interno delle strutture intrusive.

SUMMARY

This report contains the technical account of the Marine Geology campaign named "SIRENE-2024," conducted between August 26 and September 5, 2024, in the southern Ionian Sea. During the SIRENE-2024 expedition, data on morpho-bathymetry, magnetometry, Chirp reflection seismic, sediment samples using a gravity corer, and CTD were collected. The aim of the project was to acquire geological and geophysical information useful for characterizing the processes of deep material ascent near lithospheric structures that segment the continental margin of eastern Sicily. Using the equipment onboard the N/O Gaia Blu, it was possible to obtain seismic profiles, morpho-bathymetric maps, and magnetometric profiles through the suspected mud/serpentine diapirs. Additionally, a total of 13 sediment cores were collected, amounting to 37 meters of samples that will allow for the reconstruction of the lithology and age of the material being remobilized within the intrusive structures.

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THE SIRENE PROJECT

ABSTRACT

The Ionian Sea is a unique region in the world where material typically found at a depth of 20 km rises near the seabed along lithospheric faults that have generated the most destructive historical earthquakes and tsunamis in Italy and Europe. This material likely originates from the Tethys mantle, the oldest known ocean on Earth, which cannot be sampled in any other region because it is covered by kilometres of sediments. The SIRENE project proposes to collect sediment cores from key sites on diapiric structures to retrace the processes that lead to the emergence of deep fluids and materials, and to analyse their potential control over earthquake generation. We propose to investigate the diapir field of the Calabrian Arc subduction system in order to acquire fundamental elements for a drilling proposal under the IODP project to sample the material intruding the Calabrian subduction system.

1.1. INTRODUCTION AND AIM OF THE WORK

Geological processes in subduction zones influence geological cycles, seismicity, the evolution of the crust and mantle, as well as microbiological activity enhanced by geochemical flows. Fluids and materials derived from the subducting plate can rise towards the seafloor, leading to the formation of volcanoes and/or mud and serpentinite diapirs. The only example in the world where serpentinite diapirs have been observed intruding into the subduction system directly from the mantle of the lower plate is the Calabrian Arc (Polonia et al., 2017). Here, deep diapirism is linked to lithospheric faults produced by the segmentation of the continental margin (Polonia et al., 2011; 2016; Gutscher et al., 2016; 2017; Figure 1). The presence of serpentinite in these diapirs has been inferred using indirect methods, such as seismic reflection imaging, quantitative modelling of potential field data, and the observation of high V_p/V_s values in these regions. Samples from two diapirs provide indirect geochemical evidence of fluid flow from a deep source. The main scientific motivation of the SIRENE project is to acquire sediment cores to define the composition of the diapirs. This activity is associated to the international SCYLLA project, a proposal for ocean drilling under the IODP (International Ocean Drilling Project). The preliminary IODP proposal P968 (Polonia et al., 2019) was deemed valid by the IODP Science Evaluation Panel (SEP: “potentially exciting topic and worth further investigation, which could include drilling”) but suggested the need to acquire additional elements to support the scientific idea before submitting the full proposal. SIRENE aims to acquire

geophysical data and sediment samples to better define the nature and composition of the diapirs in the Ionian Sea.

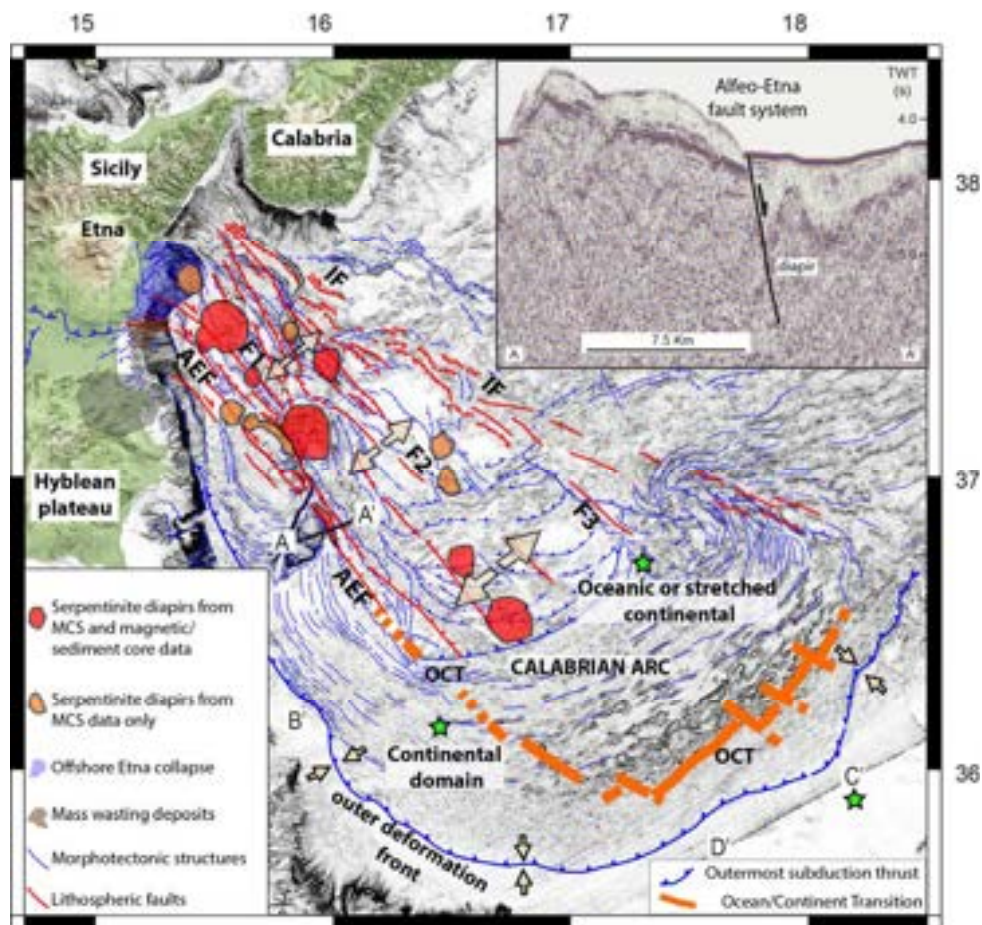


Figure 1 - Structural map of the Western Calabrian Arc subduction complex with distribution of tectonically controlled serpentinite diapirs. Faulting associated with arc-perpendicular extensional tectonics in the accretionary wedge (modified from Polonia et al., 2016) provides an opportunity for fluids to be introduced deep into the underplating plate. A-A': MCS line CALA-02 across a diapir in the sedimentary basin formed along the Alfeo-Etna fault. Green stars: OBS/H stations used for P- and S-wave velocity model for the Ionian lithosphere (D'Alessandro et al., 2016). AEF: Alfeo-Etna fault; IF: Ionian fault; OCT: Oceanic-Continent transition. F1, F2, F3: transtensional faults belonging to the AEF-IF deformation zone. Modified from Polonia et al., 2017.

The proposed coring and subsequent drilling have the ultimate goal of reconstructing the entire life cycle of subcontinental peridotites: from continental margins, to subduction zones, to the formation of mountain ranges, including seismogenic processes in an area where destructive historical earthquakes have caused hundreds of thousands of casualties in recent centuries. The environments where the rocks we wish to sample form are characterized by the circulation of methane and hydrogen under conditions similar to those which are thought to be present during the emergence of life. The microbiological analysis of sediment samples will seek to identify the

connections between the geosphere and biosphere in extreme environments (Giovannelli et al., 2022).

1.2. SCIENTIFIC OBJECTIVES

SIRENE aims to sample several diapirs at very promising sites selected through the analysis of existing data. The system of lithospheric faults that segments the continental margin produces the remobilization of material from very deep sources that could involve the mantle of the Tethys. From the analysis of the proposed sediment samples, we expect to acquire useful elements to reconstruct the composition of the diapirs and the nature of the oceanic crust of the Tethys, as well as to define the mechanisms of ascent of the diapiric material. The activities during the geological-geophysical campaign will provide the necessary information to complete the submission of a proposal for IODP ocean drilling, and to advance our understanding of the seismic processes in the Calabrian Arc, which is one of the most hazardous seismic environments in the world. The correlation between the data acquired at sea, those on land, and the seismic data (in collaboration with INGV, IGG, IGAG, and the University of Bari) will allow us to define the main seismogenic structures, their geometry, and the age of the main tectonic events, as well as possible relationships with the volcanic processes of Mount Etna (Tringali et al., 2023).

1.3. CRUISE TEAM

Tables 1 reports the name, role and affiliation of the cruise team (Figure 2).

Table 1 – Cruise team

1	Alina Polonia	Project coordinator (SIRENE PI) (observer)	CNR ISMAR
2	Luca Gasperini	Chief of expedition	CNR ISMAR
3	Andrea Gallerani	Technician (sediment sampling)	CNR ISMAR
4	Giulia Giorgetti	PhD student (sediment sampling, surveyor)	CNR ISMAR – University of Florence
5	Giuseppe Lo Mauro	PhD student (geophysical data, surveyor)	CNR ISMAR – University of Bari
6	Alessio Nogarotto	Technician (sediment sampling, surveyor)	CNR ISP
7	Alessandro Santilano	Researcher (observer)	CNR IGG



Figure 2 - Cruise team group photo.

