L-Università ta' Malta

International Conference on

Seafloor Landforms, Processes and Evolution

Valletta, Malta

4–6 July 2022

R3 · IAG GEOMORPHOLOGY GEOMORPHOLOGIE AIG · erc · MARCAN · INTERNATIONAL LITHOSPHERE PROGRAM

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Introduction

I would like to welcome you to the International Conference on Seafloor Forms, Processes and Evolution, which is organised by the **Marine Geology and Seafloor Surveying group** of the Department of Geosciences, University of Malta, and the **Submarine Geomorphology working group of the International Association of Geomorphologists**.

The main objectives of the conference are to:

1. Provide and establish a forum for sharing the state-of-the-art in our knowledge of seafloor processes and their investigation.
2. Identify the key gaps in knowledge in our understanding of seafloor processes and devise strategies to address them.
3. Bring together different stakeholders (e.g. scientists, students, industry professionals, government agencies) to promote communication and collaborative interactions.
4. Provide a platform from early career scientists to present their work and expand their networks.

In the following pages you will find the conference schedule, and information on the presentation guidelines, logistics and contact details.

This conference is sponsored by **R3 Vox**, and supported by **MARCAN** (funded by the European Research Council, grant agreement No 677898), and **LithoMar (funded by the International Lithosphere Program)**.

AARON MICALLEF

on behalf of the organising committee

Conference Schedule

MONDAY 4 JULY

08:45 – 09:00

INTRODUCTION

Organising committee & **Mauro Soldati** (President, IAG)

09:00 – 10:30

SESSION 1: Oceanography

Aula Magna, UM Valletta Campus

CHAIRS: Micallef, Esentia

09:00 – 09:15

Stow, D. (invited) | *The new bedform-velocity matrix for contourite systems*

09:15 – 09:30

Miramontes, E. | *The link between geometry, lithology and modelled bottom currents in contourite depositional systems in the Mozambique Channel (SW Indian Ocean)*

09:30 – 09:45

Ribó, M. | *Complex Morphological Changes in Seafloor Bedforms under the influence of Multi-Directional Near-Bottom Tidal Currents*

09:45 – 10:00

Puig, P. | *Topographic constrain of near-bottom currents next to submarine canyon walls*

10:00 – 10:15

Kostylev, V.E. | *Geomorphology and benthic habitat of Orphan Spur (north Atlantic Ocean)*

10:15 – 10:30

Wilckens, H. | *How do bottom currents control the development of moats and their associated contourite drifts?*

SESSION 2: Tectonics

Lecture Room 103, UM Valletta Campus

CHAIRS: Krastel, Giona Bucci

09:00 – 09:15

Maselli, V. | *Influence of tectonically controlled-topography on deep-water sedimentation*

09:15 – 09:30

Lipparini, L. | *Morphological expression of active tectonics offshore Calabria accretionary prism*

09:30 – 09:45

Fernández-Blanco, D. | *Red-blue seafloor maps to understand East Mediterranean tectonics*

09:45 – 10:00

Canari, A. | *Accurate seafloor morphology with quantitative relief-processing methods: The growing transtensional north-south fault system (Alboran Sea, western Mediterranean)*

10:00 – 10:15

Laor, M. | *Classifying offshore faults for hazard assessment: A new approach based on fault size and vertical displacement*

10:15 – 10:30

Gamberi, F. | *Geomorphic elements of turbidite systems in rifted continental margins: turbidity currents and tectonic structures interaction in submarine landscape creation*

10:30 – 11:00

Break* | *Posters

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MONDAY 4 JULY *(Continued)*

	SESSION 3: Canyons & channels	SESSION 4: Biogenic
11:00 – 12:30	Aula Magna, UM Valletta Campus **CHAIRS:** Schulten, Arjona-Camas	Lecture Room 103, UM Valletta Campus **CHAIRS:** Bialik, Varzi
11:00 – 11:15	**Amblas, D. (invited)** | *Dense water cascades as a geomorphic agent: New insights from a process-based numerical model*	**Makovsky, Y.** | *A new discovery of pronounced methane and brine seepage, and an associated biodiversity hotspot, on Palmahim Disturbance offshore Israel*
11:15 – 11:30	**Mountjoy, J.J.** | *Fine scale signature of bedrock erosion during submarine canyon flushing*	**Oliveira, L.** | *3D photogrammetric classification of cold-water coral reefs with machine learning: Preliminary results from Piddington Mound, NE Atlantic*
11:30 – 11:45	**Li, S.** | *Submarine canyon morphology in relation to active forearc tectonics along the Chilean margin*	**Lisco, S.** | *The physical features of mesophotic bioconstructions in the lower Adriatic Sea*
11:45 – 12:00	**Bernhardt, A.** | *Where and Why Do Submarine Canyons Develop? Insights from Topographic Analysis, Bayesian Regression and Point Pattern Analysis*	**Savini, A.** | *Coupling optical and acoustic remote sensing techniques in coral reef environments for geomorphological studies (Magoodhoo Reef – Maldivian Archipelago)*
12:00 – 12:15	**Nanson, R.** | *Application of a two-part geomorphology mapping approach: Cretaceous to Cenozoic controls on the genesis of the shelf-incising Perth Canyon, southwest Australian margin*	**Varzi, A.G.** | *High resolution mapping of coralligenous bioconstructions offshore south-eastern Sicily as a baseline for (bio) geomorphological studies in marine setting*
12:15 – 12:30	**Pierdomenico, M.** | *Integration of morphobathymetric data and ROV videos for the study of sedimentary processes along submarine canyons: example from southern Italy*	**Bialik, O.** | *Sediment distribution control by internal waves and bottom currents in Mediterranean mesophotic peri-reefal environments*
12:30 – 13:30	***Lunch***	

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MONDAY 4 JULY *(Continued)*

	SESSION 5: Fluids	SESSION 6: Canyons & channels
	Aula Magna, UM Valletta Campus	Lecture Room 103, UM Valletta Campus
	CHAIRS: Savini, Martínez-Loriente	**CHAIRS:** Schulten, Cerillo-Escoriza
13:30 – 15:00		
13:30 – 13:45	**Hillman, J.** | *Diverse morphology of seafloor depressions offshore Aotearoa New Zealand*	**Sagy, Y.** | *Pliocene-to-Recent depositional pattern in the deep Levant basin and the role of the Nile River*
13:45 – 14:00	**Lundsten, E.** | *North America's largest pockmark field offshore Big Sur, California is maintained over time by intermittent, non-channelized turbidity flows*	**Cerrillo-Escoriza, J.** | *Modern sedimentary processes and recent development and evolution of two shelf-incising submarine canyons in the Alboran Sea, western Mediterranean*
14:00 – 14:15	**Gay, A.** | *Elongated giant seabed polygons and underlying polygonal faults as markers of the creep deformation of shallow sediments in the Grenada and Venezuela Basins*	**Moshe, N.** | *The late Quaternary evolution of a blind Submarine Canyon: a case study from the eastern Mediterranean Sea*
14:15 – 14:30	**Sánchez-Guillamón, O.** | *Semi-automatic mapping for geomorphometric characterization of pockmarks*	**Jimmy, M.** | *Late Messinian submarine channel systems in the Levant Basin: Challenging a desiccation model*
14:30 – 14:45	**Argnani, A.** | *Morphological expression of fluid expulsion offshore Crotone (Calabrian accretionary prism)*	**Green, A.** | *Uncinated submarine canyons of the Southwestern African margin*
14:45 – 15:00	**Gupta, S.** | *Mathematical modelling of erosive fluidization, flow localization, and formation of pockmarks*	**Cabrera, C.** | *Geomorphology and evolution of the Blanes Canyon (NW Mediterranean). New insights from high resolution mapping of vertical cliffs*
15:00 – 15:30	***Break | Posters***	

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MONDAY 4 JULY *(Continued)*

	SESSION 7: Fluids	SESSION 8: Ice
15:30 – 17:00	Aula Magna, UM Valletta Campus **CHAIRS:** Gupta, Micallef	Lecture Room 103, UM Valletta Campus **CHAIRS:** Duran, Amblas
15:30 – 15:45	**Jouve, G.** | *Gas detection and quantification using ixblue echoes high-resolution sub-bottom profiler and seapix 3d multibeam echosounder from the Laacher See (Germany)*	**Batchelor, C.L. (invited)** | *Submarine glacial geomorphology: new insights into past ice behaviour and glacial sedimentation from high-resolution bathymetric data*
15:45 – 16:00	**Fallati, L.** | *Using ROV video photogrammetry to reconstruct seafloor landforms of the central part of Haakon Mosby mud volcano (Barents Sea)*	**Caruso, S.** | *3D Seismic Characterisation of a Glacigenic Basin Floor Fan System Offshore West of Shetland*
16:00 – 16:15	**Geersen, J.** | *Seafloor pockmarks offshore Vancouver Island*	**Benetti, S.** | *Geomorphology of the Celtic sea (North Atlantic) from shallow to deep water and its link with the evolution of the British-Irish ice sheet*
16:15 – 16:30	**Muhedeen, L.** | *Seabed hydrocarbon seepage linked to overlapping subsurface fluid flow systems*	**Aksenov, A.** | *On the origin of glacial bedforms at the central part of Lake Ladoga, NW Russia*
16:30 – 16:45	**Pecher, I.** | *Imaging of the plumbing system beneath pockmarks on the Chatham rise, New Zealand, with densely spaced seismic profiles*	**Bellwald, B.** | *A journey through the buried landscapes shaped by the Fennoscandian Ice Sheet*
16:45 – 17:00	**Spatola, D.** | *Mud and fluid migration in active mud volcanoes offshore Scoglio d'Affrica islet (Tuscan Archipelago, Northern Tyrrhenian Sea)*	

TUESDAY 5 JULY

	SESSION 9: Slope failure Aula Magna, UM Valletta Campus CHAIRS: Micallef, Ribo	SESSION 10: Coast to shelf Lecture Room 103, UM Valletta Campus CHAIRS: Duran, Arjona-Camas
09:00 – 10:30		
09:00 – 09:15	**Sawyer, D.E. (invited)** | *Seismic strengthening: impacts on slope stability and post-failure behaviour of submarine landslides*	**Hoffmann, J.J.L.** | *Sediment dynamics of an exposed subtidal hard bottom substrate habitat in the North Sea*
09:15 – 09:30	**Portnov, A.** | *Dating submarine landslides using the transient gas hydrate stability*	**Senolt, N.** | *Holocene Paleoenvironmental Reconstruction Of A Karst Krka River Estuary (Eastern Adriatic Coast)*
09:30 – 09:45	**Watson, S.J.** | *The underwater landslide archives of Aotearoa/New Zealand: documenting occurrence or preservation bias?*	**Miko, S.** | *Late Pleistocene and Holocene paleoenvironments of a submerged karst landform (Pirovac Bay, Croatia)*
09:45 – 10:00	**Pérez, L.F.** | *West Greenland landslides – the nearshore component: climatic link and impact on benthic habitats*	**Bastos, A.C.** | *Drowned landscapes and reefs and their relation to last postglacial meltwater pulses*
10:00 – 10:15	**Tang, Q.** | *A multitude of glide planes characterizing the proximal Sahara Slide Complex, NW-Africa*	**Summers, G.** | *A Scalable, Supervised Classification of Seabed Sediment Waves Using an Object-Based Image Analysis Approach*
10:15 – 10:30	***Group photo*** (Ariel)	
10:30 – 11:00	***Break*** | ***Posters***	

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TUESDAY 5 JULY *(Continued)*

	SESSION 11: Slope failure	SESSION 12: Coast to shelf
	Aula Magna, UM Valletta Campus	Lecture Room 103, UM Valletta Campus
	CHAIRS: Schulten, Maselli	CHAIRS: Bialik, Thomas
11:00 – 11:15	**Barrett, R.** | *Investigating the origin, frequency, and extent of submarine mass wasting processes in the Aegir Ridge, offshore Norway*	**Hasan, O.** | *Submerged marine terraces and paleo shorelines along the eastern rim of the Mid Adriatic Deep*
11:15 – 11:30	**Gadol, O.** | *Mass transport complexes reactivation revealed through multiscale geophysical observation*	**Lefebvre, A.** | *The shape of estuarine dunes, example from the Weser Estuary, Germany*
11:30 – 11:45	**Brunet, M.** | *Laboratory modeling approach of gravity-driven sliding along complex submarine slopes: application to the west offshore Martinique island (Lesser Antilles)*	**Stewart, H.A.** | *The geomorphology of the continental shelf around Scotland, UK*
11:45 – 12:00	**Katz, O.** | *Benthic foraminifera as indicators for hybrid turbidite-contourite sediments transport system in the Eastern Mediterranean upper continental slope*	**de Souza, V.A.** | *Characterizing the seascape of the Southern Brazilian continental shelf benthic layer using environmental data*
12:00 – 12:15	**Micallef, A.** | *Is groundwater an important seafloor geomorphic agent?*	**Prampolini, M.** | *Submarine geomorphology north east of the Maltese Islands*
12:15 – 12:30	**Giona Bucci, M.** | *Subaqueous Spreading: State of the Art, and first modelling attempts*	**Agate, M.** | *Geomorphological and sedimentological features of the Egadi Islands offshore (western Mediterranean)*
12:30 – 13:30	***Lunch***	

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TUESDAY 5 JULY *(Continued)*

	SESSION 13: Slope failure Aula Magna, UM Valletta Campus CHAIRS: Giona Bucci, Barrett	SESSION 14: Coast to shelf Lecture Room 103, UM Valletta Campus CHAIRS: Gupta, Wilkens
13:30 – 15:00		
13:30 – 13:45	**Elad, M.** | *Gravity flow depositional systems controlled by polygonal faults on the Guyana-Suriname Basin margin*	**Gamberi, F.** | *Old but sprightly: the role of transgressive geomorphic elements in the shaping of Sicilian and Sardinian continental shelves*
13:45 – 14:00	**Elyashiv, H.** | *Submarine slope failure initiation preconditioned by shear strength: insights from a 3D numerical modelling*	**Marco-Peretó, C.** | *Morphological evolution of embayed beaches with different morphometric and sedimentary characteristics*
14:00 – 14:15	**Tsampouraki-Kraounaki, K.** | *Seafloor morphology, offshore faulting and implications for submarine landslides in the Aegean*	**Rizzo, A.** | *Sea level rise inundation scenarios and related risk along the north-eastern coast of Gozo (Maltese Islands)*
14:15 – 14:30	**Manta, K.** | *Marine geophysical & sedimentological data reveal multiple submarine landslides triggered by the July 1956 Amorgos earthquake in the South Aegean Sea, Greece*	**Durán, R.** | *Sorted bedforms dominated by coarse-grained sediment in the Mediterranean Sea*
14:30 – 14:45	**Schulten, I.** | *Morphological reconstruction of the 1908 Messina Gravity Flow – a case study on sediment gravity flows in the western Ionian Basin, offshore Eastern Sicily*	**Andersen, M.S.** | *Classifying coastal morphology using full coverage high resolution topo-bathymetric lidar*
14:45 – 15:00	**Klein, E.** | *From Summit to Seafloor – a shoreline-crossing quantitative DEM analysis on volcanic flank instability*	**Augustin, N.** | *Volcanic activity in the sediment-covered areas of the Red Sea Rift*
15:00 – 15:30	***Break | Posters***	

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TUESDAY 5 JULY *(Continued)*

	SESSION 15: Volcanic	SESSION 16: Applied
15:30 – 17:00	Aula Magna, UM Valletta Campus **CHAIRS:** Krastel, Muhedeen	Lecture Room 103, UM Valletta Campus **CHAIRS:** Savini, Lipparini
15:30 – 15:45	**Urlaub, M. (invited)** | *State of the art in the study of volcanic flank collapses*	**Mills, A. (invited)** | *Terrain and geomorphological mapping in the characterisation of submarine ground conditions and geohazards*
15:45 – 16:00	**Pandolpho, B.T.** | *Surface indicators for vertical movements offshore Mount Etna, Eastern Sicily*	**Chiocci, F.** | *Geohazard assessment through bathy-morphological interpretation*
16:00 – 16:15	**León, R.** | *Geomorphological signs of a volcano-tectonic reactivation in the eastern canary basin from the Miocene to the Quaternary*	**Watson, S.J.** | *Anchoring by high-tonnage vessels: a global driver of seabed damage*
16:15 – 16:30	**Casalbore, D.** | *Rapid morphological changes in the subaerial-submarine Sciara del Fuoco slope at Stromboli volcano during the 2019–2020 eruptive crisis*	**Dove, D.** | *Multiple applications of seabed and shallow sub-surface characterisation in the North Sea: Offshore Wind, Carbon Capture and Storage (CCS), and Baseline Mapping*
16:30 – 16:45	**Preine, J.** | *How the interplay of magmatism, tectonics, and mass wasting shaped the morphology of the Christiana-Santorini-Kolumbo Volcanic field*	**Díaz Mendoza, G.A.** | *Distinguishing between anthropogenic and natural origin of morphosedimentary patterns in the southwestern Baltic Sea*
16:45 – 17:00	**Le Saout, M.** | *Seamount distribution along the Reykjanes ridge: Evidence of a complex underlying magmatic system*	**Ahaneku, C.V.** | *Late Miocene to Early Pleistocene mass transport deposits, Offshore Taranaki Basin: Implications for petroleum systems*

WEDNESDAY 6 JULY

09:00 – 10:30 — **SESSION 17**: Method

Aula Magna, UM Valletta Campus — **CHAIRS:** Duran, Hoffmann

09:00 – 09:15 — **Paull, C. K.** | *Maximizing the resolution of abyssal seafloor mapping for biological and geological change detection*

09:15 – 09:30 — **Lecours, V.** | *Evaluating changes in deep-sea morphological mapping of the northern Gulf of Mexico across thematic and spatial resolutions*

09:30 – 09:45 — **Warnke, F.** | *Towards high-resolution pseudo-3d imaging of seafloor pockmarks using dense echo-sounder profiles*

09:45 – 10:00 — **Niculita, M.** | *A geomorphometrical approach to submarine landform classification*

10:00 – 10:15 — **Arosio, R.** | *The first complete high-resolution geomorphological map of the Celtic Sea combining manual and automated mapping techniques*

10:15 – 10:30 — **Recouvreur, A.** | *Probability mapping for bedrock occurrence on the Irish Continental Margin: Applications for regional bedrock outcrop and habitat mapping*

10:30 – 11:00 — ***Break*** | ***Posters***

11:00 – 12:30 — **SESSION 18**

Aula Magna, UM Valletta Campus — **CHAIR:** Micallef

11:00 – 11:15 — **R3 Vox** | *Presentation by main sponsor*

11:15 – 11:30 — **Duran, R.** | *Nature's canvas: A collection of stunning submarine landforms*

11:30 – 12:30 — **Micallef, A., Gupta, S.** | *Future perspectives paper*

12:30 – 13:30 — ***Lunch***

13:30 – 15:00 — **SESSION 19**: Geomorphology Mapping Workshop

Aula Magna, UM Valletta Campus — **CHAIR:** Nanson

15:00 – 15:30 — ***Break***

15:30 – 17:00 — **SESSION 20**: Geomorphology Mapping Workshop

Aula Magna, UM Valletta Campus — **CHAIR:** Nanson

17:45 – 23:00 — ***Conference Party***

POSTERS

Gamberi, F. | *The role of seafloor geomorphology in the reconstruction of the Quaternary Evolution of the Italian territory: the METIQ project*

Rizzo, A. | *Sea-floor morphological characterization as a tool for orienting management actions in a highly contaminated coastal site: the case of Taranto (southern Italy)*

Esentia, I. | *Morphometric analysis of the northern Gulf of Cadiz continental slope.*

Adema, P.H. | *Synchronous turbidity current – contour current interaction: constraining sedimentary models with 3D velocity measurements in scaled laboratory experiments*

Novak, A. | *Sandwaves in the southern Gulf of Trieste: morphometry and granulometry*

Ribó, M. | *Kaikōura Canyon: Gravel waves, boulder-size sediments and erosional scours*

Arjona Camas, M. | *Trawling activities impact the sediment transport mechanisms along the Oreto submarine canyon (SW Mediterranean)*

Stewart, H.A. | *Submerged Landscapes Across European Seas*

Gay, A. | *The fossil pockmark of Beauvoisin (SE France) vs the modern pockmark of Regab (Lower Congo Basin) vs sandbox models: fluid seep activity and cyclicity*

Palomino, D. | *Uncovering the geomorphology of a large mud volcano-mud diapir complex and adjacent deep sea in the Gulf of Cádiz (NE Atlantic Ocean)*

Savini, A. | *Could the R/V Southern Ocean transits be an opportunity to collect seabed meaningful data? The experience from ISOBATA project*

Gamberi, F. | *Geomorphic elements of turbidite systems in rifted continental margins: turbidity currents and tectonic structures interaction in submarine landscape creation*

Maselli, V. | *Distribution, timing, and potential trigger mechanisms of submarine landslides in Pangnirtung Fiord, eastern Baffin Island, Nunavut*

Martínez-Loriente, S. | *Geomorphological expression of a transcurrent plate boundary: the lineament south strike-slip fault off SW Iberia*

Perea, H. | *Tectonic geomorphology along an active strike-slip fault: the Yusuf fault system (Alboran Sea; westernmost Mediterranean)*

Couvin, B. | *Establishing a unified classification of slow-moving subaqueous landslides by deformation style and morphological characteristics*

Sager, T. F. | *The seafloor morphology of submarine landslides – what can it tell us about landslide development?*

Presentation guidelines

A. ORAL PRESENTATIONS

The oral presentations should be prepared in Microsoft Powerpoint or .pdf formats and have a 16:9 aspect ratio. They should be a maximum of 12 minutes long to allow for 3 minutes of questions. A copy of the presentation file needs to be given to your session chair before the start of your session, ideally on a USB stick or external hard disk. The conference makes no copyright claims for any item presented in the conference and the authors are free to reuse as they please.

B. POSTER

Posters need to fit on boards that are 2.5 m high and 1 m wide. We suggest printing the posters using a portrait orientation and A0/A1 size.

C. REMOTE PARTICIPATION

Attendees who are participating remotely will be sent a Zoom link a few days before the conference. Those attendees who are participating remotely and have an oral presentation should send a video of their recorded presentation (i.e. slides + narration) to the email **seafloor2022@um.edu.mt** by the **30th June 2022** the latest. We will play the video during the conference and then the attendees can answer questions via zoom afterwards. Those attendees who are participating remotely and have a poster presentation should send their poster as a .pdf to the email **seafloor2022@um.edu.mt** by the **30th June 2022** the latest. The posters will be made available to all participants electronically via Google Docs.

Logistics

A. LOCATION

The conference will take place at the University of Malta's Valletta Campus, St Paul's Street, Valletta.

Google maps link:
https://goo.gl/maps/YccEskTnZoNzTGsYA

The venue is centrally located and within walking distance of many restaurants and bars.

B. CONFERENCE PARTY

The conference party on the evening of the 6th July 2022 will entail a boat trip to Comino that starts and finishes in Buġibba.