1.4. R/V GAIA BLU

- ✓ Year of construction: 1981; Modernisation: 2009-2012;
- ✓ Conventional rejuvenation of 23 years recognized by RINA
- ✓ Classification: DNV-GL
- ✓ Length, overall: 82.9 m Beam, overall: 13 m
- ✓ Gross tonnage: 2,024 t;
- ✓ Net tonnage: 608 t
- ✓ Maximum speed: 17 kn
- ✓ Endurance: 36 days
- ✓ Crew: 23 Researchers
- ✓ Laboratories: wet (32 m²), dry/offices (26 m²), control room (28 m²)
- ✓ Support vessel: Palfinger (7 m)
- ✓ Dynamic positioning system: EMRI Joystick/DP system



Figure 3 - The research vessel Gaia Blu.

Hull mounted instruments for acoustic surveys (Figure 4)

- ✓ Shallow water multi-beam echo sounder - Kongsberg EM 2040
- ✓ Intermediate water multi-beam echo sounder - Kongsberg EM 712 0.5×1
- ✓ Deep water multi-beam echo sounder - Kongsberg EM 304 1×1 degree
- ✓ Seapath 380
- ✓ Fishery research system - Simrad EK60, 18/38/70/120/200/710 kHz
- ✓ Simrad SH90 high-definition omnidirectional fishery sonar, 114 kHz
- ✓ Acoustic Doppler Current Profiler -Teledyne Ocean Surveyor, 45 kHz
- ✓ Acoustic Doppler Current Profiler -Teledyne Workhorse Mariner, 300 kHz

Deck facilities and other instrumentation

- ✓ CTD IBERCISA ocean winch equipped with a Launch and Recovery system (LARS)
- ✓ Multipurpose IBERCISA winch
- ✓ A-frame (~ 9000 kg), 2 J-frame (~ 9000 kg and ~ 3200 kg) and 2 HIAB cranes (1310-5200 kg)

- ✓ Piston coring system (650-1850 kg modular head) with modular rotating cradle swing from 5 to 25 m
- ✓ Ecosearch Automatic Weather Station
- ✓ HiPAP 352P & cNODE MiniS for ROV positioning
- ✓ C-band Maritime VSAT Antenna System (v240 C model)
- ✓ Starlink Flat High-Performance Kit (Maritime/Energy)

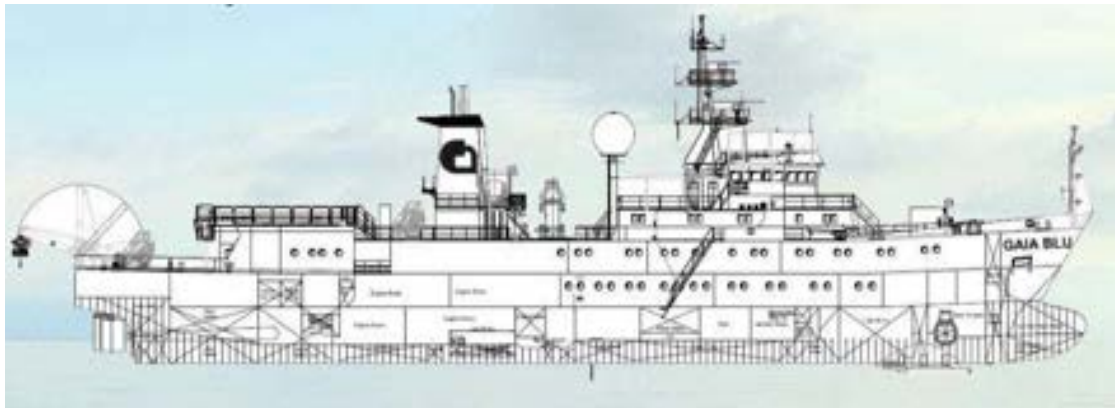


Figure 4 - Schematic side view of the research vessel Gaia Blu highlighting the vessel layout and onboard research facilities.

1.5. FIELD ACTIVITIES

The cruise lasted 11 days (August 26-September 05 2024), including MOB/DEMOB, transit time to reach the target areas and the time for swapping both the scientific crew and onboard scientific instruments.

The operational plan of the SIRENE cruise included the following scientific activities:

1. Geophysical survey of the study area (white polygon in Figure 5). New geophysical data will be acquired using:

- Multibeam bathymetric high-resolution bathymetric data will be generated using the Kongsberg EM712 and 304 multibeam echo-sounders installed on the vessel. We plan to cover part of the area between the Malta escarpment and the deep abyssal plain (Figure 5). Multibeam echo-sounder data will be daily corrected using values obtained by Valeport - MIDAS SVP;

- Chirp (Knudsen 3260 sonar profiler);
- Magnetometer SeaSpy (Marine Magnetics) equipped with 300 meters of electromechanical cable.

2. Seafloor samples using box corer if SBP highlight the presence of lithologies not suitable for the gravity corer;

3. Seafloor samples using gravity core (maximum length of 10 m). The sampling areas are shown in Figure 5;

4. CTD-Rosette casts: the CTD-Rosette system will be deployed to collect key environmental parameters (temperature, salinity, oxygen) and seawater samples at the bottom, in the middle of the water column and near the surface for multibeam calibration.

1.6. WORKING AREA AND ORIGINAL PLAN

The original cruise plan foresees the acquisition of reflection seismic and magnetometry data to complement existing datasets, multibeam data acquisition, and collection of sediment samples using gravity and piston cores in proximity to active tectonic structures and diapirs.

The reflection seismic profiles represent the baseline for identifying the most representative sampling sites to study the relationship between tectonics and sedimentation. Analysis of the collected sediment cores will allow a detailed investigation of deposits and sedimentary structures directly associated with the movement of active faults along the rupture plane, as well as remobilized sediments in correspondence with diapiric structures.

The acquisition of morpho-bathymetric and Chirp data is planned during nighttime hours, while sediment samples will be collected during daytime operations.

Reflection seismic data will be acquired along lines oriented orthogonally to the main tectonic structures and across the diapiric structures within the working area (Figure 5).

The sampling sites were selected through the analysis of existing geophysical data and are located in correspondence with diapiric structures, where the Quaternary sediment cover is minimal.

A total of 10 ship days are requested to acquire approximately 15 gravity and piston cores, selected from 40 sampling sites, for which permits have been obtained in advance from the competent authorities.

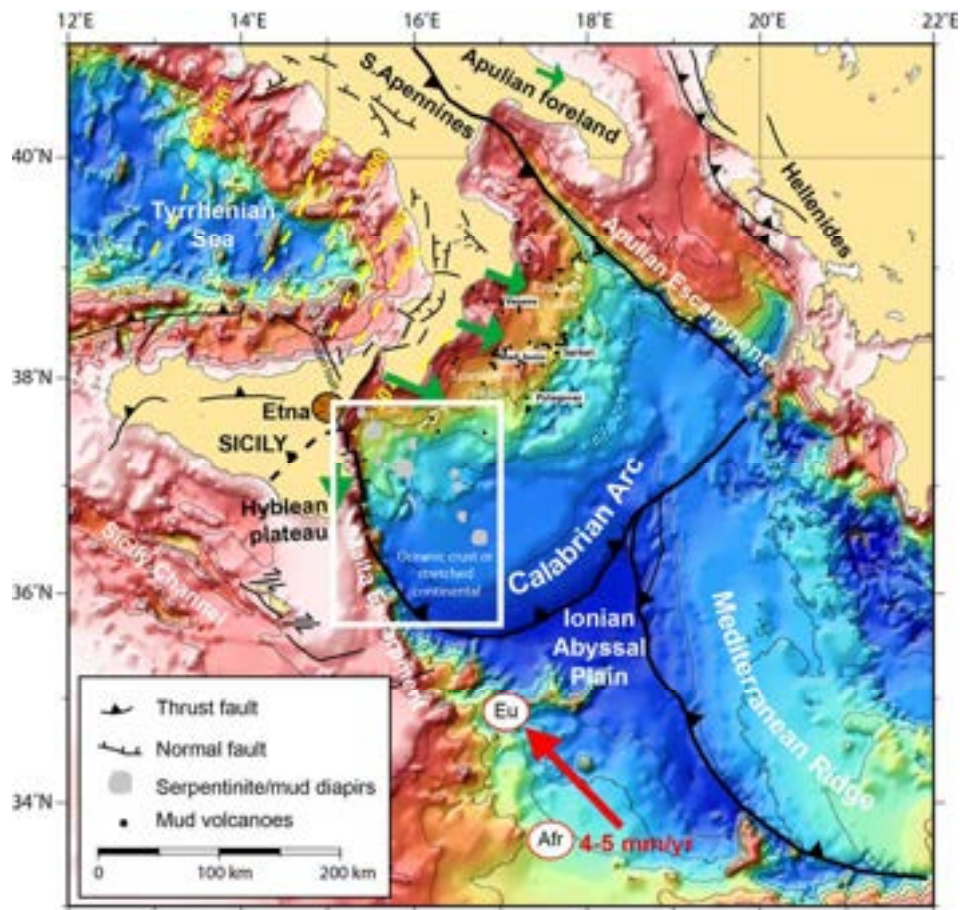


Figure 5 - Working area of the SIRENE cruise with proposed mud/serpentinite diapirs (grey patches) displayed on the schematic geodynamic map of the Ionian Sea (Polonia et al., 2011).