The plan is to leave Valletta by coach at 17:45 to go to Buġibba (meeting place will be communicated during the conference). The boat will depart Buġibba at 18:30 and return at 22:30. The coach will take us back to Valletta at around 23:00.

During the boat trip, and if the weather conditions are suitable, it will be possible to swim at Comino. Dinner will include a BBQ. Drinks can be purchased on board in cash.

We can only accommodate 80 people on board the boat. Places will be allocated via a first-come first-serve basis. Conference participants who would like to join should express their interest using this **form**.

C. TRANSPORT

Valletta is a small city and you can reach anywhere on foot.

You can move across Malta and Gozo via:

- **Public bus: publictransport.com.mt** – bus passes may be obtained from dispensing machines next to the bus station at the airport or from the main bus terminal in Valletta. Otherwise, it is possible to pay the driver directly with cash.
- **Taxis:** E-cabs (**ecabs.com.mt**), Bolt (**bolt.eu/en/cities/malta**)
- **Ferry:** Valletta to Sliema or Cospicua (**vallettaferryservices.com**)
- **Airport transfer: www.maltatransfer.com**

For both bus and taxis, be aware of congestion in the morning (7.30 – 8.30 a.m.) and afternoon (5.00 – 6.00 p.m.), and factor these into your travel time.

D. DRESS CODE & OTHER RECOMMENDATIONS

We would like to keep the conference very casual. Be aware that the venue is air conditioned but temperature outside will be warm (may reach ca. 40°C in case of a heat wave). In view of these high temperatures, we highly recommend using a hat and sunscreen (SPF 30 or higher) when spending lots of time outdoors. Drinking ample amounts of water is important; participants are encouraged to carry their own water as public faucets or drinking fountains are uncommon in Malta.

Conference organisers

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ABSTRACTS

List of Abstracts

Synchronous turbidity current – contour current interaction: constraining sedimentary models with 3D velocity measurements in scaled laboratory experiments

Adema P.H.[1], Eggenhuisen J.T.[1], Silva Jacinto R.[2], Miramontes E.[3,4]

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Sediments deposited on continental slopes record changes in climate through time, host communication cables and pipeline infrastructure, and are potential sinks for significant volumes of organic carbon and pollutants. Many aspects of these deposits remain enigmatic today because the processes involved in their formation are often not fully understood. Measurements and observations of deposit formation are scarce, and diagnostic criteria to link deposits to processes are not established. A particular process where this is the case is in turbidity current – contour current interaction. Turbidity current – contour current interaction often results in asymmetric channel formation. Opposing channel migration directions are interpreted for seemingly similar systems. Conceptual models attempt to explain channel migration in response to a contour current, but these models remain untested. We use scaled laboratory experiments to establish how turbidity currents and contour currents interact and how they shape slope sediments and morphologies. We will test four parameters that may affect the depositional architecture and channel migration direction: grain size (focusing on the finer fraction), asymmetry of the channels, timing of the interaction (synchronous vs asynchronous) and contour current intensity. 3D velocity profiles will be measured in combined turbidity current – contour current flow, and bathymetries and deposits will be scanned and sampled. Constructing a model for turbidity current – contour current interaction based on our experiments will allow for localization and quantification of sediment deposition and pollutants in deep marine systems. This may help policymakers make strategic decisions in terms of management of marine environments and conservation.

Keywords: Turbidity currents, contour currents, hybrid systems, continental slope deposition, scaled laboratory experiments, model testing

Geomorphological and sedimentological features of the Egadi Islands offshore (western Mediterranean)

Agate M.[1], Sulli A.[1], Lo Iacono C.[2], Lombardo C.[1], Chemello R.[1], Orrù P.[3]

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[3] Depart. of Chemical and Geological Sciences, University of Cagliari. SS 554 bivio per Sestu, Monserrato (CA), Italy

In this study, we reconstruct the morpho-sedimentary evolution of the Egadi Islands offshore (W Sicily, western Mediterranean Sea) during the last glacio-eustatic cycle (last 125 kyr BP), through an integrated analysis of bathymetric, seismo-acoustic and sedimentological data acquired during last three decades.

The Egadi continental shelf displays two distinct sectors, separated by a NNW trending linear incision, the Marettimo Valley, with depths ranging from 150 up to 600 m. On the shelf, an uneven marine abrasion surface is punctuated by scattered isolated relieves and upward concave breaks of slope, probably related to sea level still stands occurred during the last (post Last Glacial Maximum) marine transgression.

The islands coastline is characterized by bluffs and cliffs with abundant fallen boulders at the base of the slope, alternated to small isolated pocket beaches.

Acoustic data also display different large bedform fields: – 2D and 3D dunes and sorted bedforms have been detected around the islands up to 50 m depth; - mounded sediment drifts and related channel moats have also been observed along the Marettimo Valley.

The morpho-sedimentary evolution of the Egadi Islands offshore results mainly controlled by sea level variations, with drastic imprints on the paleo-landscape during the LGM subaerial exposure, and by recent hydrodynamic processes.

Keywords: Geomorphology, sedimentology, seafloor mapping, bedforms, sea level rise, Egadi Islands, W- Mediterranean

Late Miocene to Early Pleistocene mass transport deposits, offshore Taranaki Basin: implications for petroleum systems

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This study evaluates the architectural and sedimentological characteristics of three MTDs in the deep-water Taranaki Basin, New Zealand, using high-resolution 3D seismic reflection data and wireline logs. Based on their age and stratigraphic position, the three MTDs are MTD M-1, MTD PP-1, and MTD PP-3. Internally, the MTDs are characterised as chaotic, semi-transparent reflectors terminating laterally against coherent stratified packages of seismic facies interpreted as rafted blocks. The blocks are characterised by different degrees of deformation, which include faulted, tilted, and irregularly deformed blocks. The distance between the blocks and the degree of deformation suggests that the MTDs may not have travelled a great distance. Well-log analysis shows that MTD PP-1 contains two thick sandstone facies ranging from 47 m to 54 m, interbedded with two shale facies measuring 39 m to 70 m thick. MTD PP-1 can be classified as a sand-prone MTD and can serve as both reservoir and top seal for hydrocarbon. MTD PP-3 is composed of thick shale with a 6 m thick sand facies at the top and is considered to be an excellent top and lateral seal for fluid migration. Kinematic evidence provided by the basal shear surfaces of the MTDs and the block orientations suggests a northwest flow direction for MTDs M-1 and PP-1 and a westerly flow direction for MTD PP-3. We have demonstrated the importance of seismic and well-log analytical methods to analyse MTDs as stratigraphic components of hydrocarbon systems.

Keywords: Mass transport deposit, MTD, sedimentology, Taranaki Basin, basal shear surface

On the origin of glacial bedforms at the central part of Lake Ladoga, NW Russia

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Lake Ladoga (Russian Federation) is the biggest freshwater reservoir in Europe (area – 17765 km^2, mean depth – 47,7 m) located on the periphery of the Baltic Crystalline Shield. During the Quaternary it experienced several glaciations. Last of them occurred at the Weichselian stage (Marine Isotopic Stages 4–2, Valday stage in Russia). Signs of the Weichselian Glaciaton are traced at the bottom of the lake as ridges and mounds of various morphologies and configurations. Bathymetric and seismic data were used to investigate the genesis of these features. A digital bathymetric model (DBM) of the lake floor complied from nautical charts was used for analyzing the morphology and distribution of the ridges and mounds. DBM's spatial resolution is 500 m. Seismic profiles with different source frequencies (from 100 Hz to 2000 Hz) retrieved during several expeditions (2013–2015) were applied to study the internal structure of the ridges. Three types of features were recognized: 1) ice-proximal subaqueous fans accumulated at the grounding-line zone with sediments of intraglacial circuits; 2) moraine ridges composed by till of ablation and fan sediments; 3) composite ridges interpreted as glaciotectonized moraines. We suggest that sedimentation of these bedforms happened in proglacial subaquatic conditions during ice retreat and associated with high melted water discharge. The research was supported by the Ministry of Science and Higher Education of the Russian Federation (agreement No. 13.2251.21.0119).

Keywords: Lake Ladoga, Late Pleistocene, Weichselian glaciation, seismic profiling, digital bathymetric model, glacial bedforms

Dense water cascades as a geomorphic agent: New insights from a process-based numerical model

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Dense water cascades (DWC) are an important oceanographic process that occurs in certain polar and temperate margins when surface waters over the continental shelf become denser than surrounding water and eventually sink, overflowing the shelf edge and cascading downslope. This process generates a near-bottom gravity-driven turbulent flow that involves the massive transfer of energy and matter from shallow to deep waters. Observations show that DWC in temperate margins can rapidly reshape the seafloor, particularly in canyons. It has been suggested that DWC fluxes could also generate continental slope gullies in Polar Regions. In situ near-bottom velocities are comparable to those observed in turbidity currents, but suspended sediment concentrations are much lower. For this reason, DWC have been considered as inefficient pumps of sediment. However, the water volumes transported are exceptionally large, as they can last for days to weeks, or even months in polar areas. We advocate that this fact, together with the known large bedforms sculpted by DWC, are enough to modulate the former assumption. We tackle this question using a process-based depth-integrated numerical model initially developed for turbidity currents. It shows the importance of flow confinement by morphological features (i.e. coast capes, cross-shelf troughs, canyons and gullies) to concentrate and propagate the dense flows and brings new insights about their capacity to transport sediment and shape the seafloor.

Keywords: Dense water cascades, Geomorphology, Modelling, Hydrodynamics, Sedimentology, Morphodynamics

Classifying coastal morphology using full coverage high resolution topo-bathymetric lidar

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Knowledge about coastal seafloor landforms and processes are fundamental for sustainable management of the coastal environment. The collection and analysis of full coverage high resolution data is a key to gaining knowledge. However, it is difficult or even impossible to carry out this type of investigation in shallow coastal waters with traditional surveying techniques, such as airborne topographic lidar or vessel borne multibeam echosounder (MBES). In recent years, airborne topo-bathymetric (green wavelength) lidar has emerged as a new method for filling the gap of information in the near-coastal zone. In this study, we investigated the potential of classifying morphology in the coastal zone (<10 m water depth), and gaining knowledge about the coastal processes, using airborne topo-bathymetric lidar data. Lidar data were collected by Airborne Hydro Mapping GmbH (AHM) in two repeated surveys in 2019 (April and June) covering 50 km^2 on the coast next to Frederikshavn in Denmark. The data processing included several steps, e.g. refraction correction, strip adjustment, point cloud classification, and generation of a 0.5 m x 0.5 m digital elevation model from the processed point cloud. The study demonstrated that: 1) topo-bathymetric lidar can be used to fill the gap of information in the coastal zone, 2) detailed classification of coastal morphological features can be derived from the lidar data, and 3) we can use the data to gain knowledge on the coastal processes at multiple scales.

Keywords: Topo-bathymetric lidar, coastal morphology, coastal processes, shallow bathymetry, digital elevation model, GIS, classification

Morphological expression of fluid expulsion offshore Crotone (Calabrian accretionary prism)

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Fluid expulsion and sediment mobilization are typical processes in accretionary prisms, where sediments are scraped off the subducting plate and piled up and squeezed to originate a tectonic prism. Mud volcanoes are known to populate the inner Calabrian accretionary prism, though only few of them have been extensively documented, and their number is likely largely underestimated. The Ionian offshore of the Crotone promontory offers examples where the expressions of fluid seepage and sediment mobilization are visible both in the subsurface and at the seafloor. The analysis of seafloor morphology at variable spatial resolution and public domain and proprietary multichannel seismic data, including 3D seismic cubes, allows to characterize systems of mud diapirs, both active and fossil, and their relationships with trains of pockmarks. Mud pools and pockmarks are direct expression at the seafloor of fluid expulsion but in some instances they also contribute to destabilize the uppermost sedimentary strata, triggering small and thin-skinned landslides. The recognition of a fossil mud diapir-mud pool system, sealed by undeformed sedimentary strata, allows constraining a minimum age range of fluid and sediment mobilization.

Keywords: Calabrian accretionary prism, sediment mobilization, mud diapirs, mud pools, pockmarks, submarine landslides

Trawling activities impact the sediment transport mechanisms along the Oreto submarine canyon (SW Mediterranean)

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There is increasing evidence that bottom trawling within and around submarine canyons can alter their natural sedimentary dynamics. This anthropogenic activity can resuspend bottom sediments and favor their transference from fishing grounds towards deeper regions, forming nepheloid layers with high concentrations of particulate matter at different water depths. However, studies addressing this topic are still scarce and mainly devoted to the NW Mediterranean. In the Gulf of Palermo (SW Mediterranean), bottom trawling occurs on the outer shelf and on the upper continental slope, but mainly concentrates within the Oreto Canyon. The temporal evolution of the sediment transport in the lower part of the Oreto Canyon was assessed by analyzing 5 months of moored turbidity and currentmeter data, from July 2016 to January 2017. This study was carried out as part of the EU-FP7 Eurofleets-2 ISLAND research cruise that aimed to explore Sicilian canyon morphologies, benthic habitats, and sedimentary dynamics in relation with trawling activities. Time-series analyses, combined with hydrographic data collected along the Oreto canyon axis, revealed the presence of nepheloid layers coinciding with periods of higher fishing activity within the canyon. In contrast, very low turbidity values were recorded in the hydrographic profiles collected along the nearby Eleuterio Canyon, mainly because trawling activities are not practiced within this canyon due to its rough geomorphology. Considering the global widespread of bottom trawling, similar alterations of the contemporary sediment transport mechanisms could be expected in other trawled canyons elsewhere, alongside with the ecological consequences that may arise from this human activity.

Keywords: Bottom trawling; turbidity; nepheloid layers; sedimentary dynamics; submarine canyons, Gulf of Palermo; SW Mediterranean

The first complete high-resolution geomorphological map of the Celtic Sea combining manual and automated mapping techniques

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The Celtic Sea, situated off the south coast of Ireland is characterised by a gently southwest-sloping palaeo-glaciated seabed superimposed by a network of Holocene bedforms. During the Last Glacial Maximum (~27 ka BP) the region was occupied by the Irish Sea Ice Stream, which has left an intricate pattern of subglacial meltwater channels and moraines. Late glacial tidal action has moreover generated large tidal ridges whose formation has attracted much interest in recent years. While the region has received some attention in the past, no complete geomorphological map of the Celtic Sea had been produced to date.

The NOMANS_TIF project, relying on the extensive Irish INFOMAR datasets, aims to produce the most detailed and comprehensive geomorphological map of the Irish continental shelf. The outcome of NOMANS_TIF has the potential to benefit policy makers and industry as well as raising awareness of the marine environment to the tax payer.

As a part of NOMANS_TIF, we present the first complete geomorphological map of the Irish sector of the Celtic Sea. A series of techniques, manual and automated, have been applied with the aim of testing their efficacy and utilising their strengths in delineating particular but subtle seabed characteristics. We find that the use of non-linear filters assisted by expert cognitive mapping is particularly effective to quickly delineate and interpret single landforms. Fully convolutional neural networks are a powerful tool with a regional and morphology-based mapping scope, but strongly depend on correct labelling and are unable to discriminate unknown classes.

Volcanic activity in the sediment-covered areas of the Red Sea Rift

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The Red Sea is a comparably young ocean basin filled with Miocene salt and Plio-Pleistocene and Holocene sediments. Spreading rates increase from North to South from <10mm/yr to 16mm/yr. Accordingly, the Red Sea Rift is an ultra-slow spreading rift. The spreading center of the Red Sea is not entirely exposed along the whole rift basin but instead buried in large proportions by glacier-like salt flows and overlying sediments. The windows to the underlying oceanic crust through this salt and sediment become sparse towards the northern Red Sea, where the oceanic crust is almost entirely blanketed. As the salt and sediment blankets also influence the appearance and interpretation of geophysical data, and coverage of high-resolution bathymetric data has also been insufficient, these areas were formerly interpreted as faulted, thinned continental crust and with only limited traces of (rift-related) volcanism from magnetic data. Direct observation of the mid-ocean ridge and its neovolcanic zone in the blanketed areas is impossible for obvious reasons. We will present our latest high-resolution bathymetric data and multibeam backscatter mosaics that show indications for volcanic activity in the sediment-covered areas of the Red Sea Rift. Furthermore, we will show sparker seismic data that support the interpretation of the bathymetric features and indicate the continuation of the oceanic basement under the salt and sediment blankets.

Investigating the origin, frequency, and extent of submarine mass wasting processes in the Aegir Ridge, offshore Norway

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Submarine landslides can have devastating effects on seafloor and coastal infrastructure and ecology, and can result in potentially destructive tsunami waves. In spite of this, many questions regarding their frequency, preconditioning and triggering factors remain unanswered. The Aegir Ridge, an extinct spreading ridge in the Norway Basin offshore southwest Norway, acts as a sedimentary sink; collecting hemipelagic sediments as well as sediments transported by mass wasting processes from along the Norwegian continental margin. Here, we present the preliminary results of the analysis of a suite of sediment gravity cores and hydroacoustic data collected from a small basin just north of the Aegir Ridge by RV Maria S. Merian in early 2021. These data reveal a series of at least eight distinct, acoustically-transparent mega-turbidite units within the upper 40 m of the basin; four of which are recovered in the new sediment gravity cores. Radiocarbon dating and biostratigraphy, together with chemical (XRF) and geophysical (gamma density, velocity and magnetic susceptibility) analysis of the recovered sediments, enable us to constrain the timing and origin of the turbidite deposits within the basin. This, in turn, enables us to investigate the extent and frequency of these mass wasting processes, and consider their ultimate hazard potential.

Keywords: Aegir Ridge; Norwegian continental margin; submarine mass wasting; turbidites; sediment gravity cores

Drowned landscapes and reefs and their relation to last postglacial meltwater pulses

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The last deglaciation is marked by changes in rates of sea-level rise, leading to the formation and drowning of paleolandscapes and reefs. The occurrence of distinct types of drowned coastal morphologies and reefs have been mapped along the eastern Brazilian shelf using multibeam and high-resolution seismic. The study was conducted along the Espirito Santo and Abrolhos Shelf. The submarine features mapped are shelf-incised valleys, paleocoastlines, paleolagoon and drowned reefs. Shelf-incised valleys were mapped from 45m to the shelf break (70m), where they converge forming an elongated coastal embayment, with a paleoshoreline around 60m deep. Submerged reefs were mapped at 55–60m (shelf-break parallel elongated reefs), 28–32m (tabular, low-relief reefs) and 14–25m (pinnacles) water depth. The formations of these features are related to changes in rates of sea-level rise during the last deglaciation. The paleocoastline, paleolagoon and shelf-break parallel reef, established at 55–60m deep, represent a sea-level slowstand during the Younger Dryas. The preservation of these paleolandscapes is associated with an acceleration in rates of sea-level rise, indicative of the influence of MWP-1B. The formation of a series of shallow drowned reefs can be related to a stillstand prior to MWP-1C or the 8,2k event. The results sustain that submerged paleolandscapes and drowned reefs are records of changes in sea-level rates, and the potential preservation of these features is related to stillstands preceding MWP. The 60m isobath seems to represent a common pre-MWP-1B paleoshoreline in the southern hemisphere. Moreover, these features also form distinct benthic habitats and potential targets for archaeological sites.

Keywords: Paleoshoreline, Shelf-incised Valley, Drowned Reefs, Meltwater Pulse, Sea-Level Changes, Deglaciation, Submerged Landscape

Submarine glacial geomorphology: new insights into past ice behaviour and glacial sedimentation from high-resolution bathymetric data

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Glacial landforms preserved on the seafloor of mid- and high-latitude continental margins provide important information about the configuration and dynamics of ice sheets following the Last Glacial Maximum, about 20,000 years ago. Knowledge of past ice-sheet behaviour is needed to understand and model how climatic changes are translated into ice-sheet fluctuations, and how sediment and meltwater are transferred beneath present-day ice sheets. In this presentation, I will describe the current state-of-the-art in submarine glacial geomorphology, drawing on recent examples from my research on the eastern Antarctic Peninsula and mid-Norwegian margins. I will show how recently acquired high-resolution bathymetric data, including from Autonomous Underwater Vehicles, allow for the identification of subtle morphological features. These features include tidal ridges that are interpreted to form both along the ice-sheet grounding line by vertical motion of the grounding line during tidal cycles, and by the tidally driven motion of near-grounded icebergs. The interpretation of these subdued landforms enables new insights into past ice dynamics and glacial sedimentation at fine temporal and spatial scales.

Keywords: Glacial landforms; Bathymetry; Autonomous Underwater Vehicles; Grounding-zone wedges; Iceberg ploughmarks; Antarctic Peninsula; Mid-Norwegian margin

A journey through the buried landscapes shaped by the Fennoscandian Ice Sheet

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2D reflection seismic profiles and sediment cores have previously been the most common data types to interpret the shallow subsurface in the marine realm. 3D reflection seismic data have given birth to the discipline of seismic geomorphology, and allow studying ancient, buried geomorphological surfaces. Here I show the huge variety of buried landform assemblages shaped by the Fennoscandian Ice Sheet that were mapped out on recently collected high-resolution 3D reflection seismic data with a vertical resolution as high as 1 m and a lateral resolution of up 3 m. Paleo-landscapes and their association with the subsurface can thus be studied on a meter-scale resolution, which is comparable to conventional bathymetric technologies. The landforms identified in the shallow subsurface of the paleo-shelves (10s to 100s of meters below seafloor) consist of landforms indicative of subglacial erosion related to an active Fennoscandian Ice Sheet, such as glacial lineations, hill-hole pairs and rhombohedral ridges. Glacio-tectonic deformation is reported down to 30 m below the paleo-surfaces. Landforms representative for the disintegration of the ice sheet include iceberg ploughmarks and corrugation ridges. At a paleo-surface of the SW Barents Sea, a large canyon, the Bjørnelva Valley, is formed by a glacial lake outburst flood. Trough mouth fans are glacial depocenters recording the glacio-erosive products from the shelf, reaching thicknesses of several kilometres. Imaging the subsurface of both the Bear Island Fan and the North Sea Fan indicate that megaslides, glacigenic debris flows, turbidites, and contourites were active at different time periods in the Pleistocene.

Geomorphology of the Celtic sea (North Atlantic) from shallow to deep water and its link with the evolution of the British-Irish ice sheet

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During the Pleistocene, the British-Irish Ice Sheet (BIIS) extended over Britain and Ireland and at times onto the adjoining continental shelf as far as the shelf edge, along the NE Atlantic continental margin. At several times in the past, the entire western margin of the BIIS was marine-terminating, drained by radiating ice streams, including one occupying the Celtic Sea and would have been sensitive to both climatic and oceanic forcing. This makes it an ideal analogue for how marine-based ice sheets, such as West Antarctic Ice Sheet, currently deglaciate. The last two decades have seen major advances in the reconstruction of the BIIS through offshore glacial geomorphological mapping and an increased focus on offshore sedimentary and geophysical records, which can give insights into the nature and dynamics of the former ice sheet in this region. In particular, the extensive hydrographic and geophysical mapping carried out by the INSS and INFOMAR programs in Ireland has enabled a detailed analysis of the glacial and glacially-related geomorphology of the continental margin. This talk will present the results of the newly mapped seabed geomorphology of the Celtic Sea in the North Atlantic from shallow to deep water and explore the impact of the growth and decay of the BIIS on the submarine landscape. This work feeds into the objectives of the new consortium for research in the Celtic Sea: SPICES (Source-to-sink sedimentary Processes In and from the CEltic Sea).