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2. The SIRENE cruise – methodologies and tools

2.1. SCIENCE CONTROL ROOM

The Science Control room allows to display, monitor and operate all the navigation system and control the hull-mounted geophysical equipment (multibeam and CHIRP systems). The Science Control Room also hosts the remote control for CDT/Rosette and sediment sampling winches and, therefore, it is the neuralgic centre of the vessel (Figure 6).



Figure 6 - Above: Screen of the science control room showing real-time data. Below: Part of the cruise team monitoring data acquisition from the science control room.

2.2. GEOPHYSICAL DATA ACQUISITION

Geophysical surveys consisted in multibeam bathymetry and backscatter data acquisition using the deep water (> 1500 m) EM304 systems hull-mounted on the vessel. High-resolution seismic reflection data of the sub-bottom were acquired using the hull-mounted 3.5-12 kHz 3260 Knudsen CHIRP echosounder.

2.2.1 Positioning, Heading and Attitude

The Seapath 380 system provides continuous information of Global Satellite Positioning by 2 GNSS antenna and attitude information by 1 Motion Reference Unit MRU5. Heading information is computed from the 2 antennae position. The accuracy of positioning is achieved by differential satellite positioning DGNSS subscription (Fugro Marinestar GNSS G4, survey average accuracy 0.12 m). The Seapath 380 system is used for ship positioning, supplied by a Fugro HP differential Global Positioning System (DGPS), accurate up to 0.2 m. The Kongsberg motion sensor MRU 5 and a Dual Antenna GPS integrated in the Seapath will correct pitch, roll, heave and yaw movements (reaching 0.02° roll and pitch accuracy, and 0.075° heading accuracy).

2.2.2 Vessel draft

The vessel draft is derived using stability calculations provided by Intershalt Maritime System Stability Software -SEACOS MACS3, belonging to the bridge management system. The center of gravity of the boat (CoG) is calculated as of September 19, 2023, based on load distribution and navigation settings (longitudinal center of gravity, LcG 36.12; vertical center of gravity VcG 5.45).

2.2.3 Multibeam data (MBES)

The R/V Gaia Blu hosts three different multibeam echosounder systems: the Kongsberg EM2040-04 MKII 0.4°x0.7° suited for water depths < 250 m, Kongsberg EM712 1°x0.5° for water depth between 200 and 1200 m and Kongsberg EM304 MKII 1°x1° for water depth between 1000 and 5000 m. The MBESs are hull mounted on the R/V Gaia Blu's gondola with a T-configuration of linear transducer arrays. The Seapath 380 system was used for ship positioning, supplied by a Fugro HP differential Global Positioning System (DGPS), with Marinestar GNSS signal accuracy better than 5 cm. The Kongsberg motion sensor MRU (Motion Reference Unit) 5 and a Dual Antenna GPS integrated in the Seapath, were used to correct for the pitch, roll, heave and yaw movements (reaching 0.02° roll and pitch accuracy, and 0.075° heading accuracy). A Valeport mini SVS sensor is attached close to the transducers to continuously measure the sound velocity for the beamforming. The multibeam

coverage is about four times the water depth and a 20% overlap between lines is normally achieved. Data are logged, displayed and checked in real-time by the Kongsberg data acquisition and control software SIS (Seafloor Information System) 5 (Figure 7).

Multibeam data (MBES) during SIRENE cruise were collected using Kongsberg EM712 in water depths up to over 3000 m.

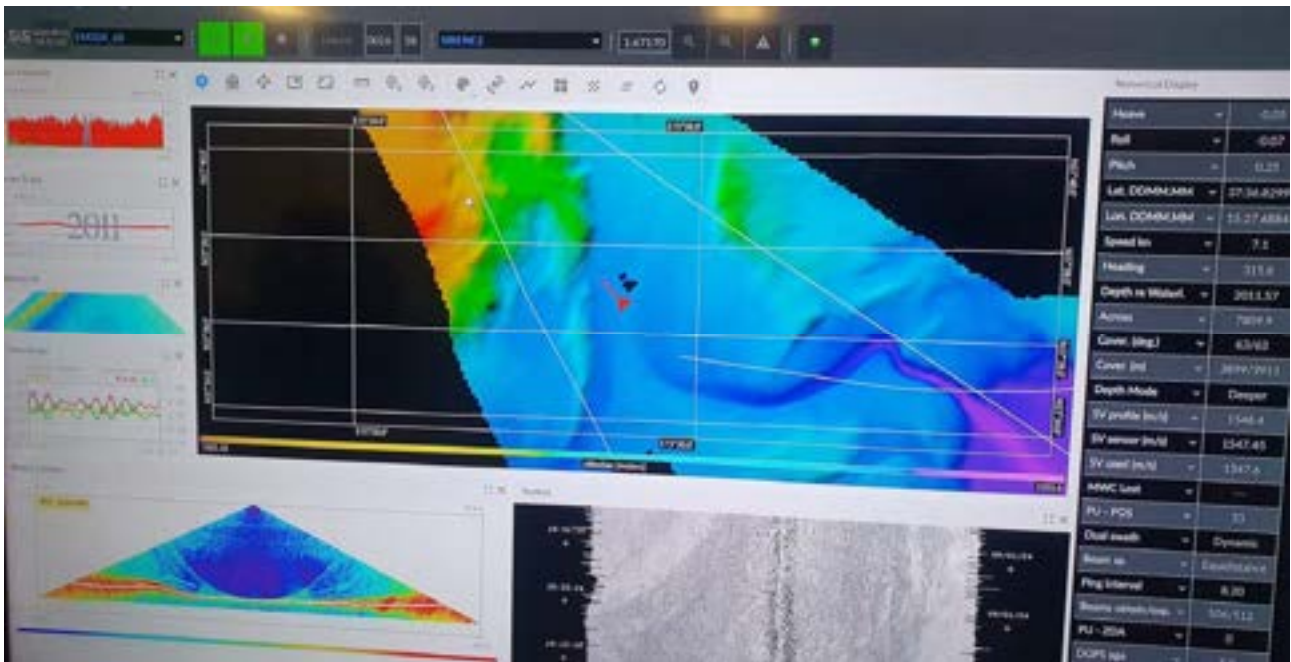


Figure 7- Time frame of the SIS5 (Seafloor Information System 5) software interface during multibeam data acquisition.

2.2.4 Navigation system

The overall navigation and bridge communications system is supported by QPS-Qinsy 9.5.6. The Seapath 380 positioning system installed provides a common reference point (CRP) for all the systems on board, including the Kongsberg Multibeam Echosounders and the Knudsen Sub-Bottom profiler (SBP). The Kongsberg Multibeam software directly applies all the necessary software and positioning inertial corrections as well as offset computations to data in both pinging and recording modes. The Qinsy navigation system stores all the offsets of the installed systems, and its positioning computations relative to each node are sent to the respective systems. The draft can be applied in post-processing to the Knudsen CHIRP data.

2.2.5. CHIRP data acquisition and processing

The processing of the SBP data is divided into the following work phases: 1) Conversion of the files from the native digital format KEB to SEG-Y and/or import in SeisPrho 4.0 for processing and interpretation. Preliminary evaluation of the quality of the raw data, even uncorrelated data when necessary, for the creation of a customized processing sequence and the Hilbert transform, where improved. 3) Application of the processing sequence, which basically includes the envelope of the amplitudes, filters and gains to improve the interpretation of the data, including e.g. time-windowing, time varying gain (TVG) with automatic and/or manual identification and picking of the reflector corresponding to the seabed. 4) Cross-checking the seabed depth using bathymetric DEMs and applying, where necessary, an offset using the speed of sound recorded at the head of the MBES during acquisition simultaneously with the SBP profile; 5) Muting of the water column.

2.2.6 Magnetic data acquisition

Marine magnetic data were collected using a Marine Magnetic SEASPY marine magnetometer towed behind the survey vessel. To minimize magnetic interference generated by the metallic structure of the ship, the sensor was deployed at a distance of approximately 250 m astern, connected via a non-magnetic tow cable. This configuration ensured that the recorded total magnetic field primarily reflected natural variations in the seafloor and subsurface geology rather than distortions caused by the vessel itself. Data acquisition was carried out continuously along predefined survey lines, allowing for high-resolution mapping of magnetic anomalies across the study area. Magnetic data were collected at 1 s sampling rate.

2.3. CTD OPERATIONS

CTD profiles (Conductivity, Temperature and Depth) were carried out with a Seabird SBE-911+ mounted on a 24-bottle Rosette sampler (Figure 8), with all sensors calibrated yearly.

The main variables measured are temperature ($^{\circ}\text{C}$), seawater conductivity (mS/cm), pressure (decibar) and oxygen (ml/l). Salinity (PSU) is inferred by the Seabird software on the fly from conductivity and temperature, using the TEOS equation. Values are recalculated later during the data processing using the Gibbs Sea Water (GSW) Oceanographic Toolbox. We conducted 4 CTD stations for multibeam calibration (Figure 9).

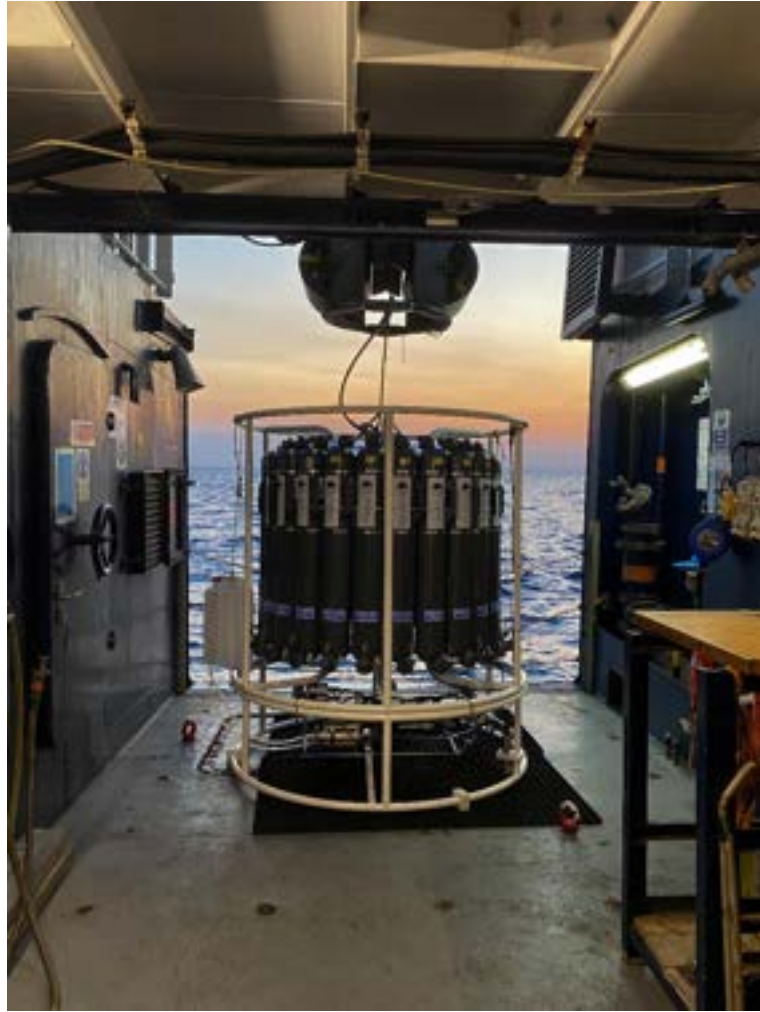


Figure 8 - Seabird SBE-911+ CTD mounted on a 24-bottle Rosette sampler used for water column profiling.

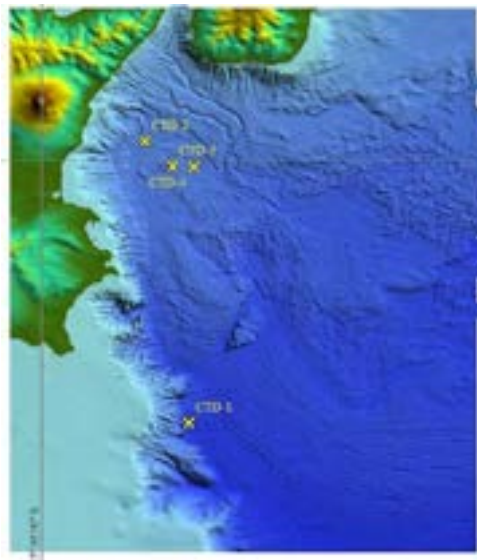


Figure 9 - Location map of CTD casts.

Table 2 - Location of CTD casts

15.6372333	36.3624817	1538.2340	3621.7489	CTD-1
15.4483167	37.5829417	1526.8990	3734.9765	CTD-2
15.5659933	37.4753200	1533.9596	3728.5192	CTD-3
15.6556533	37.4729533	1539.3392	3728.3772	CTD-4

2.4. SEDIMENT SAMPLING

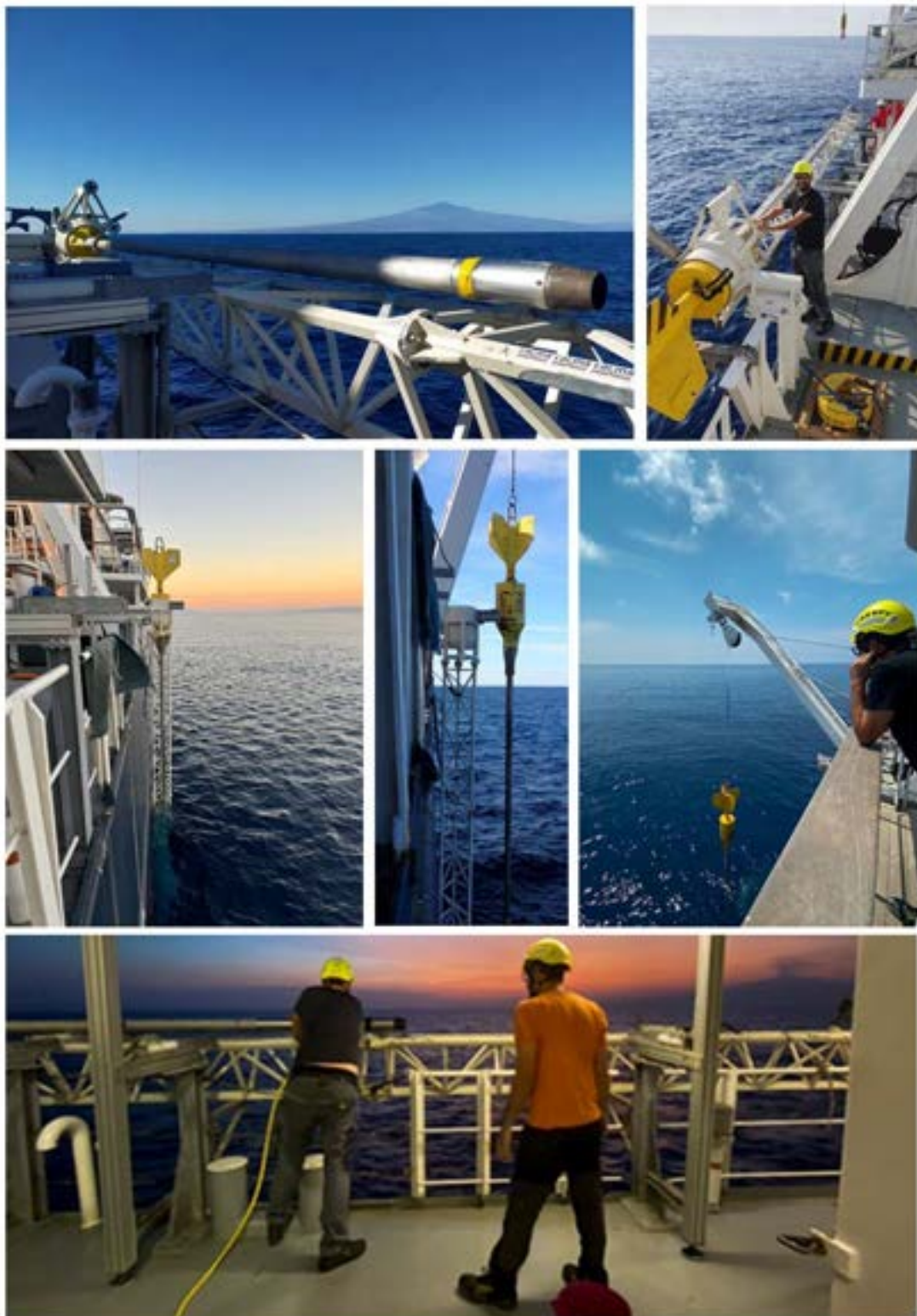


Figure 10 - Sediment sampling operations. Upper panels: the gravity corer mounted on its deployment system in front of Mount Etna (left) and the corer being armed for deployment (right). Central panels: descent and recovery of the gravity corer. Bottom panel: cleaning and preparing the corer for the next day's operations.

Sediment sampling was completed using a gravity corer lowered from the side using the dedicated winch. The gravity corer system on board Gaia Blu (Figure 10) is basically composed of: 1) a coring head providing the necessary momentum to the device for penetration. 2) Steering yellow fins designed to maintain the vertical position of the device during free fall. 3) A stainless steel, 5 m long barrel; several sections (85 kg) can be used to compose a 5 to 15 m (potentially 25 m) barrel. 4) A 100 mm diameter PVC liner placed inside the barrel to collect the sediment core. The lowermost part of the barrel is reinforced by a core nose, which ends with a cutter shoe, designed to ease core penetration and includes a core catcher, designed to hold the sediment into the liner when the core is pulled out of the seabed. To reduce friction, a cutting shoe in ertalyte is also provided for advanced coring operations. In very soft muddy sediment, this tool provides high recovery ensuring minimum disturbance of the sample.