Keywords: Glaciations, British-Irish Ice Sheet, Celtic Sea, geomorphology, tunnel valleys, iceberg scours, canyons

Where and Why Do Submarine Canyons Develop? Insights from Topographic Analysis, Bayesian Regression and Point Pattern Analysis

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Submarine canyons play a fundamental role in land-to-ocean transport of sediment, pollutants and organic carbon. Moreover, canyons that are connected to terrestrial sediment sources are especially efficient in material routing. We aim to identify the main controls on ***(1)*** submarine canyon occurrence along continental margins and on ***(2)*** whether a canyon head remains connected to terrestrial sediment input during sea-level rise. ***(1)*** We assess the first problem by employing spatial point-pattern analyses and stepwise regression using 8 marine predictor variables and 10 terrestrial predictors from adjacent river catchments. Along the continental slope of South America, preliminary results show that we can predict the general pattern of canyon occurrence along the South American margin. Stepwise regression reveals that submarine canyons occur preferentially along margins with high continental slope gradients, narrow shelves and decreased sediment thickness. Moreover, high canyon occurrence arises offshore catchments with high water discharge, resistant bedrock and decreased river-channel steepness and seismic activity. ***(2)*** Globally, we identified the main controls on canyon-to-shore connectivity using Bayesian penalized regression. Shore-connected canyons preferentially occur along narrow and steep shelves. Moreover, our analysis supports the occurrence of shore-connected canyons offshore river basins with resistant bedrock and high discharge. Our findings indicate that seafloor topography -with steep continental slopes and narrow shelves- preconditions high canyon occurrence in general and canyon-to-shore connection. However, canyons do not develop preferentially along margins with high onshore relief. However, rivers that drain resistant bedrock with high water discharges deliver coarse-grained sediment continental margins, which erodes canyon heads and floors.

Keywords: submarine canyon, topographic analyses, spatial point patterns, Bayesian regression, continental slope, seascape evolution

Sediment distribution control by internal waves and bottom currents in Mediterranean mesophotic peri-reefal environments

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The Central Mediterranean Maltase Platform hosted carbonate production dominated by coralline algae since at least the Oligocene. Through this period a wide range of parameters has changed and as such it offers a unique location to examine how the light dominated coralline algae carbonate factory had responded to these changes.

The Maltase Platform hosts three main units of coralline algae deposits: the middle to late Oligocene Lower Coralline Limestone (LCL), the late Miocene Upper Coralline Limestone (UCL) and the Pleistocene-Holocene corallines offshore. The Pleistocene-Holocene deposits are characterized by coralline sand, rhodolith and mounds. Both the rhodoliths and mounds occur in mesophotic depths. Coralline sand on the other hand can be found in nearly all locations and water depths. With the exception of special localities, these accumulations are only a few meters in thickness with minimal accumulations on shores or near shore. The UCL deposits are characterized by massive bioherms, consisting of crustose corallines and/or coralline sands. These accumulations are several meters to tens of meters (offshore). The coralline sands are building large prograding clinoform bodies as well as deposits of cross bedded deposits to intertidal depth. The UCL bioherms are align along a SE-NW line on the south of the platform with the clinoforms extending from them. The LCL deposits are characterized by several tens of meter large platforms. These deposits form large clinoform bodies which exhibit progradation, aggradation and in some cases degradation. Multiple small platforms are distributed across the platform with handover of production and export between one platform to the other observed in some locations. Corals are not common but present in all three units, both the UCL and the LCL host intervals of tropical corals while the Pleistocene-Holocene hosts only rare Mediterranean corals.

The change in the oceanographic state in the Central Mediterranean had diminished the production intensity of the light dominated coralline algae carbonate factory in this region since the Oligocene. Accumulation to accommodation space do not occur in the Pleistocene-Holocene and most of the production is limited to the mesophotic depth. The changes from the late Oligocene to the late Miocene resulted in less active production within this factory at that time. Water temperature, currents and nutrient states are likely parameters governing this change with ongoing global cooling and restriction of the Mediterranean through this period.

Laboratory modelling approach of gravity-driven sliding along complex submarine slopes: application to the west offshore Martinique Island (Lesser Antilles)

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Submarine mass-movements of sediments are common processes in the vicinity of volcanic islands. In the Lesser Antilles arc, Montagne Pelée volcano on Martinique Island suffered from several flank-collapses events during its eruptive history, resulting in debris avalanches. In entering seawater, debris avalanches emplaced over the unstable slope of the volcano, triggering seafloor sediment failure and massive landslides downstream. Using a laboratory modeling approach, we have simulated the gravity-driven sliding of a sand layer laying above a silicone layer. Experiments were performed using various slope geometries (slope lengths and number of slope breaks separating slopes with different angles), under both dry and aqueous conditions, and in varying the amount of additional sand inputs. The resulting deformations were characterized in each experiment in order to compare the obtained structures with those shown by seismic lines offshore Martinique Island. During all the experiments, a compressive frontal deformation zone made of several reverse faults formed downstream, often near the slope breaks. Downstream, a portion of sediments was mostly translated and poorly deformed in a damping zone, while an extensional deformation zone formed upstream. Our study demonstrates that slope geometry and additional sand inputs primarily promote and increase sliding deformation, while the hydrostatic pressure plays a secondary catalytic role over time. These results provide new constrains on driving factors and their consequences on gravity-driven sliding in terms of deformations and runout distance over time. This can drastically impact the hazard assessment related to offshore infrastructures, in a region known for its seismic and volcanic risks.

Keywords: Laboratory experiments; Submarine slope offshore Martinique Island; Gravity-driven sliding deformation; Morphological front; Slope geometry; Hydrostatic pressure; Sediment inputs

Geomorphology and evolution of the Blanes canyon (NW Mediterranean). New insights from high resolution mapping of vertical cliffs

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This work presents the geomorphologic characterization of the Blanes Canyon (northwestern Mediterranean), based on high- and very-high resolution multibeam bathymetry acquired in the framework of the ABRIC project. High-resolution hull-mounted multibeam data (up to 5 m grid size) were collected along the entire submarine canyon head using a Kongsberg EM710 multibeam echo sounder (MBES). Additionally, the Hybrid Remotely Operated Vehicle (H-ROV) "Ariane" was used to acquire fine-scale morphology of vertical rocky walls within the canyon with unprecedented detail (80 cm grid size). The vertical mapping was performed using an EM2040 MBES mounted on the front of the H-ROV with a 45° orientation. High-resolution video footage was acquired on the same canyon walls with the ROV "Liropus". Blanes Canyon has a marked structural character, deeply incising the margin and exposing Miocene to Pliocene successions. The tectonic control is evidenced by the rectilinear trajectories and sharp bends of the canyon axis, and by the presence of vertical rocky walls that can reach up 300 m in height. The canyon is asymmetric and has a smoothed eastern flank and a western flank dominated by a dendritic lattice of gullies. H-ROV bathymetric data on vertical cliffs allowed to trace the horizontal strata of Miocene ages, which offer the substrate for the development of benthic communities. Other identified fine-scale morphological elements include terraces, thalweg incision, under-cutting, scarps and rock avalanches. The study of the different-scale morphologies found in the canyon will allow a better understanding of its evolution trough time and the erosive processes involved.

Keywords: Submarine Canyons, Vertical Rocky Walls, Very-high Resolution Multibeam Bathymetry, Remotely Operated Vehicle (ROV), Hybrid ROV Ariane, Blanes Canyon, NW Mediterranean

Accurate seafloor morphology with quantitative relief-processing methods: the growing transtensional north-south fault system (Alboran Sea, Western Mediterranean)

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Active fault systems accommodating relatively slow deformation still produce moderate to large magnitude earthquakes, such as those in the Alboran Sea, a Neogene basin that absorbs most of the convergence between the Eurasian and Nubian plates (4–5 mm/year) in the westernmost Mediterranean Sea (i.e., the Almeria 1522 IEMS98 VIII-IX or the Al-Idrissi 2016 Mw 6.4 earthquakes). Accurate characterisations of how fault segments grow and connect are crucial to better understand tectonic regional processes in this and other regions with slow deformation. We characterise the North-South fault system, which currently evolves due to the transtensional stress field in the northern Alboran Sea, by means of new geomorphologic analyses grounded on quantitative relief-processing methods applied over ultra-high-resolution data acquired by AUV. We modify the Red Relief Image Maps (RRIM, Chiba et al., 2008) with our own new, specific visualisation approach, Red-Blue Relief. This method displays relief accurately and without lighting bias and presents multiscale capabilities that allows coupling with seismic data at adequate scale. As a result, we identify several seafloor morphologies as scarps, pockmarks, horst, and grabens better than previous efforts. Combining the seafloor morphology analyses with high-resolution seismic profiles across the study area, we related morphologic scarps to different normal faults. Concluding, the high segmentation of the N-S fault system and its small cumulative fault displacements suggest that this is an active system presently growing.

Keywords: Seafloor morphology, Red-Blue relief maps, Alboran Sea, fault growth, transtensional fault system

3D Seismic Characterisation of a Glacigenic Basin Floor Fan System Offshore West of Shetland

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This study presents a 3D seismic reflection data attribute analysis of the southernmost part of a glacigenic basin fan system, in water depths greater than 1010m within the Faroes Shetland Channel. These deposits lie at the end of a downslope gully system associated with the Foula wedge offshore West of Shetland. The latter represents a Pleistocene trough mouth fan. Both basin fan and gully systems are preserved at the present-day seafloor. Although the seafloor morphology of the area has been extensively described in literature the basin fan system subsurface architecture is less understood. This study reveals, in unprecedented detail, its basal surface. The seismic geomorphology mapping shows a basin channel network with linear diverging erosional features forming distinctive terminal lobes, stacked and backstepping events with features characteristic of both debris flows and turbidites implying a more complex basin depositional structure than previously thought. Integration of new evidence with the regional bathymetry indicates that the main distributary channels developed from two of the downslope gullies, suggesting that high energy flows initially remained partially confined across the basin area. Results at the local scale offers new insights on different mechanisms of sediment delivery processes which have affected the development of the basin fans. Consequently, the outcomes contribute to a better understanding of the large-scale effects on the associated Foula wedge, such as influence of meltwater pulses in response to paleo-morphology, substrate and unusual ice-sheet dynamics.

Keywords: Seismic geomorphology, deep-water sedimentary processes, glacigenic basin deposits, West of Shetland

Rapid morphological changes in the subaerial-submarine Sciara del Fuoco slope at Stromboli volcano during the 2019–2020 eruptive crisis

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Stromboli is a very active insular volcano located in the Southern Tyrrhenian Sea, whose NW flank was affected by multiple flank collapses in the last 13 ka. The last of them left a collapse scar that has been partially filled by the products of subsequent eruptive activity, resulting in the present-day Sciara del Fuoco slope. During the July 2019-April 2020 period, Stromboli was characterized by intense eruptive activity, with two paroxysmal explosions that triggered pyroclastic density currents along the Sciara del Fuoco slope, a two-month-long lava emission, and more intense and frequent "ordinary" explosive activity. All these phenomena produced significant changes within the Sciara del Fuoco slope, which represents the most unstable flank of the volcano. In this work, we document the morphological evolution of the Sciara del Fuoco slope during that period by integrating topographic (PLÉIADES satellite tri-stereo Digital Elevation Models) and multibeam bathymetric data, acquired before, during, and after the paroxysmal events. More generally, the results of this study highlight the need to collect repeated topographic and bathymetric data close in time for the detailed characterization of the different phases of accumulation/emplacement, erosion, remobilization and re-sedimentation of the volcaniclastic materials along the subaerial and submarine slope of an active volcano during eruptive crisis.

Keywords: multibeam, Stromboli, slope failure, pyroclastic flow, volcano geomorphology, Digital Elevation Models

Geohazard assessment through bathy-morphological interpretation

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Morpho-bathymetry is the main tool for detection and full coverage mapping of features of interest at sea, such as mass wasting, tectonic elements, benthic habitats, fluid escape, archeological structures, volcanic vents or bedforms. Despite a ground-truthing by bottom sampling, coring or ROV inspections is required to fully characterize these features and avoid misinterpretation, for first order assessment of a given phenomenon, the extensive mapping is crucial and often the only viable tool for vast areas. We describe the experience gained in geohazard assessment based on morpho-bathymetric data in Stromboli, Pantelleria and Etna volcanoes, Gioia and Cirò canyon heads and within the Italian Project Magic (Marine Geohazard along the Italian Coasts), funded by the Italian Civil Protection and involved the whole community of Italian Marine Geology (eleven universities and research centers). The aim was to identify, classify and map geohazard features on the seafloor that may represent hazards for coastal communities and marine infrastructures. The use of a common standard for interpretation and cartographic representation of features along most of the Italian Coasts in the depth range 50–1,000m, was mainly based on morpho-bathymetric interpretation. The integration with previously collected data and background knowledge was guaranteed by assigning to the different research groups study areas where they have been working extensively in the past. In detail, some 60,000 km of multibeam lines were interpreted to produce 72 geomorphological maps at the scale of 1:50,000, which were mapped using four hierarchical levels of interpretation (physiographic domains, morphological units, morphobathymetric elements, and critical points).

Keywords: Seafloor morphology, Swath-bathymetry mapping, Marine cartography, MaGIC project

Modern sedimentary processes and recent development and evolution of two shelf-incising submarine canyons in the Alboran Sea, western Mediterranean

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We characterize the recent sedimentary processes and the evolution of two closely-spaced shelf-indenting submarine canyons (Motril and Carchuna) in the northern margin of the Alboran Sea. The Carchuna Canyon is deeply incised on a 2.1 km wide shelf just 200 m off the coastline. It is narrow (2 km), straight and has a maximum incision of 226 m. The canyon walls are steep and exhibit elongated narrow terraces. Muddy sands prevail along the thalweg, with interbedded fine to medium sands. In contrast, the Motril Canyon head is wider (4.3 km) and incises the shelf edge at 100 m water depth. On the slope, the canyon exhibits a sinuous morphology, it is 1 km wide and it is incised up to 179 m. Its walls are gentler and its terraces are wider. Sediments on the canyon floor are mainly muds.

The geomorphological and sedimentary differences between both canyons suggest that they have played different roles in the recent sedimentary patterns. The higher sinuosity of Motril Canyon and the draping veneer of muddy sediments indicates the prevalence of low-energy depositional processes. Its wide terraces are interpreted as the remains of meandering channels in the recent past. In contrast, the Carchuna Canyon is an active system that is undergoing vertical and lateral erosion; the terraces are interpreted as evidence of multiple events of axial incision. Its proximity to the coastline favours the capture of littoral drift sediments that are redeposited in deeper waters, as revealed by the significant incision and the interbedded sands.

Keywords: Submarine canyons, Recent processes, Evolution, Sediment cores, ROV, Parasound, Alboran Sea

Establishing a unified classification of slow-moving subaqueous landslides by deformation style and morphological characteristics

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Slow-moving subaqueous landslides (SMSL) have been recognised from seafloor bathymetric and seismic data, originally based on common characteristics they bear with slow-moving subaerial landslides. Since the first subaqueous identification in 1982, many morphological characteristics have been considered appropriate SMSL identification tools. Despite the growing number of studies on the subject, a classification for SMSL has not yet been established. Such a classification scheme would be useful given that many SMSL studies use the same process nomenclature for very different processes and products. In this study, a process-based classification scheme is proposed based on a review of the published literature including over 30 studies from the past 40 years. At least four distinct SMSL deformation styles are inferred from their morphological characteristics and geometrical relationships in bathymetry and seismic data (2D and 3D): creep, lateral spreading, slow flank slumping and slow mudflow. Each of them is defined from a combination of characteristics, including in particular: internal block character (shape, distribution and relative position, side alignment), lateral variations in seismic facies, fault geometry and transport direction. Different SMSL types can coexist in similar depositional environments. However, SMSL types are not considered end members of a spectrum and do not appear to evolve into one another. Instead, we find that each deformation style has its own evolutionary spectrum of deposit characteristics as related to the intensity and development of deformation.

Keywords: Slow-moving, subaqueous landslides, submarine, creep, lateral spreading, slump, classification

Characterizing the seascape of the Southern Brazilian continental shelf benthic layer using environmental data

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Benthic habitat modelling based on abiotic surrogates has been widely used to represent continuous seascapes for large areas, although it still poses significant challenges due to the complex set of habitats that shift across multiple spatial and temporal scales. In Europe, the EUNIS classification scheme relies on a robust database on several environmental variables and, although proved to be efficient, it is still unclear whether it can be efficiently applied in sectors where in situ data remain scarce. Here, a combination of multiscale open-source datasets was used to build a benthic habitat model for the "South Brazil Shelf" Large Marine Ecosystem (LME), adopting EUNIS classification. Euphotic zone depth and bathymetry were combined to define the infralittoral zone, and mean wave period and bathymetry used to express energy incidence over the sea bottom to differentiate circalittoral biological zones. Sediment types were then integrated to build the benthic habitat model. Results show significant differences between two ecoregions within the LME: Southeastern Brazil (SB) and Rio Grande (RG). A high concentration of muddy habitats was identified in the RG, whereas gravelly and mixed sediment habitat types prevailed in the SB. Also, the infralittoral zone in RG is concentrated near a single geomorphic feature while large circalittoral patches occur in the north of SB. The proposed framework aims at contributing to the standardization of habitat classifications and demonstrates that EUNIS is a comprehensive benthic layer classification scheme. This is essential to support further development of ecological models in the scope of Marine Spatial Planning.

Keywords: Brazil, habitat mapping, marine substrate, continental margin, classification model, spatial analysis, GIS

Multiple applications of seabed and shallow sub-surface characterisation in the North Sea: Offshore Wind, Carbon Capture and Storage (CCS), and Baseline Mapping

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The outer Humber/Wash region is perhaps the busiest sector of the UK offshore, where several resource development activities (e.g. fisheries, Oil&Gas, offshore wind, aggregate extraction) occur within a relatively small area (that also includes protected habitats). Here we present on how separate efforts to understand ground conditions (and constraints) for offshore wind and potential CCS development are requiring detailed and accurate seabed and sub-surface characterisation. Similarly, and not coincidentally, the BGS is also undertaking seabed mapping in the region. This talk aims to demonstrate how working concurrently on these three projects brings added value to each, with observations/insights gained in one, becoming applicable to the others. One common theme is that effectively characterising features requires a good understanding on environmental origin and evolution. Relevant here are diverse tectonic, glacial, marine, and coastal processes. These projects follow a familiar pattern of former advances established over many years, with new high-resolution data providing improved understanding for broader environmental phenomena. Conversely though, regional-scale context and interdisciplinary information are also frequently beneficial for describing small-scale and ambiguous features in the new data. The wind project involves developing a refined model of shallow 3D architecture based on extensive seismic and geotechnical data, in order to identify relatively suitability for installation (limiting risk and cost). The CCS project aims to identify environmental/geological constraints on potential CCS activities and monitoring. The BGS seabed mapping will result in a series of high-resolution map products, intended as enabling resources to better inform multiple offshore activities and marine management.

Keywords: seabed mapping, seabed geomorphology, seismic stratigraphy, geological constraints, offshore renewables, carbon capture and storage

Sorted bedforms dominated by coarse-grained sediment in the Mediterranean Sea

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Sorted bedforms have been widely described in sediment-starved continental shelves. They have been defined as sedimentary features consisting of isolated slight topographic depressions (commonly <1m) composed of coarse sediment within a larger region of finer sediment. However, recent observations revealed an unusual sorted bedform pattern that is dominated by coarse-grained sediment with patches of finer sediment. Repeated geophysical and geological surveys involving swath bathymetry and backscatter mapping, side scan sonar, grab sampling and sediment cores were used to characterise this particular pattern of sorted bedforms observed at three study sites in the Western Mediterranean: The Catalan, Marettino and Malta continental shelves. Swath data revealed complex sorted bedforms patterns at water depths of 10–60 m, characterised by a subtle relief (<0.4 m) and elongated and irregular shapes in plan view. Sediment characteristics varies significantly among the three study sites. Sorted bedforms on the Catalan continental shelf are composed of siliciclastic fine sands lying over a coarse sandy layer, whereas the sorted bedforms on the Malta and Marettino continental shelves are composed of bioclastic fine and medium sand overlying a coarser sediment layer (very coarse sand and gravel). Although the sorted bedforms show variable morphology and textural characteristics among the three study sites, they exhibit similar dynamics. Repeated surveys revealed that primary sorted bedform morphology was largely stable over a decadal timescale in the three study areas, with small changes in the coarse/fine sediment boundaries and significant changes on smaller-scale bedforms developed over the coarse domain in the Catalan continental shelf.

Keywords: Bedforms, sediment-starved continental shelves, swath bathymetry, backscatter, side scan sonar, sediment dynamics

Gravity flow depositional systems controlled by polygonal faults on the Guyana-Suriname Basin margin

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Continental slope topography has a significant influence on subaqueous sediment gravity flows and their associated depositional products, such as turbidites and debris flow deposits. Numerous examples of fine-grained continental slopes and basin-floor environments are host to polygonal fault systems (PFSs), that have a considerable impact on seafloor topography. A high-quality 3D seismic dataset from the western Demerara Rise margin, offshore Suriname, is used to investigate the impact of PFSs on gravity flow depositional systems. Two stratigraphic intervals within the Neogene clastic sequence are analyzed. The Pliocene interval is characterized by a substantial slope failure that gradually transitioned downslope into genetically related turbidites. Using seismic attribute analysis, we demonstrate how the spatial configuration of the Pliocene deposystem was controlled by the intra-channel faults. High amplitude anomalies, likely associated with coarser-grained sediment, terminate abruptly against these faults, indicating the potential for sand-prone ponding along their hanging walls. The upper Miocene interval comprises several channelized fairways that terminate downslope in lobes of different morphological character. Elongated depositional lobes are interfingered with a more radial, proximal lobe complex, in which the individual lobes have a wider fan-shaped geometry. While the downdip terminus of the radial lobes is constrained by the faults, the elongated lobes further downslope appear to be less affected by them. Our findings show that the topography created by PFSs can significantly constrain the presence and stratigraphic architecture of gravity flows depositional systems through (1) formation of intra-slope accommodation space and (2) decreasing of flow energy to enable coarse sediment deposition.

Keywords: Seafloor topography, Polygonal fault systems, Gravity flows, Demerara Rise, deep-water depositional systems

Submarine slope failure initiation preconditioned by shear strength: insights from a 3D numerical modelling

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Direct observations of submarine landslides are almost impossible to achieve due to their barely predictable and remote nature. Field observations and statistical analysis of their deposits suggest that preconditioning factors to slope failure such as the sediments shear strength may control the initial size, location and dynamics of the sliding complex. However, such link between pre-slide sediment conditions and the resulting submarine landslide has not been well established. To understand the potential key role of sediments as a controlling factor of the dimensions and kinematics of mass movements, we used the Discrete Element Method. The numerical simulations tested two major parameters influencing the shear strength of sediments, the sediment type and the consolidation. These parameters evaluated the physical behaviours of sand and clay as sediment type endmembers and additionally, normally- and over-consolidated conditions as endmembers of consolidation. We used the advantage of 3D modelling to observe the influence of these parameters on the lateral distribution of slope failure. The results show that mainly low shear strength slope sediments are prone to develop large and lateral extended areas that are susceptible to failure. However, eventually large-scale slope failure developed under specific sediments type and consolidation conditions and can be possibly related to the different styles of failure plane development.

Morphometric analysis of the northern Gulf of Cadiz continental slope

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We have tested a novel approach to understanding the link between geomorphology and sedimentation for the northern Gulf of Cadiz bottom-current dominated slope, by applying a geomorphometric analytical technique normally used for river basins. This quantitative study of basins relates stream network geometries to the transmission of water and sediment through the basin. It applies systematic measurement of the linear, areal and gradient aspects of the channel network and regional slopes. Two Cadiz slope basins were analysed in detail: basin X, underlain by an accretionary wedge complex, and basin Y, the main region of contourite drift deposition. The chief distinction between the two basins is as follows: (1) Basin X has a higher *bifurcation ratio*, which reflects the tectonic effects of the accretionary wedge leading to greater topographic and geological heterogeneity. (2) Basin Y has a higher *drainage density*, which reflects the highly dissected nature of the basin with large drifts and channels and indicates a direct and rapid hydrological response to alongslope bottom current system. The lower drainage density for basin X indicates a poorly-drained basin with a slow hydrologic response and less sediment deposition. (3) Both basins have mature topography and homogenous material, according to their *hypsometric curve*, which closely resembles the standard equilibrium curve. The inflection point is higher for X than Y, which indicates a generally lower variation in relief. Overall, we conclude that there is considerable merit in applying these subaerial quantitative techniques to submarine basins, but further work is required to refine their interpretation.

Old but sprightly: the role of transgressive geomorphic elements in the shaping of Sicilian and Sardinian continental shelves

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Some sectors of the continental shelf, away from major sediment sources, are relict or palimpsest and their geomorphic elements furnish an archive of past geological processes. Such a setting occurs in some portions of the Sardinian and Sicilian margins. Here, transgressive system tract (TST) geomorphic elements stand out spectacularly on the seafloor and are the subject of our review. On the Sardinian shelf, the older submerged TST geomorphic elements consist of elongated, narrow lagoons bounded seaward by barrier islands. On the contrary, the younger barrier islands bounded narrow estuaries and lagoons confined within the rias. In some cases, the barrier dunes are very well-preserved, showing that the transgression did not destroy them. It is likely that the barrier formed during repeated sea-level still stands punctuating the last transgression. Paleo-lagoons are also present in the northern Sicilian margin, where they generally have a more restricted lateral extension. In one case, a large lagoon formed through the connection of two tombolos with a paleo-island corresponding with a structural high. While in southern Sicily, lagoons and bays formed in depressed area bounded by ridges following the structural grain of the area. Our study stresses that a wealth of information on past processes, such as climate changes, sea level dynamics, sediment storage area and routing pathways, lies on the seafloor of our continental shelves. In addition, it shows that past TST can form extensive bodies and outcrops at the seafloor, the geological study of which must form the basis for resource and biodiversity researches.

Keywords: Transgressive System Tract (TST), paleo-lagoons, sea-level change, biodiversity, relict continental shelf, paleogeography

The role of seafloor geomorphology in the Reconstruction of the Quaternary Evolution of the Italian Territory: THE METIQ_PROJECT

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The Italian territory, both on land and under the sea, is for the most part very recent and shows often the outcomes of active and recent processes, clues to the geological unrest of our region. In such a setting, the study of Quaternary successions contributes to help planning an appropriate sustainable exploitation of our territory, enacting suitable preservation strategies and geo-hazard mitigation procedures, and predicting future evolutionary scenarios. The assemblage of our knowledge on the recent evolution of our territory is therefore an important foundation for a range of studies with large societal impact. With this in mind, the Italian scientific community has launched the METIQ_project (Evolutionary model of Italian territory in the Quaternary), with the final goal of reconstructing the Quaternary evolution of Italy and synthesizing it in a geological map at the scale 1:500000. The project also involves the mapping of the submarine portion of our territory, and the community of marine geologist has gathered to provide the necessary data and knowhow. In establishing the criteria for cartographic representation, the value of a main geomorphologic approach has been recognized. Geomorphic elements are informative of recent and active processes, rather objective and less dependent on interpreter's views than other geological entities, and easier to map with the data available to the marine geologists. A geomorphologic approach also has the potential to give consistency to the mapping effort, since everywhere, geomorphic elements condense information on the whole spectrum of recent and active geological processes irrespective of different geodynamic settings.

Keywords: Cartography, geological mapping, morpho-bathymetry, sustainability, geo-hazards, national project

Using ROV video photogrammetry to reconstruct seafloor landforms of the central part of Haakon Mosby mud volcano (Barents Sea)

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Submarine mud volcanoes are seafloor landforms formed by upward migration of subsurface gas together with fluids and sediments by buoyancy and gravitational forces. Haakon Mosby mud volcano is a 1 km wide active mud volcano located at 1256 m depth in the Barents Sea (72°N, 14°44E). It is characterized by strong thermal and geochemical gradients from its center to the margins resulting in a zonation of chemosynthetic habitats.

Two zones of the active central part of the volcano were explored using Ægir6000, a work-class ROV (Remotely Operated Vehicle) equipped with three HD video cameras that filmed the ocean floor at different angles. The ROV, moving at a constant speed of 1 knot, followed predefined routes to guarantee optimal lateral overlap between adjacent transects. From the videos of the nadiral camera, a photogram every two seconds was automatically extracted. Then, the images were processed in Agisoft Metashape® following a well-established photogrammetry workflow. As final outputs, we obtained 3D mesh, orthomosaics and DTMs at ultra-high-resolution (mm) allowing us to obtain detailed morphometric maps.

These data made it possible to reconstruct accurate georeferenced 3D models that represent one of the most exciting submarine landforms with a resolution never achieved before at this site. These models can help clarify the ongoing processes in this area and their evolution over time. This work was supported by the Research Council of Norway, for AKMA – Advancing Knowledge on Methane in the Arctic, project number 287869.

Keywords: Mud Volcano, ROV, Underwater 3D Photogrammetry, 3D models, Cold Seeps, Arctic

Red-blue seafloor maps to understand East Mediterranean tectonics

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The analysis of relief is fundamental for Earth Science discoveries: from seafloor spreading and plate tectonics to lithospheric mechanics and landscape evolution. However, interpretations of relief data based on (colored) hillshades may be biased, since this widely-used visualization method requires an arbitrary selection of lighting (direction and azimuth) that emphasizes and dims sub-sets of the features contained in the data. Here, we overcome lighting biases producing quantitative relief maps that blend relief concavity-convexity and slope in our novel red-blue relief visualization. We produce original red-blue relief maps of the East Mediterranean seafloor at tectonic scale using the EMODNet bathymetry, and profit from the increased observational power in unbiased structural interpretations. We compare colored hillshades and red-blue seafloor maps at different sites, including the Cyprus Arc, the Nile Delta offshore, the Anaximander Mountains, and the Mediterranean Ridge, where we discuss the newly found observational evidence in the context of the tectonic evolution of the East Mediterranean region at large.

Keywords: Mediterranean Sea; bathymetry; ocean floor; EMODNet; DEM; Hellenic Arc; Cyprus Arc

Mass transport complexes reactivation revealed through multiscale geophysical observation

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Understanding the periodicity and phased collapse patterns of mass-transport complexes is critical to the definition of their potential geo-hazard yet allusive due to their complexity. We study the spatiotemporal distribution, over multiple scales, of mass-transport processes along the Israeli continental slope trough a detailed geophysical investigation. Semi-automated bathymetric analysis revealed a spatiotemporal variance in the style and size mass-transport features along this margin, correlative to the distance from the Nilotic sediments supply-source. The largest (>~1km^3) is the bathymetric scar of the Goliath slide-complex on the southern, proximal part of the slope. Sub-meter resolution sub-surface imaging reveals beneath this scar 11 landslide episodes of similar dimensions, over the last ~475ka (~40 ka reoccurrence), with the most recent significant event dated ~7.5 ka bp. ~110 km to the north, the seafloor is highly populated with significantly smaller (~0.04 km^3) landslide scars, interrelated with thin-skin faulting. High-resolution seismic imaging of one such moderate scar reveals a slide complex, which was formed ~16-~1 ka bp (~3 kyrs reoccurrence) through a retrogressive collapse of 4–6 events with quiescence of thousands of years in between. This pattern suggests that over-steepening of the head-scarp by each previous event preconditions the subsequent failure, but additional sedimentary accumulation is required for failure. An inherited control of the stepped morphology is formed by thin-skin faulting. No correspondence is found between landslide reactivation and glacial/intra-glacial periods. However, large-scale failure seems to intensify with elevated sea-level change rates. Furthermore, the activity and interrelation of turbidite and contourite currents correlate with climatic changes.

Geomorphic elements of turbidite systems in rifted continental margins: turbidity currents and tectonic structures interaction in submarine landscape creation

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Slopes with complex topography usually consist of distinct intraslope basins with variable degrees and styles of connection, and of turbidite systems, dominated by the interaction of turbidity currents and seafloor topography. In this review, we focus on the Latium-Campanian (Tyrrhenian Sea), stepped margin, and, through comparisons with other examples worldwide, derive general insights about the genesis of geomorphic elements in rifted margins. Within the flat intraslope basins, a longitudinal axial flow path with small distributary channels develops where the gradient is low; where the gradient is higher, flow deceleration is impeded and channels maintain a path perpendicular to the basins. Down-dip turbidity currents breach the structural ridges focussing either, in v-shaped deep canyons or shallower and wider valleys, where the gradient of the step is lower. Landslides propagate upward from the canyon heads affecting the distal portion of the intraslope sub-basins. Erosion particularly concentrates at the canyon-mouths, where deep and large plunge pools result from hydraulic jumps of the supercritical flows at the abrupt break-in-slope. Erosional and bypass processes also prevail down-dip, where, mostly unconfined flows result in extensive scours and sediment waves. Re-channelization processes occur in "Gather zones", consisting of tributary channels showing gradual flow focussing, which eventually leads to canyon heads. Our analysis shows that much of the morphology of young, rifted margins forms through erosional processes. Furthermore, it highlights that, basic geomorphic researches, aimed at the understanding of the processes, are still critical to strengthening our knowledge for successive applied studies of slope environments.

Keywords: submarine canyons, submarine scours, hydraulic jump, plunge pool, rifted margin, continental slope

The fossil pockmark of Beauvoisin (SE France) vs the modern pockmark of Regab (Lower Congo Basin) vs sandbox models: fluid seep activity and cyclicity

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Data acquired over modern seafloors have a resolution that does not allow to image the inner structure of a pockmark, even in shallow subsurface. The giant fossil pockmark of Beauvoisin (SE basin of France) developed in a 800 m wide depression for over 3.4 Ma during the Oxfordian. It is composed of sub-sites organized in clusters and forming vertically stacked carbonate lenses encased in marls. The isotopic signature (C, O and Sr) shows that at least 3 different episodes of fluid migration participated to the mineralization processes, including a late phase of bitumen-rich fluids. A 3D reconstruction shows that the carbonate lenses are organized in clusters in the same stratigraphic interval and the same geographic zone. This general organization is very similar to the modern Regab giant pockmark in the Lower Congo Basin, showing that only a few sub-sites are active at the same time. A sandbox experiment has evidenced that the seeping conduit is stable during a given period of time and suddenly shifts laterally. The general log obtained in the Beauvoisin seep area has a similar pattern with periods of seeping alternating with periods of quiescence, about 200 ka -long each. Even if a pockmark seems to have been inactive for a long period of time, it could be due to the lateral shift of the feeder conduit meaning that the sub-seafloor is still charged in gas. This is of primary importance for risk assessment, hydrocarbon exploration and general understanding of geobiology at seafloor seeps.

Keywords: Pockmarks, fluid seep, sandbox models, cyclicity

Elongated giant seabed polygons and underlying polygonal faults as markers of the creep deformation of shallow sediments in the Grenada and Venezuela Basins

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Based on 2D seismic profiles, multibeam and seabed grab cores acquired during the Garanti cruise in 2017, 1–5 km wide seabed giant polygons were identified in the Grenada basin, covering a total area of ~55000 km². They represent the top part of an active 700-1200 m thick underlying polygonal fault system (PFS) formed due to the volumetric contraction of clay- and smectite-rich sediments, initiated in the sub-surface during Pliocene. The short axes of the best-fit ellipses obtained from a graphical centre-to-centre method were interpreted as the local orientation of a preferential contraction perpendicular to the creep deformation of slope sediments. In the North Grenada Basin, the polygons are relatively regular, but their short axes seem to be parallel to a N40°E extension recently evidenced in the forearc, possibly extending in the backarc, and most probably due to a homogeneous subsidence. In the South Grenada Basin, the polygons are more elongated and their axes are progressively rotating southeastward towards the depocenter, indicating a creep deformation towards the center of the basin created by a differential subsidence. Seismic data acquired since the 70's in the Venezuela Basin coupled to DSDP/ODP well data were recently added to the project. The total area affected by Polygonal faults is about 246000 km², which is the largest area of both buried and outcropping polygonal faults (PF) ever found on Earth. The center of the basin is not affected, confirming that the creep deformation of subsurface sediments is the main driver for PF initiation and development.

Keywords: Polygonal faults, subsurface deformation, fluid seep

Seafloor pockmarks offshore Vancouver Island

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Pockmarks are crater-like depressions in marine or lacustrine sediments. They are often interpreted as the surface manifestation of hydrocarbon venting but may also result from freshwater flow in coastal regions, compaction induced sediment dewatering, or bottom scouring. New bathymetric data from offshore Vancouver Island, Canada, indicate the presence of a huge pockmark field between 100 – 200 m water depth. Owing to the presence of a large cabled underwater observatory, a wealth of multi-resolution and multi-disciplinary marine data is available from the pockmark field, including multibeam surveys, seafloor video footage, seismic and EK60 echo-sounder profiles, and multibeam water-column information. First results from seafloor mapping indicate that the field consists of several thousands of pockmarks. By automatically mapping the pockmarks in digital elevation models, we are able to quantify their morphologies and spatial distribution. The pockmarks range in size between 100 – 500 m². Their mean depth varies between 0.5 – 2 m. Seepage of gas from the seafloor could not yet been directly associated with the pockmark depressions. Instead, limited seafloor video footage indicates that some depressions host meter-sized boulders within their craters. We will next investigate temporal changes in pockmark morphology and seep activity by individual analysis of datasets that have been repeatedly collected between 2010–2020. By this resolving pockmark morphologies and seep activities on an annual time-scale over a decade, the results will help to understand pockmark formation and seep activity within one of North Americas largest pockmark fields.

Keywords: Pockmarks, submarine geomorphology, fluid seepage, multibeam bathymetry, seafloor processes, automated mapping

Subaqueous spreading: State of the art, and first modelling attempts

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Subaqueous spreading is a mass movement documented in association to some of the largest landslides observed on earth, and it is recognized as hazardous to seafloor and coastal infrastructures. However, it remains poorly documented and understood. Spreading is a ground failure that occurs on gently inclined slopes by extensional displacement along a gliding plane, experiencing a loss of shear strength. We present here a study that aims at clarifying the global distribution, morphological and geological characteristics of subaqueous spreading to gain insights on the physical properties that control this extensional mass movement and model its development. We built a database (SubSpread) collecting 33 unequivocal case studies and we found out that spreading morphology is broadly described as a hummocky topography, with tensional transversal structures and a distinctive 'staircase' morphology, otherwise recognized as ridges. Ridges and troughs are subparallel to the headwalls, and perpendicular to the direction of the movement of the landslide. A higher number of cases of subaqueous spreading is observed along passive margins and in particular along the glaciated margins of Norway and Canada Our study revealed that contourites, and their geological contrast with glacial sediments, seem to play an important role in the development of this landslide. These findings are used to develop a hydrological-mechanical model of subaqueous spreading where a sandy layer is involved as a gliding plane. Our simulations entails the use of Finite Element and Limit Equilibrium approaches.

Keywords: Subaqueous spreading, spreading morphology, ground failure, contourites, glacial margins, Finite Element model, Limit Equilibrium model

Uncinated submarine canyons of the Southwestern African margin

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The rifted margin of southwestern Africa comprises a broad and deep shelf that has been heavily explored for hydrocarbons. Despite this exploration thrust, there is a dearth of high-resolution data from the seabed, especially multibeam bathymetry. This study documents the first high resolution multibeam survey for the outer shelf and upper slope regions, in which several unusual submarine canyons were discovered. Most of the canyons impinge and terminate at the shelf edge and show distinct uncinated morphology with sharply hooked heads that deflect to the southeast. Some of them fully close to form circular depressions at the seafloor, surrounding bathymetrically higher points. There appears to be multiple phases of upslope canyon head extension and curving, with older and subdued incisions abutting higher relief incisions, now characterised by crescentic-shaped bedforms.

The canyon heads themselves are not connected to a distinct channel downslope, instead they occur as isolated semi-circular forms that increase strongly in relief on the mid slope. Seaward, the lower slope is underlain by broad, straight and shallowly incised buried canyons, with no morphological expression at the seafloor. Landward of the uncinated canyon heads, on the shelf, the canyons are filled by upslope-migrating cyclic steps. These are unusually large, up to 700 ms tall and several kilometres wide. On the slope, their low points mark several climbing vertices of the bedforms which represent palaeo-canyon troughs that have been filled and which have migrated upslope over time.

Strongly linked to the uncinated canyons are fields of pockmarks and methane-derived carbonate slabs, around which slumping and landsliding are associated with semi-circular pockmark strings. We postulate that the unusual canyon morphology is an interaction between three main processes: 1) downslope mass wasting processes deflected by the aggradation of cyclic steps during infilling 2) deflection of the canyon heads by bottom current circulation and 3) fluid seepage associated with the lowpoints between cyclic step fields.

Mathematical modelling of erosive fluidisation, flow localisation, and formation of pockmarks

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Pockmarks, the seafloor manifestations of sub-surface fluid flow, play a prominent role in global carbon emissions, subsurface hydrocarbon exploration, regulation/modulation of local biochemistry and ecology, and mechanical stability of marine sediments. Pockmarks have been reported in extremely diverse geological settings worldwide, and are found to exhibit a remarkably wide variability in their shapes, sizes, and structure, which makes their characterization hard, and quantitative analysis even harder. To further add to the complexity, pockmarks are typically found on top of focused flow conduits (called pipes and chimneys) that connect the seafloor with deep seated source rocks, which strongly suggests that formation of pockmarks is inherently linked to the physics of flow localization in the sub-surface. Many conceptual models have been proposed in the recent years to explain the observed pockmarks and seismic pipes and chimneys, but surprisingly few of these have been translated into mathematical and computational frameworks.
To address this gap, we propose a model concept for simulating flow localization and pockmarks formation based on the mechanism of erosive fluidization. The model resolves the changes in sub-surface and seafloor morphology through conservative redistribution of sediment mass due to seepage induced erosion, fluidization, and transport of granular sediment. Through numerical studies, we demonstrate that this model is not only able to simulate the formation of focused flow conduits and pockmarks of different shapes and sizes, but it also makes important predictions regarding the role of intrinsic sediment characteristics (like permeability) vs characteristics of sediment-fluid interactions (like sediment erodibility and flow anisotropy).

Submerged marine terraces and paleo shorelines along the eastern rim of the Mid Adriatic Deep

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Submerged marine terraces provide evidence of the past sea-level fluctuations or the effect of the bottom currents. Sea-level changed significantly since the lower Pleistocene, being up to 135 m lower than at present. Periods of long-term sea-level stillstands possibly enabled the formation of marine terraces. The formation of the Adriatic Sea bottom currents is related to an interaction between two south-flowing water masses: the North Adriatic Dense Water in the northern Adriatic, and the Levantine Intermediate Water in the Eastern Mediterranean. Bottom-current activity can also form marine terraces.

The investigated area is located in the central part o f the eastern Adriatic, in the SW part of the Žirje island archipelago. The archipelago is characterized by steep island escarpments and submerged islands. The morphology, with almost vertical SW island shores, is typical for the outer rim of the Dalmatian islands and extends to Telašćica and Kornati archipelago.

To successfully detect the distribution and characteristics of submerged marine terraces, we used high-resolution acoustic methods – Multibeam Echosounder and CHIRP Sub-bottom Profiler. The results of the detailed survey display abundant evidence of terraced landforms. The resulting landforms can be grouped into five depth-related classes (53–55, 70–72, 80–85, 100–105, and 125–130 m b.s.l.). Future investigations will provide an answer to whether studied landforms were created by former sea-level oscillations mainly during the Pleistocene falling stage systems tract, bottom current circulation or both phenomena affected the formation of the submarine terraces.

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Keywords: Submerged terraces, sea-level fluctuations, Eastern Adriatic Sea, bottom currents, MBES, CHIRP SBP, Pleistocene

Diverse morphology of seafloor depressions offshore Aotearoa New Zealand

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Seafloor depressions are abundant around Aotearoa New Zealand, ranging in size from 10s of metres to >10 km in diameter. Depressions are a commonly observed seafloor expression of focused fluid flow or gas venting. However, very few pockmarks around Aotearoa are observed with concomitant indicators of seep activity. Such features have been imaged using high-resolution multibeam bathymetry, with several recent research voyages acquiring dense datasets of small, densely spaced depressions in previously unmapped areas. Using multibeam data, we compile more than 15,000 seafloor depressions around Aotearoa to conduct regional spatial and statistical analyses. These features predominantly occur in water depths of 300 to 850 m. Small depressions (10s to 100s m in diameter) are widely observed, generally closely spaced and range from circular to elongate in shape. Large, more irregularly shaped, depressions of up to 12 km in diameter have been observed further offshore on the Chatham Rise. A recent voyage to the Tasman Sea imaged numerous small pockmarks in the vicinity of submarine canyons with no evidence of active seepage. Water depths in which these occur correlate well with the expected gas hydrate stability zone; however, limited evidence exists to support the hypothesis that hydrate dissociation is the primary mechanism responsible for their formation. Furthermore, morphometric variability of these structures indicates mechanisms of formation, and/or subsequent modification processes also vary. Here we present the first compilation and morphometric comparison of seafloor depressions from around Aotearoa and discuss factors constraining the distribution and morphology of these enigmatic structures.