The core barrel is mounted on a truss system (white framework), which extends over one meter from the starboard side of the vessel, while the coring head is hosted in a cradle system. The launching operation is carried out by means of the combination of a winch and a crane, which allows the framework to be rotated 90° degrees before lowering in the water.

3. The SIRENE cruise – activities and cruise narrative

3.1. METEOROLOGICAL WEATHER AND SEA CONDITIONS

The weather conditions during the SIRENE campaign were relatively good and the sea was calm throughout the whole expedition. This allowed us to acquire all the data without any problem. Nevertheless, we had to abandon the southern working area due to interference with fishing activities, even though we were officially authorized to operate in that region, while a second stop was necessary to clean the winch cable to prevent any oil spill into the sea.

3.2. SIRENE DATASET

The set of data collected during the SIRENE Cruise include over 48 Gbytes of marine geophysical data collected with different instruments mounted onboard Gaia Blu, following the routes displayed in Figure 11. It also includes 13 gravity cores (see Tab. 3) that were sampled according to the analysis of available data to fit the purpose of the scientific objectives of the Project.

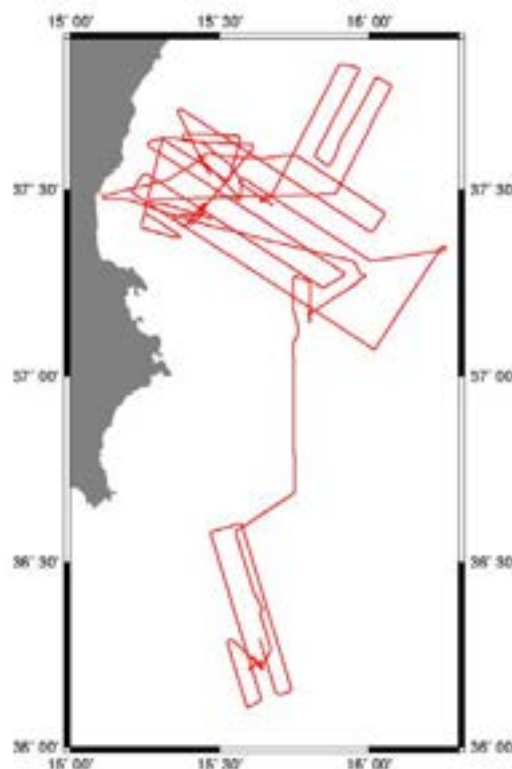


Figure 11 - Navigation map of the SIRENE cruise.

Table 3 - List of gravity cores

CORE	LATITUDE (DM)	LONGITUDE (DM)	PULL (T)	PENETRATION (m)	RECOVERY (m)
SIR24_GC_01	36°13.5436501'	15°37.5948217'	4.15	5.3	2.7
SIR24_GC_02	36°13.5715762'	15°37.6545377'	4.2	5.3	3.35
SIR24_GC_03	36°13.5886149'	15°37.6875566'	4.22	5.3	3.5
SIR24_GC_04	37°10.0562'	15°47.944'	4.9	4.8	1.47
SIR24_GC_05	37°35.0046'	15°26.9153'	4.2	5	2.55
SIR24_GC_06	37°34.3473'	15°26.7410'	4	5	1.9
SIR24_GC_07	37°28.8701'	15°33.72313'	4.1	5	3.9
SIR24_GC_08	37°28.27219'	15°33.68916'	4.2	5	3.4
SIR24_GC_09	37°26.320928'	15°25.4994684'	4.1	1.5	1.1
SIR24_GC_10	37°26.2589477'	15°25.4472083'	4.2	3.5	2.75
SIR24_GC_11	37°28.313743'	15°39.111576'	4.4	5	5
SIR24_GC_12	37°28.36733'	15°39.3383326'	4.4	3.5	3
SIR24_GC_13	37°25.9754471'	15°26.0126722'	4.4	2.5	2.47

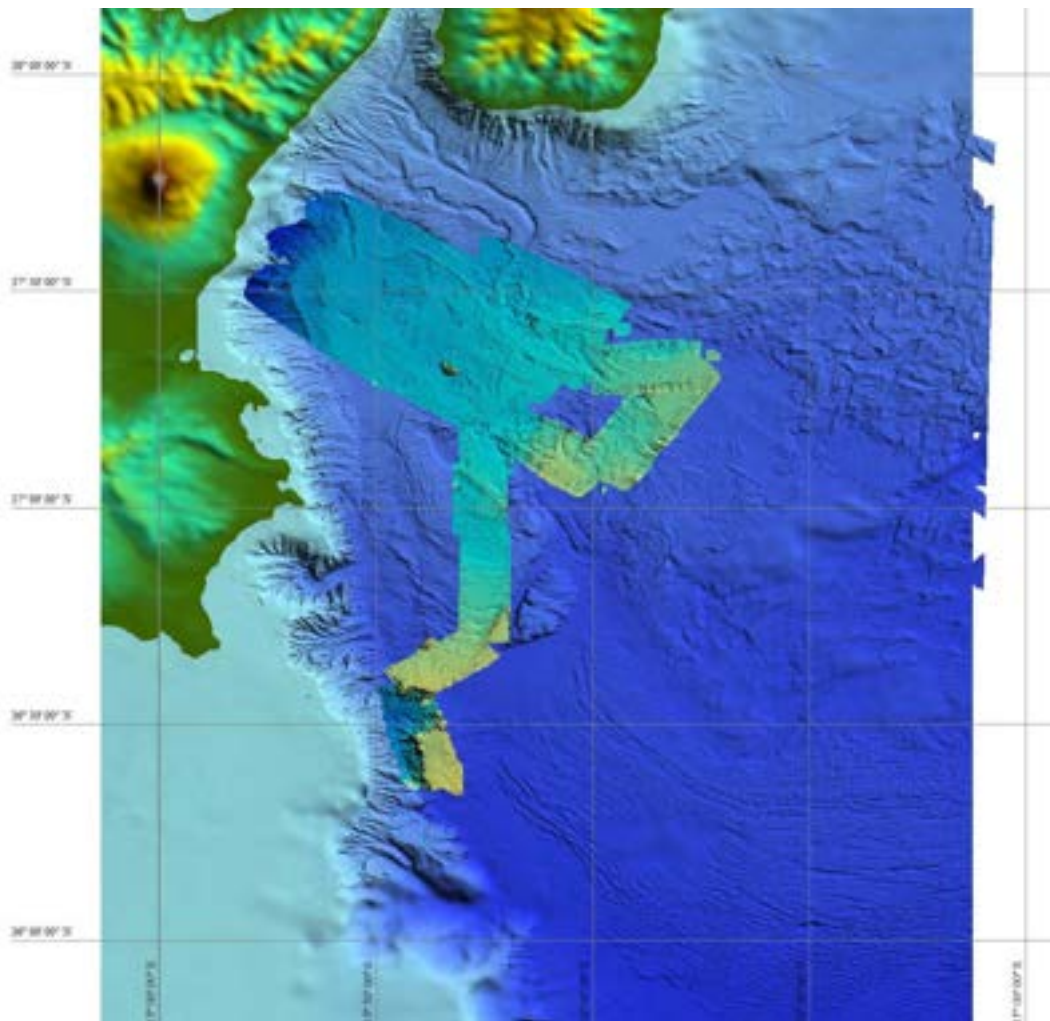


Figure 12 – Map showing the extent of the MB grid acquired during the SIRENE cruise