Keywords: Pockmarks, seafloor depressions, submarine canyons, erosion, sediments

Sediment dynamics of an exposed subtidal hard bottom substrate habitat in the North Sea

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Hard bottom substrates and rocky reefs are highly important habitats for the southern North Sea. In contrast to the widespread sandy areas, their complex topography and stable location provides island-like shelter and settling substrate for a variety of benthic organisms. Due to the important ecological role their biodiversity and spatial distribution in the North Sea is well investigated. The complexity of their hydro- and sediment dynamics as well as their temporal variations on the other hand is poorly constrained but of major importance for their sustainable management and protection. We provide the first results of one of the longest time series monitoring programs (>6 years) of a hard substrate environment in the North Sea. We use multibeam bathymetry, side-scan-sonar backscatter, and acoustic doppler current profiler data in combination with video observations and sediment sampling to determine the stability and the long-term variations of sediments at and around the reef. We investigate the sediment dynamics that affect biological communities as well as the geomorphological impacts of the reef on sessile organisms. Our results suggest a very dynamic system surrounding the reef, where large-scale scouring, reworking and transport of the mobile sand layer occurs, while the central part of the reef remains stable over time. Epibenthic communities seem to be less affected by their spatial location across the reef and much more by the grain-size of cobbles and boulders they inhabit. We demonstrate the importance of hydrodynamics and current scouring around rocky reefs for their geomorphology and spatial extent over time.

Keywords: Rocky Reef, Boulder accumulation, Scouring, Hydroacoustics, Time series

Gas detection and quantification using iXblue echoes high-resolution sub-bottom profiler and Seapix 3D multibeam echosounder from the Laacher See (Germany)

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Volcanic gases are a main trigger of explosive eruptions, but the largest amounts are emitted through passive, non-eruptive, degassing during quiescence. It is thus necessary to accurately map bubble clouds, and to monitor their dynamics, to reduce volcanic risks. We present results from near-surface geophysics of sedimentary deposits and water column gas seepage at the Laacher See (Eifel, Germany), using iXblue Echoes high-resolution sub-bottom profiler and Seapix 3D multibeam echosounder. Backscatter profiles of water column elements distinguish gas bubbles and fishes and highlight several bubble plumes. Target Strength (TS) of bubbles is centered around -70 dB, suggesting they are of very small size (35 µm), much smaller than observed elsewhere using single beam echosounders. This would explain why, in the same spot, we did not observe any gas bubbling using camera mounted on ROV. Recent measurements at the nadir of a gas flare, in static positioning, using the steerable mills cross multibeam capability of the SeapiX, offered a 4D observation of the gas bubbling. It also provided an equivalent TS of the bubbling we observed two years earlier. Meanwhile, Echoes 10 000 provides high-resolution paleoenvironmental reconstruction using 3D modeling of remobilized materials, and gas diffusion through the sediment. Fusion of all geophysical data using Delph Roadmap allows 3D modeling of gas flare dynamic from 40m in sediment to water-atmosphere interface. Our scientific approach contributes to improve forecasting of volcanic and limnic eruptions and participates to improve early warning systems by constant collaborations with academic research.

Keywords: hydroacoustic, volcanic eruption, gas bubbles, backscatter, multibeam echosounder, seismic reflexion, paleoenvironment

Benthic foraminifera as indicators for hybrid turbidite-contourite sediments transport system in the Eastern Mediterranean upper continental slope

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Nile derived siliciclastic sediments are the main source for sedimentation along the Levant continental margins. The sediments are transported along the southeastern Mediterranean coast via jet and longshore currents, mainly operating along the shelf. However, the cross shelf component of sediments transport, responsible for conveying sediments towards the upper slope, is less known. To better understand the cross-shelf vs. the longshore components of sediment transport we studied a ~6 m piston core (DOR280) sampled in the upper continental slope (280 m water depth). We analyzed benthic-foraminiferal assemblages and their shells taphonomy, for documenting both the source and the transport mechanism of the upper continental-slope sediments. The radiocarbon sediment age at the core-base is ~650 Cal Yrs. B.P., indicating an exceptionally high average sedimentation rate of ~850 cm/Kyr. DOR280 consists of alternating two sedimentary facies: (1) Laminated (L) intervals with high ratio of allochthonous vs. autochthonous (allo/auto) foraminiferal species, characterized by a high percentage of benthic-foraminiferal broken shells, indicating contribution of transported sediments originating from mid-shelf habitats. (2) Non-laminated (NL) intervals with low allo/auto ratio and low percentage of broken shells, indicating mostly *in-situ* deposition. The L intervals are interpreted as sediment laden gravity currents, possibly turbidites, numerous centimeters-thick events were identified. Sedimentation rate calculated only for the NL intervals is still exceptionally high, excluding hemipelagic sedimentation as the sole deposition. Thus, a contour bottom-current transported component is suggested for the NL sediments. We conclude that a hybrid contourite-turbidite system actively prevails along the the Levant coast, offshore Israel.

Keywords: Turbidite, Contourite, SE Mediterranean, Continental slope, Benthic foraminifera, Taphonomy

From Summit to Seafloor: A shoreline-crossing quantitative DEM analysis on volcanic flank instability

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The instability of volcanic islands can lead to either or both of two processes; slow sliding of a flank of several cm per year (i.e. Etna, Italy) and/or the catastrophic collapse of a large portion of the edifice (i.e. Anak Krakatau, Indonesia). The PRE-COLLAPSE project (Slow sliding of volcanic flanks as PREcursor to catastrophic COLLAPSE), in which this study is embedded, aims to understand the connection between the two processes.

The limited availability of high-resolution bathymetry data especially at the coast is often restricting the quantitative geomorphological investigation to the subaerial part of the volcanic island. It is essential, however, to include the entire volcanic edifice as the majority of its volume is below the sea level. Satellite-derived bathymetry, on the other hand, is widely available, yet its usefulness for our investigation is unclear, due to its low resolution.

For this study we therefore combine openly available high-resolution (50–150m) topographic and bathymetric grids of four areas of high coverage (archipelagos of Hawaii, Canaries, Mariana Islands and South Sandwich Islands) to parameterize the geomorphology of the entire edifice of volcanic islands from summit to seafloor. These shoreline-crossing parameters are described statistically across all volcanic islands of the four study areas and compared with a dataset calculated from satellite-derived, lower-resolution (15''x15'', 500×500m at equator) bathymetry (GEBCO) respectively.

Geomorphology and benthic habitat of orphan spur (North Atlantic Ocean)

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We describe the geomorphology of Orphan Spur, a sediment drift deposit located on the northeast Newfoundland Shelf in eastern Canada. This drift with thick, acoustically stratified sediments was shaped during the late Quaternary under influence of Labrador Current. It is located within a fishery closure area, established for protecting deep-water corals and sponges and has a potential for hydrocarbon exploration. In 2019 – 2021 multibeam and sub-bottom profiler data, piston cores and optical samples were collected in water depths from ~600 m to ~2500 m. Iceberg scours, semi-parallel to the shelf edge, are abundant above the shelf break, down to ~680 m water depth. U-shaped gullies several km wide, with walls reaching 100 meters incise the upper slope north of the Spur. Closer to the Spur the upper slope has massive slumps interconnected with V-shaped canyons continuing into deep water (>2500 m). The Orphan Spur drift reveals a series of large-scale retrogressive slope failures, long and multiple escarpments (75 m to 150 m high), mass transport deposits and block failures. Mid-slope there are pockmarks approximately 500 m across, elliptical, commonly appearing as pairs. Well-defined, potentially recent slope failures, lacking sediment cover, occur in the shallow part of the spur (700 – 900 m water depth). Hard corals are rare, and soft corals occur in moderate abundance, dependent on habitat type and water depth. Better understanding of sediment dynamics and geohazards in the area is important for balancing conservation activities with potential hydrocarbon exploration.

Keywords: Benthic habitats, geohazards, sediment drift, pockmarks, ocean management

Classifying offshore faults for hazard assessment: A new approach based on fault size and vertical displacement

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The Israeli continental slope is dissected by numerous salt-related, thin-skinned, normal faults, forming tens of meters high seabed scarp. This faulted zone is currently being crossed by pipelines transporting gas from offshore fields, highlighting the need to assess the hazard posed by the faults. Unfortunately, however, the methodology for geohazards mitigation in the marine environment lags tens of years after the well-established methodology onshore. One possibility is to follow the onshore practice. In that case, a Holocene horizon needs to be detected in the sub-seabed for each fault. However, we suggest an alternative approach that takes advantage of the unique opportunities available in the marine environment, where seismic data can be superior in quality and quantity. Instead of investing huge efforts (multiple coring to a dated horizon) in finding whether or not each specific fault in the study area meets a pre-defined criterion of 'activeness', we map the subsurface and determine the levels of fault hazard, highlighting "green" and "red" zone, based on the amount of recent displacement and fault plane size. A particular red zone is the upper slope south of the Dor disturbance, where a series of big listric faults with large displacements rupture the seabed. Noteworthy, the sedimentation rate in this area is four times faster than the displacement rate, yet fault scarps are still a few tens of meters high. We suggest that this indicates seismic rupture rather than creep.

Seamount distribution along the Reykjanes ridge: Evidence of a complex underlying magmatic system

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The Reykjanes Ridge is a 900 km long segment of the slow-spreading volcanic Mid-Atlantic Ridge located south of Iceland. The Reykjanes Ridge shows significant variations in water depth, lava chemistry, crustal thickness, thermal structure, and ridge morphology with distance from Iceland which have been primarily attributed to the interaction between the ridge and the Iceland magmatic anomaly (plume). The active volcanic ridge is flanked by V-shaped ridges (VSR), attributed to melting anomalies in the mantle migrating away from Iceland. During the MSM75 expedition in 2018, we mapped and sampled four sections of the ridge to study whether volcanic and tectonic processes on the seafloor also vary along the ridge. Our analysis combines 15 m resolution ship-based bathymetry, ground-truthing from ROV dives, and geochemical analysis from glass samples to look at variations of magma composition, seamount density, and morphology along the ridge axis. Unlike other plume/ridge interaction systems, the seamount distribution, especially the density of flat-topped seamounts, does not increase with the distance from the plume center. This indicates that the Iceland plume is not the only contributor to the along-axis volcanic variations. Instead, the peak in seamount density (which is especially strong for flat-topped seamounts) appears correlated with the interaction between VSR and the ridge axis. These observations are compatible with the buoyant upwelling melting instability hypothesis for VSR formation (Martinez et al., 2019) and suggest that buoyant melting instabilities create many small magma batches which by-pass the normal subaxial magmatic plumbing system, erupting over a wider-than-normal area.

Keywords: Mid-ocean ridge, Reykjanes ridge, Plume/ridge interaction, volcanism, high-resolution bathymetry

Evaluating changes in deep-sea morphological mapping of the northern Gulf of Mexico across thematic and spatial resolutions

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Characterizing submarine geomorphology benefits a range of marine applications and is often critical for understanding the spatial patterns of seafloor environments. On the seafloor of the Gulf of Mexico are found a variety of bedforms that create important seafloor habitats and drive the distribution of anthropogenic activities such as oil and gas exploitation. In 2017, the United States Bureau of Ocean Energy Management released a 1.4-billion-pixel bathymetric dataset of the deep northern Gulf of Mexico, with a pixel size of about 12m. The computational power required to analyze this dataset has limited the amount of analysis that has been done on it. Here, morphological maps of the deep Gulf of Mexico are presented based on different classification schemes and at various spatial resolutions. Regardless of schemes and resolutions, flat areas and slopes dominate the seascape, totalizing more than 70% of the studied area. In general, the nature of bedforms itself dictated their relative coverage and abundance within the Gulf of Mexico, with naturally small features like peaks and pits covering less area than others. In terms of individual bedforms, shoulders and footslopes are the most abundant, followed by different types of slopes (e.g., flat, concave, convex). In general, finer thematic and finer spatial resolutions resulted in significantly more individual features captured. Correlation analyses confirmed that analyses at different spatial scales capture different morphological features. Classifications from multiple scales were combined within a single product, highlighting changes in morphological mapping across spatial resolutions and helping to identify the dominant seafloor features.

Keywords: Seafloor mapping, Gulf of Mexico, Bathymetry, Segmentation, Spatial Scale, Topographic Openness

The shape of estuarine dunes, example from the Weser Estuary, Germany

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Dunes are ubiquitous features in sandy shallow and deep-water environments. They are active morphodynamic elements which both reflect and influence hydrodynamics, sediment dynamics and geomorphology at various spatiotemporal scales. Traditionally, the interaction of flow, sediment transport and bedform has been investigated over dunes with an angle-of-repose (30°) lee side and a triangular shape. However, it has recently been shown that dunes in large rivers have a mean lee side angle of around 10°, with their steepest slope (around 15° to 20°) situated in the lowest portion of the lee side, closer the trough than to the crest. On the other hand, earlier observations suggested that dunes in estuaries generally exhibit a concave shape, with a pronounced peakedness of their crest and a flat trough. Recently, the distribution and morphology of tidal bedforms in the Weser Estuary, Germany, were analysed for a five-year period (2009–2014) based on monthly bathymetric surveys carried out along the main waterway. The analysis showed that bedforms in the Weser Estuary are predominantly low angle dunes, with their steepest slope situated near the bedform crest. The origin of the difference in river and estuarine dune shape, and its potential impact on flow and sediment transport will be discussed, as well as the implications for marine bedforms.

Keywords: bedforms, estuary, morphology, low-angle

Geomorphological signs of a volcano-tectonic reactivation in the eastern canary basin from the Miocene to Quaternary

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In the eastern Canary Basin, the locations and characteristics of the main geomorphological features show a clear tectonic control. Sedimentary, volcanic and tectonic seafloor features are controlled by two tectonic trends matching with the oceanic fabric: WNW-ESE and NNE-SSW. The former direction controls the location of the linear turbidite channels and debris flow lobes and the lateral continuity of structural and volcanic reliefs. In addition, escarpments, linear ridges and volcanic edifices follow a NNE-SSW trend matching normal faults delimiting blocks of oceanic basement. The morpho-structural analysis of these features shows evidence of a volcanic and tectonic reactivation from the middle–upper Miocene to the lower–middle Pleistocene. We argue a tectonic uplift in the eastern Canary Basin with a thermal anomaly triggered volcanic and hydrothermal activity and the subsequent flank collapse and emplacement of mass transport deposits on the Western Canary Slope. Furthermore, this uplift reactivated the normal basement faults, generating folds and faults that control the location of turbidite channels, escarpments, mass transport deposits and volcanic edifices.

Keywords: Canary Basin, geomorphology, tectonics, oceanic fabric

Submarine canyon morphology in relation to active forearc tectonics along the Chilean margin

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Convergent plate margins host more than half of all global submarine canyons. In these environments, canyon morphology is often shaped by active tectonic processes including forearc erosion, compressional folding and faulting, local or regional uplift and subsidence. Unrevealing canyon morphologies, can therefore help to reconstruct the tectonic development of a convergent margin. In this study, we investigate ship-based bathymetric maps from the Chilean convergent margin (19°S-45°S) to link forearc tectonics to canyon morphology. In total, 30 submarine canyons are resolved, but only 17 of them extend from the continental shelf or upper slope to the trench. We automatically extract the canyon thalweg and systematically calculate canyon width, incision depth, relief, sinuosity, and slope gradient. We also separately investigate their morphology within the actively deforming accretionary prism as well as within the tectonically more stable backstop in the South-Central margin segment. The results show that submarine canyons in the erosive North Chilean margin (19°S-33°S) are smaller in width and depth, compared to those in the South-Central Chilean margin (34°S-45°S). Larger width, incisional depth, slope gradient and lower sinuosity are observed within the accretionary prism segment compared to the backstop. Additionally, longitude profiles of canyon thalweg with a concave shape in the prism segment seem to be related to regional uplift of the overriding plate, while those with convex shapes maybe ascribed to the reentrant of seamount subduction. Our results may help to read tectonic signals in submarine canyon morphologies along the Chilean margin as well as in other active margins.

Keywords: Submarine canyons, Chilean margin, tectonics, automatic mapping

Morphological expression of active tectonics offshore Calabria accretionary prism (Ionian Sea-Italy)

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Accretionary prisms are very dynamic systems where active tectonics deeply affect the morphological landscape and hence the intensity and distribution of main processes active at seabed, such as erosion, landsliding, canyon incisions and pathways of sediment transport. The analysis of morphobathymetric and multichannel 2D/3D seismic data allows to characterize the tectonic deformation affecting the seafloor in the Ionian Sea, offshore of the Crotone promontory, and to highlight the relationships between tectonic-related morphology and seafloor sedimentary processes. Besides the uppermost thrust fault of the Calabrian accretionary prism, outlined by the steep slope the Crotone promontory, the area is characterized by a belt of some main broad and flat-topped anticlines, and a set of minor structures, mainly NNW-SSE oriented. These anticlines display different internal structure and likely different origin. The uppermost sedimentary strata within these anticlines are often affected by numerous small-scale extensional faults, not rooted at depth, that appear due to outer-arc extension. In places, an inversion of a pre-existing depocenters is also evident from seismic reflection data. The seafloor relief originated by the growth of these anticlines controls the location of the two major canyon systems known in the area whereas, at a smaller scale, minor incisions and landslides fringes the steeper slopes of the anticlines and the flanks of major channels. This new analysis of a limited portion of the Calabrian accretionary prism, based of high-resolution 3D seismic data, reveals a remarkable complexity and illustrates how tectonic and sedimentary processes interact at different scale to shape the present-day seafloor morphology.

Keywords: Calabrian accretionary prism, active tectonics, tectonic landscape, extensional faults, incised channels, landslides, seafloor morphology, 3D seismic data

The physical features of mesophotic bioconstructions in the lower Adriatic Sea

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Marine bioconstructions are the result of the biological activity of some taxa that erect widespread structures on the seabed, modifying their morphology. In these habitat the interaction between physical and biological processes determines the evolution of the system. Recently, the attention on the bioconstructions of the mesophotic zone has grown both on a global scale and in the Mediterranean Sea. In the Adriatic Sea a system of mesophotic bioconstructions (between 30 and 60 meters deep) built in places mainly by non-symbiotic scleractinians (*Phyllangia americana mouchezii* and *Polycyathus muellerae*) or by deep-sea oyster (*Neopycnodonte cochlear*) has been described in different points of the Apulian coast (from the Tremiti Islands to Santa Maria di Leuca). This work aims to describe the physical system in which these bioconstructions develop, using a multidisciplinary and multiscale approach. Geophysical surveys (sub-bottom profiler, multibeam and side-scan-sonar), ROV and sampling procedures were used to describe the main sea-bottom features and their lateral extension. Petrographic and image analysis have been carried out to highlight the meso- and microscopic features of the biconstructions. Our research integrates methods of marine geology and marine biology considering the system as the result of the delicate balance between the two aspects.

Keywords: Marine bioconstructions, mesophotic reef, Adriatic sea, Apulian coast

Huelva underwater maritime province paleocoast, paleochannels and fluvial landforms during the Flandrian interglacial: geophysical survey and identification of submerged human contexts

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In the SW coast of Spain, the environmental changes, and their effects in the landscape dynamics during the Holocene time intervals based on climatic fluctuations have attracted the interest of researchers for years. This interest is now especially high and associated to the knowledge of the fragile Atlantic landscapes and the role of the Guadalquivir basin within the Atlantic Ocean and the Mediterranean Sea. The interrelationship between climate and the genesis of geomorphological processes has a singular importance in the palaeogeographical research. Nevertheless, the reaction of river basins to climatic variations since the Flandrian interglacial transgression and the linkage to the human settlement patterns is an important research subject and still the matter of scientific debate. Understanding the relationship between archaeological and geological datasets represents the main objective of the present project that has been developed in the common framework of Geology and Anthropology. Climate trends and its variations have a powerful influence on human settlement patterns, migrations, technology adaptations, demographic evolution, etc.... These aspects are the main reason of the rise, evolution, and collapse of the civilizations.
The main objective of this work, through the application of geophysics survey techniques, remote observation and combined sampling procedures are the assessment, characterization and mapping using a digital elevation model (DEM) to understand the paleochannels and fluvial landforms now submerged in the river basin of Huelva´s maritime province; and understand how these features, based in their typologies and distribution, can help understand the depositional systems in the paleo estuaries.

Keywords: Spain, paleochannel, underwater, DEM, environment, remote sensing, interglacial

North America's largest pockmark field offshore Big Sur, California is maintained over time by intermittent, non-channelized turbidity flows

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The Morro Bay Wind Energy Area has been identified offshore Big Sur, California, which happens to coincide with North America's largest pockmark field. To better understand the geohazard that pockmarks may pose to windfarm infrastructure, high-resolution Autonomous Underwater Vehicle multibeam bathymetry and sub-bottom surveys, Remotely Operated Vehicle video footage, and sediment cores were collected in 2018 and 2019. Detailed analyses of these data provide no evidence of past or present fluid venting in this pockmark field. Instead, data show that sedimentary processes periodically modify the pockmarks' morphology. CHIRP data reveal that the upper ~4 meters of the entire region consists of a low-reflectivity hemipelagic drape underlain by higher reflectivity horizons, which are more reflective and generally thicker in the pockmark centers. This sequence of low-reflectivity deposits draping more reflective layers persists for multiple cycles in the sedimentary record. Piston cores (~7-m long) that penetrated the uppermost reflective layer inside and outside of the pockmarks indicate that the reflective horizons are turbidites, suggesting that regional non-channelized turbidity flows occur periodically in this region. Based on subsurface imaging and a regional sedimentation rate of ~23 cm/103 years, individual pockmarks have persisted in approximately the same location since the Pleistocene; however, some have moved laterally tens of meters over that period. Pockmark flanks have low reflectivity sediment with asymmetrical thickness as well as occasional truncated high reflectivity layers that suggest both deposition and erosion are leading to this lateral migration, and that the pockmarks are being maintained by intermittent, non-channelized turbidity flows.

Keywords: Pockmarks, turbidites, seafloor mapping, high-resolution bathymetry, Autonomous Underwater Vehicle

A new discovery of pronounced methane and brine seepage, and an associated biodiversity hotspot, on Palmahim disturbance offshore Israel

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Palmahim Disturbance (PD) is a salt-rooted mass transport complex, extending ~50×15 km (100–1,200 m water depths) across the southeastern Mediterranean margin. Recent discovery of deep-sea coral gardens and gas-seep habitats prompt the declaration of a marine protected area (MPA) in PD, the first in Israel's EEZ. We exploited the correlation of high-amplitude reflectivity on 3D seismic data with observed seafloor seepage to define additional potential seepage sites. Quantifying all available observations into a common database we modelled the potential presence of rare benthic habitats on PD, constraining the desired MPA extent. Reconnaissance AUV surveying was carried to validate our predictions, collecting 3-cm resolution synthetic aperture sonar (SAS) backscatter and additional data. The distribution of imaged pockmarks and carbonates corroborated our geophysical approach and MPA modelling, while reflecting non-linearity of the seepage distribution. Moreover, SAS imaging discovered previously un-known brine pools, associated bubbles emissions and varied rocky formations. Subsequent ROV surveying videoed brine seeps, forming streams and pools on the seafloor, and frequent gas ebullition. CTD measurements and water sampling showed that the brine discharges are salty (> 60 PSU), warm (~22°C) and contained methane, sulfide and ammonia at millimolar concentrations. The surrounding area is vastly covered with a flourishing chemosynthetic ecosystem, characterized by vast bacterial mats, tubeworm fields and a variety of typical fauna. Moreover, we discovered an exceptionally pervasive nursery of deep-sea sharks (*Galeus melastomus)*, with a myriad of eggs at different developmental stages. This discovery highlights the potential importance of seepage to the Eastern Mediterranean marine environment.

Keywords: seafloor gas seeps, brine pools, synthetic aperture sonar, deep sea environment, marine protected areas, deep sea sharks

Marine geophysical & sedimentological data reveal multiple submarine landslides triggered by the July 1956 Amorgos earthquake in the South Aegean Sea, Greece

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The largest tsunami in the 20th century in the Mediterranean Sea occurred after the July 9th, 1956, M:7.8 Amorgos earthquake in the South Aegean Sea with maximum run-up values up to 10–30 m. We present here results from marine geophysical data (multibeam, airgun profiles, side scan sonar, deep-towed chirp profiles) obtained during three cruises of R/V AEGAEO (2016, 2017, 2019) and laboratory analyses performed on sediment cores.

The seismic and bathymetric data indicate active NE-SW faults creating steep slopes and enhanced subsidence of the basins. The infill of the basins is largely composed of MTDs. Multibeam and side scan sonar data revealed multiple slope failures and associated MTD lobes in the area between Amorgos, Astypalea and Anaphi Islands. Deep-towed chirp profiles show multiple chaotic layers in the shallow sub-seafloor, with the recent one forming the present seafloor. More than 20 sediment cores were retrieved from the basins and MTD features. The most recent MTD varies in grain texture between structureless clay to sand and in thickness between a few tens of cm and over one meter. It is draped by a thin mix layer and overlays an oxidized layer, possibly the previous seafloor that was abruptly covered by the landslide. Laboratory analyses and Pb210 decay analyses strongly suggest that the observed MTDs are younger than 100 years and may thus be related with the 1956 earthquake. These results support the hypothesis that multiple submarine landslides were triggered by the 1956 Amorgos earthquake and they have generated multiple tsunamis.

Keywords: Submarine landslides, tectonics, earthquake, tsunami, Amorgos, slope stability, bathymetry

Morphological evolution of embayed beaches with different morphometric and sedimentary characteristics

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It is usually assumed that the morphological evolution of embayed beaches on a microtidal coast largely responds to the degree of exposition to wave conditions; decreasing the mobility with the increase of beach indentation (and vice-versa). However, the amount of sediment arrivals on the beach, such as local streams inputs or longshore or cross-shore sediment transport, can modify that relationship. Here, we present the analysis of ten embayed beaches along the Catalan coast (NW Mediterranean) with very different morphometric and sedimentary characteristics, with the aim of identifying the most relevant parameters controlling the morphological evolution of embayed beaches at inter-annual and decadal scale. The study is mostly based on LIDAR topographic data collected from 2012 to 2017, and aerial photographs from 1946 to 2020. Based on these data, the main characteristics of the beaches were determined. The results show a net loss of volume on all studied beach at inter-annual scale and a general shoreline retreat during the last decades. Only one beach shows an opposite behavior due to the bypass of large amounts of sediment by longshore transport from the next beach. Small pocket beaches with medium-high indentation displayed higher variability on volume of the emerged beach and shoreline position, being more sensitive to changes induced by local factors, and standing up with the higher potential vulnerability. Among the possible causes of the erosion of these beaches, it is suggested that the reduction of the sedimentary contributions supplied to the beach by the streams could be a relevant factor.

Keywords: Beach indentation, shoreline evolution, beach volume, streams sediment supply

Geomorphological expression of a transcurrent plate boundary: the lineament south strike-slip fault off SW Iberia

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The SW Iberian margin host the present-day convergent plate boundary between Iberia and Nubia. Regional seismic activity is characterized by low to moderate events, although large historical and instrumental earthquakes (Mw>8.0) have been occurred, such as the 1755 Lisbon and 1969 Horseshoe ones. The NW-SE convergence (4–5 mm/yr) is accommodated by thrusts and a set of strike-slip faults that conforms a 600 km-long and 300 km-wide deformation band named the SWIM Fault Zone. The seismogenic Lineament South (LS), a WNW-ESE 350 km-long dextral strike-slip fault, is the most prominent among them and represents an important tsunami hazard for the SW Iberian coasts due to its extension, orientation and proximity to the coast. In this work we show multi-scale seismic profiles across the LS that reveal the Plio-Quaternary activity of the fault. The LS cuts and displaces the entire sedimentary sequence up to the seafloor, generating a set of continuous crest-and-troughs of hundreds of meters wide over the seafloor. Ultra-high resolution bathymetry acquired with AUV along two 15 km-long segments of the LS shows the presence of pull-apart basins, pressure ridges, semi-circular escarpments interpreted as collapsed structures, sedimentary features such as submarine dunes with lengths ranging from 200 m to 6 km, large longitudinal erosive bed-forms interpreted as furrows, and mass movement scars.

Keywords: SW Iberia, strike-slip fault, active tectonics, seafloor morphology, AUV bathymetry, pull-apart basins, submarine dunes

Influence of tectonically controlled topography on deep-water sedimentation

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Increasing availability of high-resolution bathymetric and seismic data along the slope of continental margins has allowed a step change in understanding processes and products of turbidity currents. Yet, many questions regarding how such flows interact with tectonic-driven deformation of the seafloor are outstanding. Using 3D seismic reflection data from the Levant Basin (Eastern Mediterranean Sea), we investigate the spatial and temporal evolution of bedforms on a deep-water fan cut by an active normal fault. The goal is to understand how a dynamic knickpoint controls sediment deposition from superficial to transcritical turbidity currents, and how allogenic signals, such as tectonic processes, are preserved in the sedimentary record. Seismic data show that in the footwall the fan comprises cyclic steps and antidunes along its axial and external portions, respectively, which we interpret to result from the spatial variation in flow velocity due to the loss of confinement at the canyon mouth. Conversely, in the hanging wall, the seafloor is nearly featureless at seismic scale. Numerical modelling of turbidity currents shows that the fault triggers a hydraulic jump that suppresses flow velocity downstream, thus explaining the lack of visible bedforms basinward. This study shows that the topography generated by active normal faulting controls the downslope evolution of turbidity currents and the associated bedforms, and that seafloor geomorphology can be used to evince syn-tectonic deposition.

Keywords: Deep-water fans, turbidity currents, supercritical and transcritical bedforms, active tectonics, seismic geomorphology, Eastern Mediterranean Sea

Distinguishing between anthropogenic and natural origin of morphosedimentary patterns in the southwestern Baltic Sea

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A wide range of human activities severely impacts coastal areas and the marine environment. Activities such as trawling, dredging, dumping or pipeline and cable installations, amongst many others, interfere with the natural processes and leave traces on the seabed. In many cases, the characteristics and locations of anthropogenic structures such as wrecks, submarine cables, or dumping sites are well known. However, many morphosedimentary patterns of potential anthropogenic origin can also be found outside known and designated areas, meaning a lack of knowledge on their spatial distribution. It is straightforward to recognize linear patterns like trawl marks in hydroacoustic data (e.g., side-scan sonar mosaics or multibeam echosounder bathymetry) as these features have a distinct morphological and backscatter character. However, the identification of other more complex structures can become challenging, especially if they have not been documented or related to any human activity. Many natural and anthropogenic structures on the seabed can have similar hydroacoustic signatures, thus in many cases, the impact of anthropogenic activities on the seafloor cannot be quantified without doubt. This study aims to characterize and define different human and natural morphosedimentary patterns on the seabed using hydroacoustic methods and ground-truthing observations to understand the differences between these features and thus better quantify the integrity of the seafloor in the southwestern Baltic Sea.

Keywords: anthropogenic processes, hydroacoustic, morphosedimentary patterns, human impact, integrity of the seafloor

Is groundwater an important seafloor geomorphic agent?

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Offshore, groundwater has been associated to seafloor geomorphic processes since the 1930s. There are a number of ways in which OFG is thought to generate landforms: (a) Development of excess pore pressure, which lowers sediment shear strength and results in sedimentary deformation or slope failure, (b) Seepage of groundwater, which can form depressions, karstic features or even retrogressive canyons. There are also a number of important knowledge gaps that hinder our understanding of seafloor evolution by offshore groundwater. These groundwater systems are poorly characterised in terms of extent, distribution and dynamics. We also lack mechanistic understanding of geomorphic processes, their rates and scales associated with groundwater erosion. Here I presents results from the MARCAN project whereby geophysical data, experimental simulations and numerical modelling are integrated to address these questions in siliciclastic and carbonate margins. I show that pore pressures generated by offshore groundwater flow can trigger slope instability in carbonate slopes during sea-level lowstands. In carbonate escarpments, fluid seeping via joints can lead to the retrogressive evolution of a box canyon via episodic block failure at the head due to a reduction in rock strength. In siliciclastic margins, flushing of saltwater by groundwater flow can reduce the shear strength of silty sediments, giving rise to shallow slope instability.

Keywords: offshore groundwater, submarine landslides, submarine canyons, geophysics, experimental simulations, numerical modelling

Terrain and geomorphological mapping in the characterisation of submarine ground conditions and geohazards

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Geomorphological mapping is commonly used onshore as a tool to enable systematic site wide characterisation of natural features in support of engineering projects. A majority of practitioners (of whom there are relatively few), have learned to map using classical morphological mapping techniques involving the identification and mapping of breaks and changes in slope planform and profile curvature (e.g. Savigear, 1965; Brunsden and Jones, 1972). The resultant morphological patterns are compared with other site characteristics (such as soil and geology) to define geomorphological units. In offshore environments, high quality bathymetric datasets lend themselves well to geomorphological mapping techniques, however, these are rarely applied in site characterisation work for offshore projects. This paper considers through the presentation of applied examples two scales of delivery of mapping: i) terrain mapping for preliminary site characterisation, and ii) detailed geomorphological mapping for geohazard characterisation, and demonstrates how these approaches add value over and above the more standard 'seabed features' maps typically produced for offshore engineering projects.

Keywords: Geomorphology, geohazards, mapping, bathymetry, engineering, risk

Late Pleistocene and Holocene paleoenvironments of a submerged karst landform (Pirovac bay, Croatia)

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The Pirovac Bay karst depression in central Dalmatia is up to 25 m deep is partially separated from the Adriatic Sea by a series of islands and shallow sills (< 5m). The present-day marine bay was studied using bathymetric and sub-bottom profiles to reconstruct the basin-wide sedimentation. A 7.2 m sediment core spanning the last 14.500 cal yr BP was analyzed. The seismic data identified up to 12 m of sediments in the deepest parts of the bay. Distinct seismic-stratigraphic units are interpreted as records floodplain, lacustrine environments, brackish to lagoonal environments, and finally a marine environment with a connection to the open sea. The marine-lacustrine transition was dated at 7.500 cal. yr BP using ostracod and foraminifera data. A freshwater lake was established sometime after 14.000 cal yr BP due to sea level rise and the lake was by karst springs from the neighboring Vrana polje (today Vrana lake). The karst lake in Pirovac Bay coexisted with the newly formed Vrana lake in the hinterland from 8.000 to 7.500 cal yr BP. The sea level rise plays an important role in controlling the sedimentation changes and formation of coastal lakes along the karst coast of the Adriatic Sea. There are uncertainties in timing of the freshwater/marine transition and its relation to relative sea level rise since the karst is permeable and the marine conditions could have been established before the flooding of the basin.

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Keywords: karst basin**,** karst paleolake, submerged landscape, seismic stratigraphy, late glacial, Holocene, Adriatic Sea

The link between geometry, lithology and modelled bottom currents in contourite depositional systems in the Mozambique Channel (SW Indian Ocean)

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Near-bottom currents related to oceanographic processes (i.e. bottom currents) can profoundly reshape the seafloor and control the distribution of sediment and related particles such as organic matter and microplastics. Multiple erosional and depositional features directly formed by bottom currents (i.e. contourites) have been identified in the Mozambique Channel (SW Indian Ocean) in multibeam bathymetry, seismic reflection and sub-bottom profiles, and in sediment cores. In this study, we characterize the morphology, stacking pattern and sedimentary characteristics of these sedimentary systems, and analyze the intensity and variability of bottom currents at these systems using a hydrodynamic numerical model. Modelled bottom currents are the strongest at abraded surfaces and moats, but they also display a relatively high variability, suggesting that the observed erosion is not the result of a constant or persistent current but rather of episodes of intense circulation. Modelled bottom currents at contourite terraces (zones with low accumulation, dominated by sand and often presenting erosional surfaces) are not significantly different from modelled currents at adjacent plastered drifts (zones dominated by mud where accumulation is enhanced). The formation of contourite terraces thus could not solely be explained by the mean ocean circulation and eddies, implying that other processes such as internal waves may play a relevant role in their formation. Finally, we propose a simplified classification of contourites that can be applied to any contourite system worldwide, and that comprises erosional and depositional features, including muddy and sandy contourite deposits.

Keywords: Contourite drift; Ocean circulation; Deep-water environment; Contour current; Bottom current; Sediment transport

Late Messinian submarine channel systems in the Levant Basin: Challenging a desiccation model

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The enigma of the Messinian Salinity Crisis (MSC) has long fascinated the geological community. It is accepted that about six million years ago, the entire Mediterranean Sea turned into a hypersaline basin for ~640ky; its fauna died, and a ~kilometers-thick salt layer accumulated on its floor. Nevertheless, the magnitude of sea-level fall at that time is still debated after more than 50 years of research. Did the Mediterranean sea-level drop by 1000–2000m, leaving large parts of the Mediterranean desiccated, as several generations of geologists were taught, or maybe salt was deposited from an extremely salty deep-water basin, as others argue? An excellent opportunity to study the MSC was given by a hydrocarbon exploration campaign carried out in the deep Levant Basin from 2009–2012, which provided high-quality seismic data tied to wells. This new data, however, did not settle the debate; on the contrary, it re-ignited the old controversy about yes-or-no-desiccation. This time, the controversy is focused on the third stage of the crisis when extreme transition occurred from hypersaline to brackish conditions – did this happen in deep waters or was it associated with desiccation? Here, we bring into the hot discussion a new observation provided by cutting-edge visualization technology. This reveals a dense net of paleo-seabed channels within a unique stratigraphic unit now buried under 500–1000m of Plio-Quaternary sediments. Aggradation characteristics of these channels indicate a deep-water origin rather than fluvial. Our conclusion adds to a previous study, which interprets a deep-water top-salt truncation.

Keywords: Messinian Salinity Crisis, Channel systems, Evaporites, Seismic Reflection Profiles

The late Quaternary evolution of a blind submarine canyon: A case study from the eastern Mediterranean Sea

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Submarine canyons are prominent features in continental slopes, playing an important role in sediment transport to the deep sea, by forming conduits for turbidity currents, and landslides caused by their steep slopes. Such mass transport events could create geo-hazards and compromise infrastructures along continental slopes. Here, we report the results of two piston-cores sampled in Nahariya Canyon (offshore northern Israel, eastern Mediterranean), at water depths of 650 m (NAC650) and 915 m (NAC915). The sediment ages were determined by 210Pb and radiocarbon dating, and their major and trace element concentrations, TOC, particle size distributions, and foraminiferal assemblages were determined. Our results show that both cores are capped by a ~40 cm interval of young (~150–200 years) laminated mud, reflecting hemipelagic sedimentation. This capping unconformably overlays a consolidated sequence in both cores. In NAC650 it is mostly homogenous, dated to ~40 ka. In NAC915 it consists of a 70 cm interval of mud clasts with disordered ages (27–46 ka), a result of a down canyon mass wasting, which overlays a homogenous glacial (25 ka) unit. Broken shells of shallow shelf foraminiferal species, indicating transported sediments, were more abundant in the transported intervals. The cores suggest that the canyon is an erosive environment at least since the LGM. The Holocene is missing from both cores, probably due to the dominance of erosion processes, except for the capping laminated layer representing the last two centuries, that reflects a down canyon mass wasting mechanism of accumulation and transportation.

Keywords: Submarine canyon, Nahariya blind canyon, Foraminifera assemblages, Taphonomy, Mass wasting, Eastern Mediterranean, Late Quaternary

Fine scale signature of bedrock erosion during submarine canyon flushing

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Submarine canyon flushing is the large scale process of sediment evacuation from canyons out into the deep ocean. Canyon flushing can deliver vast quantities of sediment and carbon to the deep ocean, transform ecological systems, and is hypothesized to be the main agent of bedrock canyon erosion. In 2016 the Kaikōura Mw7.8 Earthquake triggered a canyon flushing event that transported sediment > 560 m along the deep sea Hikurangi Channel. Pre and post shipborne multibeam data show large scale changes in the canyon floor consistent with canyon downcutting. In 2020 we collected high-resolution (1-m) multibeam and side-scan sonar data using a Hugin 3000 Autonomous Underwater Vehicle (AUV) and mapped the entire canyon floor and at the same time collected video camera tows to image the geological materials left after canyon erosion. The new data document the geomorphic signature of bedrock erosion at a fine scale and provide insight into how this occurs and the relationship with gravel dynamics down the canyon axis. The study has significant implications for understanding how bedrock submarine canyons form.

Keywords: submarine canyon flushing, seafloor erosion, turbidity currents, AUV

Seabed hydrocarbon seepage linked to overlapping subsurface fluid flow systems

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This study investigates hydrocarbon migration and seepage processes at the toe of a submarine slide, the Palmahim Disturbance (PD), and the adjacent eastern extension of the Nile fan at the base of the southeastern continental slope of the Levant Basin, eastern Mediterranean. To do this, we combined three-dimensional seismic data and visual seafloor observations, obtained by remotely operated vehicle dives in the area. Several seepage-related features, including active cold seeps, were identified. Seismic-derived bathymetry reveals two domains; the PD toe and Nile fan in the east and west, respectively. The PD toe comprises three km-scale ridges, above which seven pockmarks (100s of metres wide) were recognized. Four of these host verified seeps. In the Nile fan, multiple sub-circular pockmarks (10s of metres wide) were identified alongside two elongate pockmarks that were verified as seeps at the flanks of a channel. Seismic data analysis reveals that the PD pockmarks overlie deep anomalous high amplitude reflections, indicating gas/fluid-bearing intervals at the base of faulted and folded blocks. Nile fan pockmarks overlie pervasive sub-seafloor/shallow high amplitude reflections that terminate at the PD toe, but locally extend towards the PD pockmarks and are interpreted as gas/fluid-bearing channel and lobe sediments. Gas escape from the two gas systems occurs via lateral-to-updip and/or sub-vertical routes. Extension of fan sediments to the PD pockmarks suggests additional updip focusing of gas, complementing sub-vertical fluid flow to the PD pockmarks. We reveal evidence of two active and overlapping gas plumbing systems and variable gas migration patterns in the area.

Keywords: Hydrocarbon migration, seepage, slides, channel-lobe systems, faults and folds

Application of a two-part geomorphology mapping approach: Cretaceous to Cenozoic controls on the genesis of the shelf-incising Perth Canyon, Southwest Australian margin

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Perth Canyon's shelf-incising morphology contrasts with the more common slope-confined canyons that typify Australia's passive continental margin. The canyon has a sinuous course that extends 120 km from the shelf break (~180 m depth) to its fan at the foot of the continental slope (~4500 m). A new two-part seafloor classification approach was used to objectively map the complexity of the system in unprecedented detail. Part 1 used an established semi-automated approach to classify the seafloor bathymetry, and Part 2 defined these features as geomorphological units via the interpretation of reflection seismic, sediment samples and acoustic backscatter datasets. The resulting geomorphic map reveals an array of aggradational (cyclic steps and sediment waves), incisional (entrenched canyon floor and nick-points) and mass movement (slump and slab failures) features.

These data also reveal the Perth Canyon to be a predominantly relict feature; a large Late Cretaceous infilled incised valley (subaerial) beneath the canyon headwall likely initiated the canyon's development and represents its initial and most active phase. Two more infilled incised valleys are stacked above the first, and demonstrate a progressive decrease in scale, and presumably also canyon activity. Each incised valley represents lowstand incisions of the palaeo-Swan River, and their timing is linked to large-scale Late Cretaceous to Cenozoic sea level regression events, palaeoclimatic change, and onshore catchment enlargement. This work demonstrates the utility of the two-part mapping scheme, and highlights the need for the development of Part 2 (Geomorphology) of this two-step mapping approach.

A geomorphometrical approach to submarine landform classification

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Using the GEBCO bathymetric DEM I investigate the usability of geomorphometric methods for the classification of submarine landforms. By synthesizing the international literature on submarine landforms, I have chosen to classify and delineate automatically the following types of (i) major landforms: shelf, slope, rise, abyssal plain, seamount, sea mountain, trough, basin, plateau. Minor landforms like canyon, valley, fan, mound, ridge, knoll, guyot, sill could also be approached but are not considered now. Previous approaches were considered a critique is presented with proposals for improvements. The use of object-based segmentation, followed by the unsupervised and supervised classification, proved to be the optimal approach to follow. Segmentation of objects with similar properties regarding slope is able to delineate well the edges and the main slope units, which is the base of the major landforms: flat, gentle sloped, and steeply sloped units. The thresholds for flat and gentle vs. sloped are objective, but unsupervised approaches can help investigate global thresholds. The optimal size of the objects can be obtained through further classification based on objects' geometry and slope values. Further, the classified slope objects need to be assigned an upland or lowland status. This way, the shelf, rise, abyssal plains, and plateaus can be found. The upland vs. lowland geomorphometry can be assigned based on the relative elevation of the objects and their neighbours. The continental slope can be constrained using the already delineated shelf and its adjacent areas. The troughs and basins are approached as depressions, while seamounts are as summits.

Keywords: global bathymetry, submarine landform, geomorphometry, object-based classification, unsupervised classification, supervised classification

Sandwaves in the southern Gulf of Trieste: morphometry and granulometry

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The seafloor morphology of the southern part of the Gulf of Trieste (northern Adriatic Sea) is well known thanks to high-resolution multibeam sonar surveying. One of the most prominent seabed relief features is an (at least) 7.5 km x 4.8 km large sandwave field with bedforms rising up to 3 m above the seafloor. The bedforms have a typical crescent shape and longitudinal axes oriented in NNE-SSW, NESW, and ENE-WSW directions. The two largest barchans are symmetrical and indicate flow directions from SSW and SW. Their width is between 1500 and 2300 m and their length varies between 2000 and 3200 m. Several smaller barchans are also present within the sandwave field. Contrary to the larger bedforms, they are all superimposed, less symmetrical, and demonstrating flow directions from NE and ENE. The smaller barchans are between 700 and 950 m wide and 600 to 1200 m long. We took two gravity cores from the largest barchan: from the upstream toe (39 cm long) and near the tip of the horn (31 cm long). Granulometric analysis of samples from both cores showed a relatively uniform composition with predominant medium sand sized grains. The grain size and horn width to slip face height ratio of the barchans indicate that the sandwave field formed in submarine conditions at flow velocities in the 10–1 m/s scale. We propose that the sandwaves are periodically active during episodes of more or less unidirectional wind-induced currents, most probably related to strong "bora" and "scirocco" wind events.