4. The SIRENE cruise – summary of scientific findings

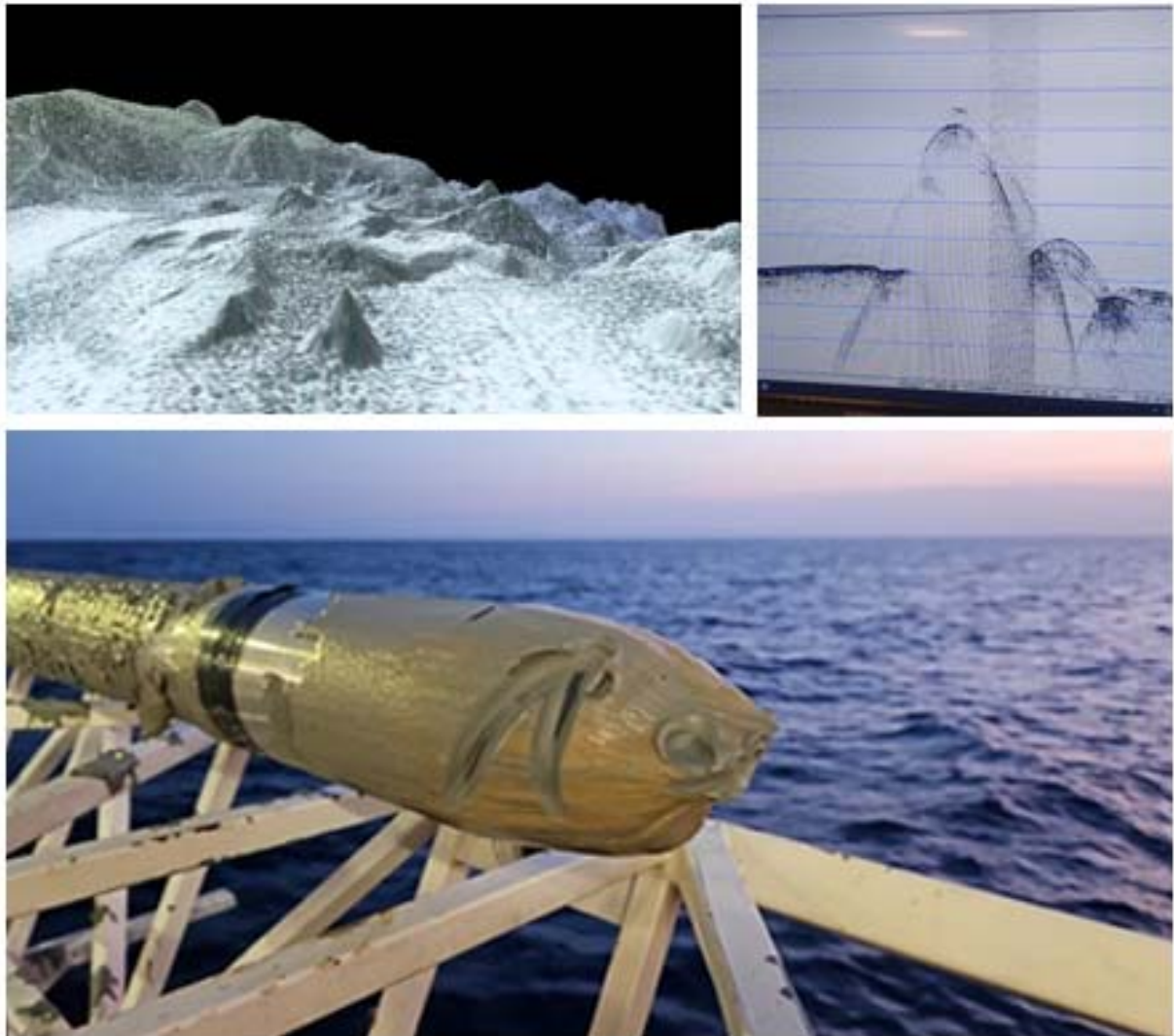


Figure 13 - Above: Submarine reliefs aligned along structural lineaments imaged by the new bathymetric survey and new high-resolution geophysical dataset. Below: Core collected on the flank of the most promising diapir selected through the analyses of multibeam, Chirp and existing MCS data. The photograph shows the sticky mud sampled attached to the core catcher.

During the SIRENE campaign we investigated seabed morphologies and shallow structural development in the southern Ionian Sea, where a system of deep faults is progressively pulling Calabria away from Sicily, slowly sinking the Earth's crust offshore of the strait. Using the cutting-edge geophysical technologies available on the CNR research vessel Gaia Blu, a field of underwater reliefs aligned along the lithospheric faults identified during past oceanographic expeditions was discovered. These features consist in diapirs and mud volcanoes, which are elevated structures that

form when deep material rises to the surface along with fluids and gases, sometimes generating fluid and viscous eruptions.

The sonar images recorded onboard Gaia Blu have highlighted the morphologies of these reliefs in detail (Figure 13), showing indications of recent eruptive and tectonic activity. Some volcanoes have a perfectly conical shape, while others, likely diapirs, show sub-circular but very corrugated and elongated forms aligned in the direction of the faults, often associated with submarine landslides.

The acquisition of high-resolution geophysical data combined with sediment samples and magnetometry will allow for the reconstruction of the morphology of the structures and the physical properties of the materials involved. This study aims to understand whether these structures are fed by mud, volcanic material (somehow connected to Mount Etna volcanism) or by diapiric ascent of rocks in the Earth's mantle at depths of over 20 km. If this were the case, these would represent the last remnants of the Tethyan ocean.

With the coring system of Gaia Blu, we have recovered sediment and rock samples from the flanks of underwater volcanoes. Compositional analyses in the laboratory will allow us to reconstruct the processes that control the emergence of deep fluids and materials. Since mud volcanoes are characterized by the circulation of methane and hydrogen, the analyses of the collected sediments may provide useful information on the connections between the geosphere and the biosphere in extreme marine environments, under conditions similar to those in which life is thought to have emerged on Earth. Finally, the integrated study of the data acquired onboard Gaia Blu will help to understand the nature and origin of the material that rises along these large lithospheric faults, and how it influences the generation of strong earthquakes in one of the most seismically active areas in Europe.

APPENDICES

LOGBOOK of the SIRENE cruise

Table 4 - Logbook of the SIRENE cruise

Data	Ora (UTC)	Latitudine	Longitudine	Evento
27/08/2024	13:30	-	-	Magnetometro in mare
27/08/2024	14:07	-	-	Inizio acquisizione magnetometro
27/08/2024	16:16	36°16.9033	15°38.3277	Depressione sub-circolare alla base della scarpata di Malta evidenziata su dati multibeam (Foto 01)
27/08/2024	16:49	36°13.5090	15°39.6031	Problema acquisizione MBES (Delfini?) (Foto 02)
27/08/2024	17:15	36°11	15°40.5	Campi di vulcani di fango o rumore? (Foto 03)
27/08/2024	17:28	36°09.05	15°41.25	EOL SIR2 - EOL 2_MB
27/08/2024	17:58	36°09.856	15°44.28	SOL SIR1 - SOL 3_MB
27/08/2024	21:55	36°35.9402	15°34.4589	EOL SIR1 - EOL 4_MB
27/08/2024	22:40	36°34.5908	15°28.3085	SOL SIR3 - SOL 5_MB
28/08/2024	00:01	36°25.0080	15°31.9160	Errore GPS magnetometro: "Please sync the fish with GPS"
28/08/2024	02:37	36°8.0630	15°38,2852	EOL SIR3 - EOL 6_MB
28/08/2024	03:07	36°6.9636	15°35.3239	SOL SIR4 - SOL 7_MB
28/08/2024	03:20	36°8.4844	15°34.7614	Possibili strutture artefatte trasversali alla valle
28/08/2024	04:19	36°14.9407	15°32.3349	Stop registrazione MB - Accensione CHIRP
28/08/2024	04:33	36°16.5211	15°31.7413	Stop pinging MB
28/08/2024	04:39	36°17.1856	15°31.6534	Inizio accostata e avvicinamento al punto 63
28/08/2024	04:51	36°16.9622	15°33.2750	Inizio rotta verso punto 63
28/08/2024	05:25	36°14.4012	15°36.5563	Riduzione velocità a 5kn
28/08/2024	05:40	36°13.5434	15°37.5973	Passaggio sul punto 63
28/08/2024	05:49	36°12.9514	15°38.2276	Riduzione velocità a 2 kn per recupero magnetometro

28/08/2024	05:52	36°12.8540	15°38.3179	Stop logging magnetometro
28/08/2024	06:01	36°12.6106	15°38.5314	Stop registrazione CHIRP - Inizio accostata per riavvicinarsi al punto 63
28/08/2024	06:08	36°12.7118	15°38.5935	Start registrazione CHIRP su rotta verso il punto 63
28/08/2024	06:59	36°13.5428822	15°37.5859	(NAV coring) - Carotiere in mare
28/08/2024	07:26	36°13.5436501	15°37.5948217	(NAV coring) - Carotiere sul fondo SIR24_GC_01
28/08/2024	08:00	36°13.5441246	15°37.5946084	(NAV coring) - Carotiere a bordo - Penetrazione=5.3m - Recupero=3.7m - Imbando=10m - Tiro=4.15T
28/08/2024	08:25	36°13.6157	15°37.6730	Start registrazione CHIRP linea 14
28/08/2024	08:36	36°13.9819	15°38.2210	Stop registrazione CHIRP linea 14
28/08/2024	08:37	36°13.9004	15°38.1447	Start registrazione CHIRP linea 15 - SOL CHIRP-1
28/08/2024	09:02	36°13.1526	15°36.7158	Stop registrazione CHIRP - EOL CHIRP-1
28/08/2024	09:10	36°12.9740	15°36.2670	Start registrazione CHIRP linea 16
28/08/2024	09:29	36°13.1497	15°36.6190	Start registrazione CHIRP-2
28/08/2024	09:53	36°13.8523	15°38.3893	EOL CHIRP-2 - Stop registrazione CHIRP; linea 16 - Start registrazione CHIRP linea 17
28/08/2024	10:09	36°13.1200	15°37.952	SOL CHIRP-4 - Start registrazione CHIRP linea 18
28/08/2024	10:38	36°14.6668	15°36.9030	EOL CHIRP-4 - Start registrazione CHIRP linea 19
28/08/2024	10:43	36°14.4420	15°36.6947	Start registrazione CHIRP linea 20
28/08/2024	10:57	36°13.5836	15°37.6567	Start registrazione CHIRP linea 21 (in posizione sul punto di carotaggio)