3D photogrammetric classification of cold-water coral reefs with machine learning – preliminary results from Piddington mound, NE Atlantic

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Cold-water corals such as *Lophelia pertusa* and *Madrepora oculata* develop three-dimensional complex frameworks that baffle sediment and generate coral mounds. Among benthic species, CWC's play an major role on the development of microhabitats that promote enhanced biodiversity. The use of Structure from Motion (SfM) photogrammetry combined with Machine Learning techniques can provide detailed descriptors of these environments. This research focus on the application of photogrammetry techniques and machine learning to yield automatic high spatial resolution analysis of CWC reefs and seabed features. The aim is to develop a multiclass classification scheme using optimised algorithms by analysing the parameters for pre-processing, classification, and feature selection. To this end, this study analyses a range of machine learning classification algorithms to understand the impact of feature and parameter selection on the classification accuracy. Four classes and four predictor variables were chosen to best represent the benthic variability of the specific area and feature importance analysis, respectively. Seven algorithms have been tested on the 3D point clouds generated from the photogrammetric reconstructions of the Northeastern segment of the Piddington Mound (Porcupine Seabight, NE Atlantic). Preliminary results show that kernel-based methods such as Support Vector Machines yield an average F1 score of 0.66, whilst ensemble classification algorithms such as Random Forests and Gradient Boosting Trees provide an average F1 score of 0.79. The results herein and the work in progress are expected to be a baseline for more robust ML methods that can be applied in both marine and terrestrial environments.

Keywords: Cold-water Corals, coral reefs, photogrammetry, machine learning, high-resolution mapping, 3D data

Uncovering the geomorphology of a large mud volcano-mud diapir complex and adjacent deep sea in the Gulf of Cádiz (NE Atlantic Ocean)

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Fluid venting submarine structures such as mud volcanoes and mud volcano/mud diapir complexes are very common features in the Gulf of Cádiz. High resolution bathymetric and backscatter data and very high-resolution parametric profiles have enabled the geomorphological analysis and the interpretation of internal structures in the Hespérides mud volcano/mud diapir complex and the adjacent bottoms for understanding the geological processes and the relationship with the different geomorphological features. Hespérides complex is located in the middle continental slope of the Gulf of Cádiz at 670–850 m water depth, and it represents a large triangular-shaped diapiric outcrop (13.5 km^2) with a main summit and two associated mud volcanic cones. The main summit is limited to the south by 80 m high scarps. Volcanic cones are crossed by mud flows where several lobes can be differentiated. The highest backscatter values correspond to the diapiric outcrop where isolated mounds have been identified and methane derived authigenic carbonates have been recovered. The adjacent seafloor displays a variety of splattered negative reliefs, including elongated depressions around the base of volcanic cones, half-moon shaped hollows, linear furrows composed of coalesced minor linear depressions, and a large flat-bottomed basin of 2.3 km of diameter that presents numerous slide scars along its flanks. All these geomorphological features result from the interaction between fluid-venting related processes, gravitational processes and the effect of the deep water masses circulation.

Keywords: geomorphology, mud volcano, mud diapir, fluid-venting, gravitational processes, Gulf of Cádiz

Surface indicators for vertical movements offshore Mount Etna, Eastern Sicily

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Uplift features (e.g. diapirs) are described as fast-growing structures that reshape the seafloor forming steep flanks that decrease slope stability, favor landslides, change current paths, form minibasins, control the sediment deposition, distribution, and geometry. Mainly associated with the presence of salt, the recognition of diapirs in the deep sea is generally limited to the availability of costly and sparse seismic data. In the complex tectonic area of the Calabrian Ridge, the presence of active vertical movements possibly linked to Messinian evaporitic deposits outside the abyssal basin is still elusive. To better understand the area offshore Mt Etna, this project aims to exploit geomorphological indicators through surface attributes, bathymetry, and backscatter data unraveling seafloor structures related to depositional, erosional, and tectonic processes, to establish patterns and features affected and induced by uplifting. We identify changes in the channels' path, landslide scars, detached sediment waves and drifts, minibasins, escarpments, and radial faults. These features differ from the expected/natural depositional process of the sedimentary basin and can be linked back to active tectonics and vertical movements serving as proxy indicators of uplift. Preliminary results show that through seafloor observation it was possible to identify two different scales of vertical movements: a longwave uplift, affecting a broader area, deviating the channels, forming minibasins, and escarpments; and shortwave uplifts that are smaller in comparison, tectonically affected, present radial faults, and landslide scars. This approach can provide the first insight into vertical movements, especially in diapiric areas, using less expensive and widely available data.

Keywords: Seafloor geomorphology, surface attributes, uplift, salt diapir, proxies, bathymetry

Maximizing the resolution of abyssal seafloor mapping for biological and geological change detection

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The Monterey Bay Aquarium Research Institute has focused on developing systems to collect high resolution bathymetric maps of the seafloor. One approach has been to use Autonomous Underwater Vehicles (AUV) carrying multibeam sonars and operating 50 m off the seafloor, to provide 1-m lateral resolution surveys, regardless of water depth. These surveys reveal features in deep water which are unresolvable in surface ship multibeam surveys. Repeated 1-m resolution AUV surveys document on-going landscape evolution occurring over several-years intervals in geologically active areas (e.g., seafloor volcanos and submarine canyon floors). However, the amount of change that can be anticipated to occur within most abyssal areas even over decade-long intervals is too small to be captured with repeated 1-m resolution surveys. A still higher resolution seafloor visualization system, involving a suite of complementary survey technologies, is being developed with the goal of quantifying changes in seafloor morphology associated with on-going biological and geological process at abyssal depths. This system incorporates co-registered, multibeam sonar, stereo cameras, and LiDAR sensors on a remotely operated vehicle. When surveys are conducted ~2–4 m above the seafloor, lateral resolutions of 5-cm are achieved with the multibeam sonar, 1-cm with LiDAR, and 2-mm with the stereo cameras. An added advantage of the co-registered multibeam and LiDAR mapping systems is that most fauna are acoustically transparent, but optically opaque. Thus, a biomass estimate can be obtained from the difference between the images collected simultaneously by the two sensor systems in the same survey.

Keywords: Seafloor mapping, AUV, LiDAR, repeat mapping, change detection

Imaging of the plumbing system beneath pockmarks on the Chatham rise, New Zealand, with densely spaced seismic profiles

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Seafloor depressions are widespread on the Chatham Rise east of New Zealand covering over 50,000 km^2. Their distribution and sizes seem bathymetrically controlled. While larger depressions in water depths >800 m may be caused by complex interaction between bottom-water currents and fluid escape, smaller features with diameters of 150–500 m in 350-800 m water depth appear to be "classic" seafloor pockmarks related to sudden release of fluids. Buried pockmarks identified in echosounder data align with horizons interpreted as marking past glacial-stage maxima. Combined with geochemical and isotopic evidence, it has been hypothesized that these pockmarks formed from episodic release of CO_2-rich fluids at the end of glacial terminations. The CO_2 is thought to originate from the Hikurangi Plateau, a large igneous province that was subducted beneath the Chatham Rise in the Cretaceous. This origin would imply fluid migration through the Chatham Rise crust and overlying sediments transporting CO_2 for pockmark formation. Previous seismic studies have revealed extensive faulting in the sediment section, potentially providing fluid conduits. We here present initial images from a dense grid of high-resolution seismic data acquired during R/V Tangaroa voyage TAN 2006 in 2020 across a pockmark field on the western edge of the Chatham Rise. Several faults can be traced from basement highs through sediments to buried and seafloor pockmarks, some of which appear to be stacked. These results support a link between fluid migration through the Chatham Rise and formation of the seafloor pockmarks.

Keywords: Pockmarks, seafloor depressions, faults, fluid conduits, seismic reflection surveys

Tectonic geomorphology along an active strike-slip fault: the Yusuf fault system (Alboran Sea; Westernmost Mediterranean)

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The NW-SE convergence (4–5 mm/yr) between the African and Eurasian plates controls the present-day crustal deformation in the Alboran Sea (westernmost Mediterranean). Although instrumental seismicity is characterized by low to moderate magnitude events, large earthquakes (I > IX and M > 6.0) have occurred in this region (i.e., 1522 Almeria, 1790 Oran, 1910 Adra, or 2016 Al-Idrissi earthquakes). The dextral strike-slip Yusuf Fault System (YFS) is one of the largest active faults in the Alboran Sea and its seismogenic and tsunamigenic hazard needs to be characterized. The fault system trends WNW-ESE and has a length of ~150 km. Using multi-scale bathymetric data and different morphological analysis tools (i.e., slope or relief image maps), we have characterize the changes in the morphology of the seafloor along the YFS related to its Plio-Quaternary activity. The tectonic evolution of the fault system has resulted in the formation of a large pull-apart basin, which is deeper than the surrounding areas, a topographic ridge, an elongated depression and morphologic lineaments following its trend. The dataset also images several submarine landslides scars, mainly on the steeper slopes surrounding the pull-apart basin. In addition, the analysis of ultra-high resolution bathymetry acquired with AUV has revealed the presence of a series of en-echelon scarps with heights ranging from few centimeters to less than 10 meter. Seismic profiles across these scarps show that they are related to different fault strands of the YFS that are offsetting the seafloor, possibly because of an earthquake occurred in historical times.

Keywords: Alboran Sea, seafloor morphology, bathymetry, active tectonics, strike-slip faults, geomorphologic scarp, pull-apart basin

West Greenland landslides – the nearshore component: Climatic link and impact on benthic habitats

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On 17-June-2017, a rock avalanche in Karrat Fjord generated displacement waves with a runup of 10 m, 30 km away in the village of Nuugaatsiaq where four lives were lost. Catastrophic rock slope failures have happened before on the Greenland coast. About 150 km south of Karrat Fjord, Vaigat has experienced at least two large displacement waves in the last 70 years and numerous Holocene landslide deposits have been mapped. In addition to the societal impact, the submarine rock avalanche components, collectively included on mass transport deposits (MTD), drastically change the seafloor morphology impacting on marine habitats and the benthic ecosystems. Despite these consequences, the long-term history, frequency, sediment volumes and controlling factors of rock avalanches in West Greenland are not fully understood. To shed light on these coastal geohazard phenomena, expeditions to Karrat Fjord and Vaigat in 2019 and 2021 onboard RV Sanna collected ~4000 km of seismic, sub-bottom and swath bathymetry data, and a suite of gravity cores, with focus on areas of nearshore exposed slope failures. In the West Greenland Landslide project, we aim to develop detailed morpho-structural and seismic-stratigraphic analyses based on this extensive database. The key objective of our work is to understand linkages between slope instability and climate changes in West Greenland fjord settings, and the associated impacts on benthic habitats. Moreover, the project aims at improving long-term geohazard assessment of MTDs in West Greenland.

Keywords: West Greenland Fjords, rock slope failure, mass transport deposits, long-term geohazard, benthic habitats, slope instability, climate change

Integration of morpho-bathymetric data and ROV videos for the study of sedimentary processes along submarine canyons: example from Southern Italy

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The continental margin of southern Italy hosts several shelf-indenting submarine canyons having their headwall close to the coastline, which act as main collectors for sediments transported by stream outflows and/or littoral drift, from coastal toward bathyal areas. High-resolution bathymetric data were collected along some of these canyons, namely Gioia, Petrace and Punta Alice canyons, characterized by different physiographic and oceanographic settings. The analysis of bathymetric data revealed a variety of erosive-depositional features in all canyons, including landslide scars and gullies on flanks, as well as upper flow regime bedforms and knickpoints along the thalweg, mostly related to the action of recent instability processes and sedimentary gravity flows. The aim of this work is to integrate morphobathymetric data with Remotely Operated Vehicle (ROV) videos, collected between 10 and 480 m depth, in order to determine small-scale morphological and sedimentological seafloor characteristics associated with the above-mentioned erosive-depositional features and to compare them among the different canyons. A very recent sedimentary activity of the studied canyons in their upper reach is testified on videos by evidence of erosion, locally observed along the crests of the bedforms and the canyons' flanks. Squared mudstone blocks with a fresh appearance, observed at the base of the knickpoints, further indicate recent activity for sedimentary gravity flows. A strong role of riverine and coastal inputs can be inferred and is witnessed by the abundant terrestrial or coastal vegetal material and land-sourced litter, often embedded within the seafloor.

Keywords: submarine canyons, Multibeam bathymetry, Remotely Operated Vehicles (ROV), sedimentary processes, gravity flows, marine litter

Dating submarine landslides using the transient gas hydrate stability

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Submarine landslides are hazardous events that can cause deadly tsunamis and destroy costly infrastructure at the seafloor worldwide. Accurate dating of submarine landsides can indicate their origin and repeatability patterns. Yet, we lack a comprehensive record of well-dated landslides to analyze past slope failures and predict future events. We present a novel technique for submarine landslide dating that doesn't require sediment core analyses. We date a submarine landslide in the Orca Basin, Gulf of Mexico using bottom simulating reflections (BSR) below the landslide escarpment and landslide deposit in 3D seismic data. BSRs are non-stratigraphic reflections that indicate the base of the temperature sensitive gas hydrate stability zone. Submarine landslides disturb the temperature field in the sediments, and BSR can be used to predict the timing of such disturbance. We apply a numerical conductive heat flow model at two landslide-impacted locations and correlate it with the BSR-derived depth and temperature. Our modeling shows that the current temperature field established ~8 thousand years after the slope failure, which is equivalent to the age of the slide. In addition, these results indicate that submarine landslides can be impacting gas hydrate systems thousands of years after slope failures. Furthermore, we provide a rapid quick-look analytical solution for submarine slide dating that can be applicable at the continental margins worldwide, which is especially relevant with the extending public seismic databases.

Keywords: submarine landslide, gas hydrate, landslide dating, 3D seismic, numerical modeling

Submarine geomorphology north east of the Maltese Islands

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The seafloor of the Maltese Islands shows remarkable landforms, of both terrestrial and marine origin, and carry evidence of the progressive sea level rise which occurred since the end of Last Glacial Maximum. This paper focuses on the submarine geomorphological features occurring north east of the Maltese Islands, which were depicted on a geomorphological map at 1:50,000 scale covering an area of ca. 300 km^2 from northern Gozo to south-eastern Malta down to 400 m below sea level. The map was produced through the integration, analysis and interpretation of high-resolution seafloor bathymetry datasets. It shows erosional and depositional landforms mainly shaped in subaerial environments and subsequently drowned by sea level rise. The submerged landforms include structural, fluvial, gravity-induced, karst, coastal and anthropogenic features formed during the sea level lowstand of the last glacial cycle and successive deglaciation. Particular attention was given to the mapping of palaeo-coastlines. The outstanding preservation of relict terrestrial landforms on the seafloor can be related to the carbonate lithology and limited input of terrigenous sediments from inland. The study was carried out in the frame of the EU Project EMODnet Geology, aimed at collecting and harmonising geological, geomorphological and submerged landscapes data of European seabeds and making them available for the scientific community, stakeholders and general public.

Keywords: submarine geomorphology, geomorphological mapping, continental shelf, relict landscapes, climate change, Maltese Islands

How the interplay of magmatism, tectonics, and mass wasting shaped the morphology of the Christiana-Santorini-Kolumbo Volcanic field

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The Christiana-Santorini-Kolumbo (CSK) volcanic field lies in the southern Aegean Sea and is one of the most hazardous volcano-tectonic regions in the world posing a major threat to the eastern Mediterranean region. Its volcanic centers lie in a 100-km-long and 45-km-wide rift zone and include Santorini Caldera and Kolumbo Volcano, which produced the 1600 BCE Minoan Eruption of Santorini and the 1650 CE eruption of Kolumbo. Fresh fault scarps in the basin near the island of Amorgos have been associated with the 1956 magnitude 7.4 Amorgos earthquake. Although intensively studied in recent decades, the interplay between magmatism and extensional rift tectonics remains poorly constrained. We will present new high-resolution seismic data, which combined with bathymetric data, reveal how the interaction of volcanism, tectonics, and mass-wasting shaped this prominent morphological zone. Our data highlight the wide variety of morphological features comprising active fault zones, large fault scarps, young and old volcanic edifices, as well as sediment waves associated with submarine emplaced ignimbrites and debris-avalanche deposits. Several complex fault systems visible in the bathymetry and seismic data overprint the large-scale tectonic system and imply a shift in the style of tectonic deformation, which may have influenced the emplacement of volcanic features. The upcoming IODP expedition 398 "Hellenic Arc Volcanic Field" is going to drill six deep boreholes in the CSK rift basins and inside the Santorini Caldera from December 2022 to February 2023 and offers the opportunity to further constrain the morphological and seismic reconstructions.

Keywords: Volcano-Tectonics, Mass-Wasting, Santorini

Topographic constraints of submarine canyon walls on near-bottom currents

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To investigate the topographic constraints caused by submarine canyon walls on near-bottom currents, four moorings arrays were deployed in the Blanes Canyon (NW Mediterranean) at ~600 m water depth during winter and spring 2020. Two moorings were placed at a main canyon head and two at the head of a canyon tributary, in regions characterized by narrow gorges and the presence of vertical canyon walls. This study was carried out during the Spanish ABRIC Project aimed to investigate sediment transport mechanisms and their influence on suspension feeder benthic communities. Preliminary results reveal that near-bottom currents were aligned with the canyon wall orientations and oscillated up- and down-canyon mainly at inertial frequencies. The highest current velocities measured at both study sites were ~35 cm/s and directed up-canyon, although the residual flows in both monitored sites were predominantly down-canyon. Suspended sediment concentrations did not exceed 4 mg/L and they mainly increased during down-canyon flows, which contributed to a continuous and persistent transfer of suspended particles towards deeper parts of the canyon. These new findings reveal a complex interaction between local hydrodynamics and steep canyon morphologies, which ultimately affect the ambient suspended sediment transport throughout the canyon, potentially driving the settlement and development of benthic communities inhabiting submarine canyon walls.

Keywords: submarine canyons, vertical walls, bottom currents, suspended particle transport, topographic steering, benthic communities

Probability mapping for bedrock occurrence on the Irish Continental Margin: Applications for regional bedrock outcrop and habitat mapping

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The Irish continental margin hosts many complex sedimentary basins, and diverse geomorphological domains displaying bedrock outcrops that can host a large variety of habitats from shallow to cryptic fauna. More recent surveying in the Irish offshore territory has indicated extensive areas of bedrock exposure. The BeTar_Drill2 (Bedrock Target analysis for ROV RockDrill sampling) project applies novel bedrock suitability mapping to the full Irish continental margin (ICM); to determine potential habitat areas from shallow to deep domains for the entire ICM; to ground truth this mapping with petrographic analysis of physical samples correlated to existing seismic data. The project's overall aim is to improve the appraisal of the regional geology and habitat mapping of the Irish margin.

BeTar_Drill2 has improved the Bedrock Suitability Index (BSI) previously developed for the Porcupine Bank Canyon (Strachan, 2020) by fine tuning the variables to the wider margin. The improved BSI model has been constructed across the southern Irish continental margin, covering more than 140,000 km^2, producing a high resolution (25m^2) model of predictive bedrock outcrop locations. Validation by video observations and correlations of predicted bedrock exposures has established an appropriate level of confidence with BSI accuracy. The BSI mapping reveals a strong structural control on bedrock outcrop occurrence, with BSI correlating with deep structural fabrics of the margin as expressed by fault lines.

Kaikōura Canyon: Gravel waves, boulder-size sediments and erosional scours

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The Kaikōura Canyon is one of 183 active canyons worldwide known to lie within 6 km of shorelines. This shelf-incising canyon intersects the northward littoral sediment transport, with gravel input derived locally from several small rivers, local coastal erosion and reworking of post-glacial transgressive sedimentary deposits. Following the 2016 Kaikōura Mw7.8 Earthquake, repeat multibeam surveys show up to 30 m erosion into the bedrock in the axis of the canyon and > 560 m down-canyon transport of pre-existing gravel waves. Here we present new high-resolution (1-m) multibeam and side-scan sonar data acquired using an Autonomous Underwater Vehicle (AUV), together with sub-bottom profiles and Remotely Operated Vehicle (ROV) observations to provide detailed geomorphological analysis of the gravel waves, boulder-size deposits and erosional scours within the Kaikōura Canyon axis.

Our results show down-canyon variations in the geometry and changes in the gravel wave crest planform shape throughout the mid- and lower canyon (1450 to > 1800 m water depth). Moreover, the new high-resolution AUV data reveal the presence of superimposed small-scale bedforms over the large gravel waves in the lower canyon. These findings suggest that changes in the dynamics of the turbidity currents flowing down-canyon form, modify, and move the coarse-grained sediment waves. Results from this study will be incorporated into the global classification of large coarse-grained sediment waves in submarine canyons, and will contribute to a better understanding of coarse-grained sediment transport processes and their role in shaping submarine canyons globally.

Keywords: submarine canyon erosion, gravel waves, erosional scours, turbidity currents, high-resolution multibeam bathymetry, Autonomous Underwater Vehicle

Complex Morphological Changes in Seafloor Bedforms under the influence of Multi-Directional Near-Bottom Tidal Currents

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Repeat, high-resolution, multibeam surveys are crucial to identify and monitor spatial- and temporal changes in submarine bedforms, and determine their evolution patterns in extremely dynamic shallow waters (< 200 m water depth). This information is central to understanding the sediment transport processes and related hydrodynamics, but also to determine the settings for benthic ecosystems and prevent potential damage of offshore infrastructure and maritime pathways. We present three multibeam data sets acquired in 2017, 2020 and 2021 over a field of bedforms located in the high-energy Cook Strait, New Zealand. We combine the bathymetric timeseries together with ground-truth data (i.e., video footage, sediment samples) and oceanographic information (i.e., hydrodynamic modelling (RiCOM and ROMS) with in-situ observations from an Acoustic Doppler Current Profiler). Results show that coarse sand and gravel dunes with superimposed megaripples have undergone intricate morphological changes over both 1-year and 3-year timescales. The ~100-m length and ~15-m height submarine dunes crests bifurcate between 2017–2020, followed by the re-straightening of the crests between 2020–2021. Hydrodynamic data and modelling suggest there is a morphological positive feedback, created by the interaction between the multi-direction tidal near-bottom currents and the sediment transport. This study reveals the dynamic nature of the seabed over short time-scales (years) in highly dynamic areas, such as the tidally vigorous Cook Strait region. Our findings demonstrate the importance of repeat multibeam mapping in understanding of the rate and scale of changes on the seafloor.