28/08/2024	11:12	36°13.5708	15°37.6527	(NAV coring) Carotiere in mare SIR24_GC_02
28/08/2024	11:46	36°13.5715762	15°37.6545377	(NAV Coring) Carotiere sul fondo SIR24_GC_02 - Touch down=1968m - Tiro=4.2 T
28/08/2024	12:10	-	-	Carotiere a bordo
28/08/2024	12:37	-	-	Start registrazione CHIRP linea 22 - Linea verso il punto di carotaggio 61
28/08/2024	13:19	36°15.5882	15°37.6867	(NAV coring) Carotiere a mare SIR24_GC_03
28/08/2024	13:45	36°13.5886149	15°37.6875566	(NAV coring) Carotiere sul fondo SIR24_GC_03 - Tiro=4.22 T
28/08/2024	13:55	-	-	Interruzione recupero carotiere
28/08/2024	14:33	-	-	Recupero carotiere ricominciato
28/08/2024	14:58	36°13.7481	15°37.5484	(NAV coring) Carotiere a bordo - Recupero=3.5 m
28/08/2024	16:08	36°13.4591	15°38.6911	Riaccensione multibeam e riavvio
28/08/2024	16:12	36°13.7712	15°39.9472	Inizio transit verso linea SIR6 - nessuno strumento in acquisizione
28/08/2024	16:44	36°15.98	15°40.21	Nuovo progetto multibeam SIRENE2 - il conteggio delle linee riparte da 0
28/08/2024	17:02	36°17.98	15°39.57	CHIRP già in acquisizione - Start recording QUINCY SIR6
28/08/2024	17:43	36°21.7489	15°38.2340	Stop registrazione CHIRP - Fermi per CTD
28/08/2024	20:00	-	-	SOL 0000-SIRENE2 Multibeam
28/08/2024	20:09	-	-	SOL Magnetometro
28/08/2024	22:22	36°33.987	15°33.561	EOL SIR6 - Linea accorciata per evitare manovra di 360° - Multibeam in acquisizione fino a cambio rotta

28/08/2024	22:30	36°34.82	15°33.31	EOL MB 0001-SIRENE2
28/08/2024	22:33	36°35.08	15°33.46	SOL TRANSIT - SOL MB 0002-SIRENE2
29/08/2024	00:19	36°41.0874	15°44.7944	EOL TRANSIT
29/08/2024	00:23	36°41.2923	15°45.0520	EOL MB 0002-SIRENE2 - Inizio accostata verso SIR7
29/08/2024	00:24	36°41.4680	15°45.0614	SOL MB 0003-SIRENE2 - SOL SIR7
29/08/2024	04:29	37°5.3690	15°44.8502	Stop MB 0004-SIRENE2 per precedenza ad altre navi - Start MB 0005-SIRENE2 su rotta ad Est di SIR7 - Mound su MB appena prima del cambio di rotta
29/08/2024	05:15	37°9.6514	15°45.2127	Rilievi sul MB
29/08/2024	05:29	37°10.9839	15°44.7728	Stop MB 0005-SIRENE2 - Start MB 0006-SIRENE2 di nuovo sulla linea SIR7
29/08/2024	06:09	37°15.2841	15°40.8926	EOL NAV
29/08/2024	06:16	37°14.5923	15°44.7237	EOL MB
29/08/2024	06:36	37°12.8613	15°56.0695	SOL MB - accostata
29/08/2024	06:46	37°11.59	15°55.93	EOL accostata MB - SOL MB (ridotta larghezza fascio a dritta - overlap molto grande)
29/08/2024	07:39	37°9.103	15°48.176	EOL MB - EOL NAV - Star recording CHIRP verso punto 66
29/08/2024	08:32	37°10.0337	15°47.9533	STOP recording CHIRP
29/08/2024	08:54	37°10.0562	15°47,9353	Carotiere in mare SIR_GC_04
29/08/2024	09:24	37°10.0562	15°47.944	(NAV coring) Carotiere sul fondo SIR_GC_04 - Tiro=4.9 T
29/08/2024	10:01	37°10.0591	15°47.9337	Carotiere a bordo - Penetrazione = 4.8 - Recupero = 1.47
29/08/2024	10:15	-	-	Stop attività per problemi al sistema di refrigerazione. Fermi in rada per riparazione

31/08/2024	14:30	-	-	Ripartenza verso il punto 68
31/08/2024	14:30	-	-	Start registrazione CHIRP linea 36 - avvicinamento al punto 68 da Catania
31/08/2024	16:05	37°35.0055	15°25.9004	Stop recording CHIRP
31/08/2024	16:13	37°35.0134	15°26.9140	Avvicinamento al punto 68 - Distance to bull = 2 m - DTM = 1973 m
31/08/2024	16:23	37°35.0094	15°26.9128	Carotiere in acqua
31/08/2024	16:49	37°35.0046	15°26.9153	(NAV coring) Carotiere sul fondo SIR24_GC_05 - Tiro=4.2 T
31/08/2024	17:14	37°35.0049	15°26.9149	(NAV coring) Carotiere a bordo - Penetrazione=5m - Recupero=2.55m
31/08/2024	18:00	37°34.9765	15°26.899	(NAV CTD) Calata CTD
31/08/2024	19:24	37°35.5065	15°26.8759	Start registrazione magnetometro
31/08/2024	19:46	37°35.4860	15°29.5963	Start registrazione MB e QUINCY
31/08/2024	20:18	-	-	Crash QUINCY
01/09/2024	00:01	37°26.3905	16°02.8227	Crash SeaLINK - Problema con il cambio del giorno?
01/09/2024	00:05	37°26.16	16°03.16	EOL SIR10 - EOL MB 0011- SIRENE2 - linea interrotta a circa 6 km dalla fine a causa di un peschereccio sul tragitto
01/09/2024	00:37	37°23.2118	16°00.4247	SOL MB 0012-SIRENE2 - SOL SIR11
01/09/2024	04:25	37°37.2466	15°33.1434	Anomalia magnetica in alto batimetrico (Foto 09-01- 2024/01)
01/09/2024	05:52	37°42.7035	15°22.541	EOL SIR12 - EOL MB 0014- SIRENE2 - Start registrazione CHIRP - Accostata verso punto 72
01/09/2024	05:02	37°42.291	15°21.7395	SOL MB 0015-SIRENE2 - avvicinamento al punto 72

01/09/2024	07:27	37°32.85	15°27.8027	EOL MB 0015-SIRENE2
01/09/2024	07:33	-	-	Magnetometro a bordo
01/09/2024	07:34	-	-	Start registrazione CHIRP linea 37 - in accostata verso il punto 72
01/09/2024	08:11	-	-	Stop registrazione CHIRP linea 38 - Start registrazione CHIRP linea 39 - cambio rotta e accostata sul punto 72
01/09/2024	08:56	37°34.3535	15°26.7410	Stop registrazione CHIRP linea 39 - Carotiere in acqua SIR_GC_06
01/09/2024	09:22	37°34.3473	15°26.7410	(NAV coring) Carotiere sul fondo - Tiro=4 T;
01/09/2024	09:50	-	-	Carotiere a bordo - Recupero = 1.90 m
01/09/2024	10:10	37°34.3757	15°26.8358	Start CHIRP
01/09/2024	10:14	37°34.2720	15°27.0022	Start registrazione CHIRP linea 41 - avvicinamento al punto 74
01/09/2024	11:20	37°28.66	15°33.99	Attraversato il punto 74 accostiamo per tornare al punto di carotaggio
01/09/2024	11:32	37°28.87	15°33.72	Stop CHIRP
01/09/2024	11:45	37°28.8809	15°33.7248	Carotiere in acqua SIR24_GC_07
01/09/2024	-	37°28.8701	15°33.72313	(NAV coring) Carotiere sul fondo
01/09/2024	12:45	-	-	Carotiere a bordo - Recupero = 3.90 m - Penetrazione = 5.0 m
01/09/2024	13:04	37°28.7330	15°33.6938	Start registrazione CHIRP linea 44 - verso punto 75
01/09/2024	13:10	37°28.0840	15°33.6892	Stop registrazione CHIRP 44 - ci dirigiamo verso il punto 75
01/09/2024	13:53	37°28.2787	15°33.6866	Carotiere in acqua SIR24_GC_08

01/09/2024	14:21	37°28.27219	15°33.68916	(NAV coring) Carotiere sul fondo - TIRO=4.2 T
01/09/2024	14:48	37°28.2790	15°33.6864	Carotiere a bordo
01/09/2024	15:44	37°28.5192	15°33.9596	CTD
01/09/2024	17:09	37°28.5192	15°34.1753	SOL QUINCY - SOL MB - in transito verso linea SIR12 MAG-ETNA
01/09/2024	17:37	37°32.1291	15°33.74	Start registrazione magnetometro
01/09/2024	18:54	37°37.7291	15°25.0387	Alto magnetico
01/09/2024	19:48	37°37.988	15°17.528	Alto magnetico
01/09/2024	19:56	-	-	Inizio accostata per SIR-13
02/09/2024	00:00	37°22.9965	15°44.7240	Crash SeaLINK magnetometro
02/09/2024	01:25	37°16.7174	15°54.8736	EOL SIR13 - EOL MB 0022- SIRENE2 - Inizio accostata verso SIR14
02/09/2024	02:08	37°14.4131	15°50.3528	SOL SIR14 - SOL MB0023- SIRENE2
02/09/2024	03:24	37°19.2734	15°40.9908	Ampia anomalia magnetica positiva
02/09/2024	03:37	37°20.0953	15°38.4113	Il campo magnetico continua ad aumentare
02/09/2024	05:22	-	-	Il campo magnetico sembra in aumento, cresce più velocemente in prossimità dei punti di campionamento 1,2,3
02/09/2024	06:20	-	-	Alto magnetico
02/09/2024	07:01	37°32.4700	15°15.1002	Stop registrazione Quinsy e MB - Inizio accostata verso linea SIR15
02/09/2024	07:31	-	-	Stop registrazione MB
02/09/2024	07:32	37°29.3700	15°12.8612	SOL SIR15 - Start registrazione MB
02/09/2024	08:37	-	-	Stop registrazione Quinsy - accostata verso il punto 3 e recupero magnetometro
02/09/2024	08:39	37°24.3305	15°22.4769	Stop registrazione MB

02/09/2024	08:47	-	-	Magnetometro a bordo - Start registrazione CHIRP verso punto 3
02/09/2024	09:32	-	-	Stop registrazione CHIRP - si torna indietro verso punto 3 - Start registrazione CHIRP
02/09/2024	09:57	-	-	Stop registrazione CHIRP
02/09/2024	10:19	-	-	Arrivo al punto di carotaggio 3
02/09/2024	10:25	37°26.3301	15°25.4906	Carotiere in mare SIR24_GC_09
02/09/2024	-	-	-	Interruzione carotaggio per perdita olio da cavo e conseguente pulizia cavo
02/09/2024	15:08	37°26.320928	15°25.4994684	(NAV coring) Carotiere sul fondo SIR24_GC_09 - Tiro=4.2 T
02/09/2024	15:47	-	-	Carotiere a bordo - Penetrazione=1.5 m - Recupero=1.1m
02/09/2024	16:47	37°26.2519	15°25.4529	Carotiere a mare sul punto 49
02/09/2024	17:11	37°26.2589477	15°25.4472083	(NAV coring) Carotiere sul fondo SIR24_GC_10 - Tiro=4.2 T
02/09/2024	17:55	-	-	Avvicinamento SIR15
02/09/2024	22:59	37°04.76	16°00.26	EOL SIR15
02/09/2024	23:05	37°04.38	16°01.02	EOL MB 0032-SIRENE2
02/09/2024	23:08	37°04.48	16°01.38	SOL SIR20 - SOL MB 0033-SIRENE2
03/09/2024	00:00	37°10.24	16°05.95	Crash SeaLink magnetometro
03/09/2024	01:25	37°20.12	16°14.07	EOL SIR20 - inizio loop per linea SIR 21
03/09/2024	01:29	37°20.4389	16°14.3078	EOL MB 0033-SIRENE2
03/09/2024	01:47	37°20.1980	16°14.2600	SOL MB 0034-SIRENE2 - SOL SIR21
03/09/2024	03:11	37°18.5238	16°0.3611	EOL MB 0034-SIRENE2 - EOL SIR21
03/09/2024	03:13	37°18.6283	16°0.0844	SOL SIR 12 - SOL MB0035-SIRENE2

03/09/2024	05:08	37°27.0648	15°43.8520	Segnale MB disturbato da rumore
03/09/2024	06:26	37°30.5781	15°34.9528	Stop registrazione MB
03/09/2024	06:27	-	-	Start registrazione CHIRP verso i punti di carotaggio 79 e 77
03/09/2024	07:06	-	-	Stop registrazione QUINSY - rallentiamo per recupero magnetometro in avvicinamento al punto 79
03/09/2024	08:16	37°28.03634	15°38.32423	Start registrazione CHIRP in avvicinamento al punto 79
03/09/2024	11:07	37°28.313743	15°39.111576	(NAV coring) Carotiere sul fondo SIR24_GC_11 - Tiro=4.4 T
03/09/2024	11:36	-	-	Carotiere a bordo - Penetrazione=5m - Recupero=5m - Top perso
03/09/2024	12:52	37°28.3626	15°39.3439	Carotiere in discesa SIR24_GC_012
03/09/2024	13:14	37°28.36733	15°39.3383326	(NAV coring) Carotiere sul fondo
03/09/2024	13:40	-	-	Carotiere a bordo - Penetrazione=2.5m - Recupero=3m
03/09/2024	13:58	37°28.3772879	15°39.3392885	Inizio CTD
03/09/2024	15:22	37°28.5782	15°39.8269	Start registrazione CHIRP e magnetometro - transito verso SIR31
03/09/2024	15:34	37°29.8500	15°41.0570	SOL SIR 31 - CHIRP + magnetometro
03/09/2024	15:45	37°31.2981	15°41.9844	Problema con magnetometro e CHIRP risolto. Non hanno acquisito per alcuni minuti
03/09/2024	-	-	-	CTD - Acquisizione su linee SIR31, SIR32, SIR34

03/09/2024	22:35	37°47.5616	16°01.2423	EOL SIR34 - EOL MB 0046- SIRENE2 - SOL MB 0047- SIRENE2
03/09/2024	22:57	37°46.5306	16°04.4441	SOL SIR35
03/09/2024	23:33	37°42.0765	16°01.4546	Deviazione per evitare nave sulla rotta
04/09/2024	00:00	37°38.4275	15°59.2398	Crash SeaLink magnetometro
04/09/2024	01:06	37°29.8586	15°53.6813	EOL SIR35 - EOL MB 0047- SIRENE2
04/09/2024	01:11	-	-	SOL SIR37 - SOL MB 0048- SIRENE2
04/09/2024	02:22	-	-	Crash QUINCY - riavvio
04/09/2024	02:33	37°28.9054	15°37.7400	Spike anomalo del campo magnetico (rumore)
04/09/2024	02:46	37°28.8467	15°35.3010	Campo magnetico in aumento avvicinandoci ai punti di campionamento delle carote SIR24_GC_07 e SIR24_GC_08
04/09/2024	07:44	37°25.9789	15°26.0139	Carotiere in acqua SIR24_GC_13 - Punto 6
04/09/2024	09:53	37°25.9754471	15°26.0126722	(NAV coring) Carotiere sul fondo - Tiro=4.4 T
04/09/2024	10:48	-	-	Carotiere a bordo - Penetrazione=2.5m - Recupero=2.47m
04/09/2024	11:21	37°25.8370	15°25.9920	Start registrazione CHIRP in avvicinamento verso SIR40
04/09/2024	11:27	37°25.6266	15°26.0243	Start registrazione magnetometro in avvicinamento verso SIR40
04/09/2024	12:00	37°27.3613	15°26.4211	SOL SIR40 CHIRP - Stop registrazione magnetometro
04/09/2024	12:42	37°24.5940	15°24.0920	EOL SIR40 CHIRP - Start transit
04/09/2024	12:50	37°24.5990	15°24.8742	SOL SIR41 CHIRP + magnetometro
04/09/2024	13:22	37°26.8588	15°26.7437	SOL SIR42 CHIRP + magnetometro

04/09/2024	14:38	37°33.421	15°33.537	Alto magnetico in corrispondenza del diapiro
04/09/2024	14:58	-	-	Evidente dislocazione superficiale da CHIRP nella seconda metà (verso NE) della linea SIR42 (circa 3km dalla fine)
04/09/2024	15:10	37°36,5184	15°36,6731	EOL 42 CHIRP
04/09/2024	15:17	37°37,1516	15°36,3949	SOL 43 CHIRP
04/09/2024	16:54	37°37.66183	15°22.92646	STOP SIR43 - ci spostiamo su SIR44
04/09/2024	17:05	37°38.8928	15°23.2960	SOL SIR44 (Siamo sulla stessa rotta 100 m prima del SOL) - Acquisiamo CHIRP e dati magnetometrici
04/09/2024	18:11	37°38.5736	15°33.7781	ci spostiamo verso la linea TRANSIT (Qincy). Stop chirp.

A special thank...

This work is dedicated to Giovanni Bortoluzzi who died in 2015. His skill and scientific curiosity in different fields of marine geology have stimulated many multidisciplinary studies in the Institute of Marine Sciences, ISMAR (former Institute of Marine Geology, IGM). He organized tens of cruises in the Mediterranean Sea and other oceans and dedicated his life to training students and foster collaborative research among colleagues in different disciplines. The acquisition of geophysical data during the SIRENE project was possible thanks to his valuable contribute during previous cruises when he never missed an opportunity to use the magnetometer providing important information on the distribution of rocks and basement geometry in the subsurface.

We all miss you, Giovanni.



In this photograph Giovanni is helping Andrea Gallerani, our core drilling expert, during a previous cruise.

PHOTO GALLERY