Keywords: submarine bedform evolution, repeated multibeam mapping, near-bottom currents, multi-directional tidal currents, hydrodynamic modelling, Cook Strait

Sea level rise inundation scenarios and related risk along the North-Eastern coast of Gozo (Maltese Islands)

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With the aim of analysing the interactions between sea level rise and coastal processes, we focused our attention on the assessment of inundation risk under different climate scenarios along the north-eastern sector of the Island of Gozo (Malta). Being located in the center of the Mediterranean Sea, the area represents a key site for studies related to the evaluation of potential sea level rise impacts. Furthermore, due to the presence of urbanized areas, summer facilities and wide natural areas, the investigated coastal sector has a remarkable economic, touristic, and environmental value. For the inundation risk evaluation, we applied an index-based methodology that first requires the assessment of coastal susceptibility, expressed in terms of proneness of the coastal sectors to be influenced by sea variations and classified accordingly to the topographic elevation with respect to future sea levels. Then, the overlay of the information related to the exposure of natural and anthropic assets and vulnerability of the local population allows obtaining the risk level of the investigated sectors. To allow a more effective benefit to stakeholders, the results are provided in form of risk maps. The analysis showed that, under the worst-case climate scenario, the littoral area is prone to remarkable inundation risk in 2100. In particular, the bays of Ramla and Marsalforn were found to be the sites where expected impacts of future sea level rise will be higher if no management action is taken in the near future.

Keywords: sea level rise; vulnerability index; coastal inundation risk; Maltese Islands; Mediterranean Sea

Sea-floor morphological characterization as a tool for orienting management actions in a highly contaminated coastal site: the case of Taranto (Southern Italy)

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In this study, we analyzed the direct and indirect impacts of human activities on the seafloor of the Taranto coastal area (Apulia region, southern Italy). The site was impacted by intensive human activities since the second half of the XIX century and, being characterized by a high level of environmental risk, is included in the Italian list of contaminated Sites of National Interest. The analysis is based on the characterization of bottom morphologies derived from acoustic surveys (multibeam echosounder and side scan sonar) carried out in the framework of the interdisciplinary activities funded by the "Special Commissioner for urgent measures of reclamation, environmental improvements, and redevelopment of Taranto" in 2015 and 2017. The interpretation of the available data has allowed defining the coverage of different anthropic traces, which are mainly related to past and present shipping activities and mussel farming. Furthermore, the geospatial mapping of the identified traces has allowed elaborating, in a GIS environment, the density maps of bottom morphologies and identifying hotspot areas for which management actions should be defined. The study proposes a methodological approach for the assessment of the spatial distribution of human impact on seafloor and can be considered as a tool for supporting the implementation of coastal reclamation activities. The obtained results provide a benchmark for further investigations aimed at evaluating the evolution of morphological change and possible correlations between bottom modifications and sediment quality alteration.

Keywords: Mar Piccolo; Mar Grande; Multibeam; Side Scan Sonar; human impact

The seafloor morphology of submarine landslides – what can it tell us about landslide development?

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Submarine landslides occur around continental margins and pose significant risk to offshore infrastructure and surrounding coastal areas. These landslides reach up to thousands of kilometers in length but are rarely fully covered by reflection seismic data. This data is essential for understanding landslide development, which in turn is crucial for assessing the hazard that submarine landslides in specific areas may pose. Here, we use a unique dataset that fully covers the Ana Slide, Eivissa Channel within the Western Mediterranean Sea to identify what information the seafloor morphology of a submarine landslide can reveal about its kinematic development. We consider several questions: does the relative size of the evacuational source and accumulational sink area provide information on a landslide's mode of frontal emplacement? Can the narrowing of the translational zone between the source and sink area provide insight into geotechnical properties of mobilized landslide material? If compressional ridges are located some distance upslope of the front of the landslide, meaning its downslope-most extent, in frontally confined landslides, could this indicate multi-staged retrogressive development with successively smaller amounts of landslide material being mobilized from the source area? Among others these questions may be interpretational guidelines to provide a first-order approximation of assessing hazards posed by submarine landslide in areas without extensive seismic coverage.

Keywords: landslides, development, seafloor morphology, emplacement, retrogression, hazard, kinematics

Pliocene-to-Recent depositional pattern in the deep Levant basin and the role of the Nile River

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The Pliocene-to-Recent succession in the deep Levant basin coeval to the development of the Nile River delta and to the progradation of the thick (~1500 m) Sinai-Israel shelf. It hides a series of paleo-channels exhibiting transportation and sedimentation patterns revealing a world-class source to sink system feeding a deep (>1500 m) siliciclastic basin. The general agreement that the Pliocene-to-Recent succession originates from the Nile Delta dispersing sediments via a system of counterclockwise currents does not reveal how the sediments were transported to the deep basin. Particularly, how sediments originating from the Nile Delta could have bypassed the ~50 km wide Sinai-Israeli shelf. Based on 3D and 2D seismic data covering the shelf, slope and deep basin we map channel sets, analyze their morphological features and interpret their erosional and depositional patterns. Results show that sediment sources vary from eastward remnant Arabian drainage network at the onset of the Pliocene, to direct Nilotic origin during the Pliocene, and reworked sediments, deriving from the Israeli shelf and northern Sinai since the Late Pleistocene. In addition, channel's complexity increases since the Early Pliocene to Recent suggesting a gradual transition from sporadic submarine flow events, carrying fewer sediments to the deep basin at the Early Pliocene, to more frequent events during the Late Pleistocene-to-Recent characterized by an increase in sediment load. The gradual increase of channel complexity from Pliocene-to-Recent is discordant to the general trend of sea-level fluctuation, suggesting that sea-level has a minor effect on sediment accumulation in the deep basin.

Keywords: Submarine channels, Sediment accumulation, Levant, Nile, Source to sink, Seismic stratigraphy, Deep basin

Semi-automatic mapping for geomorphometric characterization of pockmarks

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Morphologically, pockmarks are widespread seafloor depressions (crater-like) that are caused by fluid flow seepages through the seabed sediments. In this work, we present a semi-automatic method to spatially delineate these features and characterize morphometrically them to minimize the extremely time-consuming and subjectivity of manual mapping and to get behind a robust, objective and repeatable mapping technique. The bathymetric and backscatter datasets selected to test the proposed approach were acquired within the INTEMARES and VIATAR projects and comprise 4 different study areas, with specific morphological context : a canyon head in the Mallorca Channel, a smooth area of the middle slope off Murcia coast, a sector of the intertributary platform in the Capbreton canyon system and a deep fan of the western Alboran Sea, where pockmarks occur. This method is based on a multi-stage and workflow of a geoprocessing model that allows the systematic application of a sequence of tools comprising i) optimization of the bathymetry, ii) pockmark identification using Benthic Position Index (BPI) tool, iii) pockmark contour mapping in individual polygons, iv) extraction of size, slope and shape parameters of each pockmark, v) extraction of other terrain variables and backscatter values and vi) distribution of pockmark densities. Furthermore, we tested the effectiveness of the method with the pockmark morphologies (i.e, small vs. giant depressions, merged pockmarks, eroded pockmarks), among the study cases as well as through a comparison between the manual delimitation and semi-automatic extraction of parameters.

Keywords: Pockmark, Geomorphometry, Morphological Parameters, Semi-automatic mapping

Coupling optical and acoustic remote sensing techniques in coral reef environments for geomorphological studies (Magoodhoo Reef – Maldivian Archipelago)

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Combining optical imagery and acoustic seafloor mapping data have greatly improved geomorphological mapping techniques in tropical coral reef environments. Our work made use of multisource elevation data (i.e.: satellite derived bathymetry; 3D optical models generated by applying photogrammetric techniques to UAV imagery; multibeam bathymetry) collected over the entire Magoodhoo reef, which marks the discontinuous southwestern marginal rim of Faafu Atoll, in the Maldivian archipelago. Remote data were ground-truthed using an observational ROV on the forereef and within the lagoon, and by collecting photo-transects over the reef flat. A geomorphological map of the Magoodhoo Reef was then generated, covering the entire Magoodhoo Island, the reef flat and the backreef zone, and the submerged sector of the reef to a depth of 120 m along the oceanic edge of the atoll, and 60 m along the lagoon edge. The map has led to a more detailed understanding of the processes driving the morphological changes of the entire Magoodhoo reef. The ocean ward margin shows steep terraced slopes that reveal a complex history of late Pleistocene/Holocene sea-level fluctuations, while the backreef slopes are generally gentler, although in places they may show abrupt escarpments and overhangs. We mapped several levels of submerged reef terraces on the forereef (from ~10 to ~120 m below present sea level) and a variety of reef associated sedimentary landforms in the lagoon that respectively allowed us to better investigate the mechanisms and timing of reef formation and the present morphodynamic processes governing the evolution of the island.

Keywords: Coral reef, MultiBeam EchoSounder, Photogrammetry, 3D models, geomorphological mapping, reef terraces

Could the R/V Southern Ocean transits be an opportunity to collect seabed meaningful data? The experience from ISOBATA project

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ISOBATA is a recently approved Italian National Antarctic Research Program (PNRA). It focuses on efficiently exploiting seafloor data sets collected during transit times of the Icebreaker R/V Laura Bassi within the Antarctic region. A case study area (i.e.: The Emerald Fracture Zone – EMZ – SW Pacific Ocean) has been selected to test the potential of transit acquisition in remote areas, normally affected by adverse weather conditions.

An expected output of the ISOBATA project is the compilation of a "national geodatabase of Southern Ocean Bathymetric data" and a structured "Antarctic Data Storage Repository" (developed in accordance to the National Antarctic Data Centre – NADC and the CNR), that can be shared at international level. The project aims indeed at fulfilling SCAR, CONMAP, IHO and Seabed 2030 guidelines, for an effective contribution to the mapping of Antarctic waters. Accordingly, we planned to develop best practices and dedicated workflows to implement QA in multi-beam data acquisition procedures during transit times, as well as in the processing, analysis and archiving of data and metadata. The first oceanographic expedition took place during winter 2021/2022, and made us aware of critical issues associated with collection of multibeam data in remote waters. Operational procedures need more standardization to avoid inconsistent and unreliable data acquisition. Our paper would like to open a discussion on the design of standardization procedures, which should include consideration of the geomorphological/geographical nature of the working areas and an endorsement from the maritime industry and perhaps other stakeholders.

Seismic strengthening: impacts on slope stability and post-failure behaviour of submarine landslides

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Earthquakes are a primary trigger of submarine landslides yet some of the most seismically active areas on Earth show a surprising lack of submarine landslides. We have explored this apparent paradox using shear strength measurements from 50 years of scientific ocean drilling that demonstrate within the uppermost 100 meters below seafloor, active margins have elevated shear strength by a factor of 2–3 relative to an equivalent interval on passive margins. The mechanism that leads to the strengthening is not fully clear but is consistent with the seismic strengthening hypothesis that repeated exposure to earthquake energy over time gradually increases shear strength by shear-induced compaction. This may help explain the relative paucity of landslides observed on active margins, especially where low sedimentation rates and hydrostatic pore pressure exist. However, a different result is observed in a high-sedimentation and high-seismicity setting such as the southern Alaskan offshore margin where glacially enhanced mountain erosion constructs the large Surveyor Fan. Shear strength measurements acquired by Integrated Ocean Drilling Program Expedition 341 reveal lower-than-expected sediment strength. We interpret that high sedimentation rates and fluid overpressure within the slope and Surveyor Fan offset potential strength gains from seismic shaking. When earthquake shaking is sufficiently strong to trigger submarine landslides, the post-failure behaviour and mobility of the landslide will be strongly affected by the pre-failure strength properties. In particular, seismically strengthened sediments may be more prone to produce blocky landslides, while those with limited or no seismic strengthening may more likely evolve into a liquefied debris flow.

Keywords: Seismic strengthening, submarine landslides, earthquake, hazard, ocean drilling, shear strength

Morphological reconstruction of the 1908 Messina Gravity Flow: A case study on sediment gravity flows in the western Ionian Basin, offshore Eastern Sicily

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Sediment gravity flows are geologically common events that shape the seafloor and significantly impact the global sediment transport. They can, however, also destroy submarine infrastructure and may contribute to tsunamis. Earthquakes, tsunamis and gravity flows are common processes offshore Eastern Sicily. The 1908 Messina earthquake and tsunami resulted in >60,000 casualties. It caused a large turbidity current, which broke the Malte-Zante telecommunication cable. Yet, this gravity flow is poorly characterized. This study aims to reconstruct the behavior of the 1908 sediment flow to improve the current understanding about the 1908 event and the hazard potential of these kind of flows. A comprehensive analysis of multibeam bathymetry, backscatter and sub-bottom data and information from sediment cores provide new information about this sediment flow. The easternmost canyon-channel system of the western Ionian Basin extending from the Straits of Messina south to the accretionary wedge likely was the main conduit for this gravity flow. It confluences with tributaries from north-eastern Sicily and western Calabria and led to two of three cable breaks. There are numerous scours and high-backscatter patches along its thalweg that indicate recent sediment erosion. Sediment failures along channel walls as a result of flow undercutting and the presence of sediment basins indicate repeated sediment transport through this conduit. Gravity flows along the Sicilian margin south of Fiumefreddo Valley (<37.8°) in comparison, are restricted to the tributary systems and do not travel far from the margin. The new results will be used to evaluate the role of gravity flows for tsunamis.

Keywords: submarine gravity flows, 1908 Messina event, turbidity current, tsunami, cable breaks

Distribution, timing, and potential trigger mechanisms of submarine landslides in Pangnirtung Fiord, eastern Baffin Island, Nunavut

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High-latitude fiords are susceptible to submarine and subaerial landslides that can affect low-lying coastal communities and damage essential infrastructure. Most fiords surveyed in Baffin Island, including Pangnirtung Fiord, show evidence of submarine landslides, although their timing is relatively unknown. Using multibeam echosounder data, sub-bottom profiles, and gravity cores collected in 2019, this study sought to generate a comprehensive understanding of the distribution, timing, and potential trigger mechanisms of submarine landslides in Pangnirtung Fiord. In total, 180 submarine landslides were delineated, with an average area of ~0.13 km^2. Of eleven landslides dated using 14C AMS dating and 210Pb/137Cs activities, eight are younger than 500 years, indicating that modern processes should be considered to determine potential triggering mechanisms. Four categories of landslide triggers were identified; 53% are associated with subaerial sources and 31% are influenced by shallow-water, non-subaerial triggers. This suggests that most landslides in Pangnirtung Fiord are triggered by processes such as rapid flood-water input, subaerial debris flows, and sea-ice loading during low tide. Most submarine landslides do not appear to have the capacity to initiate a tsunami because of their small size. However, tsunami modelling simulations for the largest submarine landslide (2.1 km^2; 25 million m^3), which occurred about 2500 years ago offshore the Kolik River delta, show that it had the ability to generate 2-m-high waves. The interaction of subaerial and submarine processes suggests that a potential rise in the occurrence of subaerial debris flows and flooding due to climate change may increase the frequency of submarine landslides.

Keywords: landslides, geohazards, tsunami, triggers, mass movements

Holocene paleoenvironmental reconstruction of the karst Krka river estuary (Eastern Adriatic Coast)

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The Krka River Estuary is a microtidal karstic salt-wedge estuary located in the central Dalmatia (Croatia). The upper part of the estuary, i.e. the submerged narrow canyon and the Prokljan Lake, was studied for the first time by multiproxy analyses of 5 sediment cores supplemented with bathymetric and high-resolution seismic data. The aim was to identify the main processes controlling the sedimentary infill and to reconstruct its paleoenvironmental evolution during the Holocene. The study revealed a unique and well preserved submerged paleolandscape with an evolution from lowstand fluvial and lacustrine environment to transgressive and highstand estuarine to marine conditions. Seismic data showed a Pleistocene fluvial incised Krka River valley, with low accumulation rates and sediment bypass towards the Adriatic shelf. At the beginning of the postglacial transgression, a favorable conditions were established for the growth of tufa deposits in the form of barriers with waterfalls. Erosional power of the river was low during this period and fluvial to lacustrine sediments started to accumulate. With further sea level rise, at approx. 10000 y BP, the sea started to inundate the Prokljan Lake. This led to the cessation of tufa growth and the deposition of the estuarine muds with the establishment of the fully estuarine/marine salt-wedge conditions during the highstand (approx. 7500–7000 y BP). Our study revealed a very dynamic paleoenvironmental evolution of the estuary controlled by a rapid sea level rise, local geomorphology and hydrodynamics.

Keywords: salt-wedge karstic estuary, sea level, submerged landscape, seismic stratigraphy, sedimentary infill, Eastern Adriatic Coast, Holocene

Mud and fluid migration in active mud volcanoes offshore Scoglio d'Africa islet (Tuscan Archipelago, Northern Tyrrhenian Sea)

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Fluid migration and active seepage at the seafloor are global phenomena documented in different geodynamic contexts. Scoglio d'Africa islet is a dominant physiographic element of the Elba-Pianosa Ridge where submarine methane emissions have been studied since the 1960 and where a violent gas outburst occurred in 2017. This study focuses on the morphological analysis of the mud volcanoes and pockmarks characterising this area. We integrate high resolution multibeam (bathymetry and backscatter) and ROV videos to infer the state of activity of these features. The mud and fluid migrating through a thick Eocene-Early Miocene siliciclastic succession and overlying sedimentary layers form a number of mud volcanoes characterised by conical shape and steep flanks. They are few hundreds of meters wide and sometimes display a flat summit with hummocky morphology between 10 and 25 m depth. The seafloor morphology in the area is also characterised by more than 250 small pockmarks with sub-circular planform shapes and U/V-shaped cross-section located between 20 and 60 m and predominantly arranged in clusters or oriented ca. N-S, running parallel to the main structural morphologies of the area. Where the gases leakage from the seafloor, they rise through the water column as focused gas bubbles that were documented by ROV videos, confirming the active fluid migration in the area. Considering the event occurred in 2017 and the shallow water setting of these features, their characterization is important since they can herald marine geohazards around Scoglio d'Africa region.

Keywords: Mud Volcanoes, Pockmarks, Methane, Mud Breccia, Fluid Flow, Elba-Pianosa Ridge

The geomorphology of the continental shelf around Scotland, United Kingdom

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The continental shelf around Scotland covers an area of ~286,500 km^2, around 3.5 times the size of the Scottish landmass, owes much to the Cenozoic geological history of NW Europe. Superimposed on this, at a smaller scale, is a vast and largely well-preserved array of submarine landforms recording key global and regional events spanning the last ~1 Ma. This relatively shallow underwater realm (mainly <200 m water depth) boasts extremely varied geomorphology: from small individual landforms (<100 m^2) to large extensive landsystems (>1000 km^2). These landforms and landsystems relate to both past terrestrial processes, when global sea levels were >100 m lower than at present, and more recent marine processes, active since sea levels rose. This presentation outlines the main geomorphological landsystems found on the shelf, highlighting notable landform examples imaged in high-resolution digital bathymetry data.

Many of the landforms have remained exceptionally well preserved since deglaciation, unlike on land, having not been subject to significant disturbance by human activity. However, human disturbance of the seabed has been increasing over the last 50–60 years, with geomorphological evidence of the commercial fishing, hydrocarbon extraction and renewable energy industries all clearly evident on the seabed. Offshore activities have been geographically restricted with the introduction of government legislation and the subsequent establishment of the Marine Protected Areas network – now covering around 22% of Scotland's seabed. In the coming decade, further conservation of Scotland's unique submarine geoheritage and seabed geomorphology should be encouraged, especially where these landforms host rare or valuable ecosystems.

Keywords: Glaciation, Multibeam bathymetry, Seabed landforms, Sea-level change, Marine geoconservation

Submerged landscapes across European seas

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on behalf of the EMODnet-Geology partners

The EMODnet Geology project is delivering integrated geological map products across all European Seas and now includes the Caspian and Caribbean seas. A dedicated work package works to compile and harmonize available information on submerged landscape features by integrating existing records of palaeoenvironmental indicators with interpretations of geomorphology, stratigraphy and type of sediment. The fully attributed GIS layer now comprises more than 16,000 features representing 27 classes of submerged landscape and palaeoenvironmental indicators including mapped and modelled palaeocoastlines, evidence for submerged forests and peats, and submerged freshwater springs across all European seas. Sea level is known to have fluctuated by more than 100m over repeated glacial cycles, resulting in recurring exposure, inundation and migration of coastlines not only across Europe but worldwide. Landscape response to these changes in sea level, and the preservation of these features on continental shelves around Europe, are an invaluable resource for improving our understanding of human history and environmental change over geological time, whilst also providing data for potential use in examining future sea-level rise scenarios. This presentation will explore the use of these harmonised products to underpin regional palaeogeographic reconstructions at 20000, 9000, and 6000 years BP during the current phase of the project.

Keywords: Submerged Landscapes, Palaeoenvironment, sea-level, Palaeogeographic reconstruction, Last Glacial Maximum

The new bedform-velocity matrix for contourite systems

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The impact of bottom currents in moulding the deep seafloor is well known. Long-term erosion creates widespread hiatuses, contourite channels and other erosive features, whereas deposition leads to the construction of mounded and sheeted contourite drifts. In both cases, the seafloor beneath these bottom currents is characterized by a variety of smaller-scale erosional and depositional bedforms that provide valuable information about flow direction, strength, variability and continuity. Since publication of our *bedform-velocity matrix*, a wealth of new data has become available, for example on mud, sand and gravel giant sediment waves, seafloor honeycomb structures, and large crescentic scours. Shallow-water contourite systems (50–300 m water depth) and sand sheets reveal high-energy bedforms in coarser-grained contourites. A new sortable silt and sand (SSS) proxy has been developed for calibration of current speed from sediments up to fine sand size[2].
In coarser sediments, grain size must be cross-correlated with bedform to infer current speeds.
for application to bottom current systems. Despite imperfections, these are valuable models for assessing strength and variability of bottom currents, which can significantly influence the siting of submarine cables, pipelines and other seafloor installations.

Keywords: contourites, bedforms, bottom-current speed, sortable silt and sand proxy

A Scalable, Supervised Classification of Seabed Sediment Waves Using an Object-Based Image Analysis Approach

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National mapping programs (e.g., INFOMAR and MAREANO) and global efforts (Seabed 2030) acquire large volumes of multibeam echosounder data to map large areas of the seafloor. Developing an objective, automated and repeatable approach to extract meaningful information from such vast quantities of data is now essential. Many automated or semi-automated approaches have been defined to achieve this goal. However, such efforts have resulted in classification schemes that are isolated or bespoke, and therefore it is necessary to form a standardised classification method. Sediment wave fields are the ideal platform for this as they maintain consistent morphologies across various spatial scales and influence the distribution of biological assemblages. Here, we apply an object-based image analysis (OBIA) workflow to multibeam bathymetry to compare the accuracy of four classifiers (two multilayer perceptrons, support vector machine, and voting ensemble) in identifying seabed sediment waves across three separate study sites. The classifiers are trained on high-spatial-resolution (0.5 m) multibeam bathymetric data from Cork Harbour, Ireland and are then applied to lower-spatial-resolution EMODnet data (25 m) from the Hemptons Turbot Bank SAC and offshore of County Wexford, Ireland. A stratified 10-fold cross-validation was enacted to assess overfitting to the sample data. Samples were taken from the lower-resolution sites and examined separately to determine the efficacy of classification. Results showed that the voting ensemble classifier achieved the most consistent accuracy scores across the high-resolution and low-resolution sites.

Keywords: object-based image analysis (OBIA), seafloor classification, bathymetric derivatives, multibeam echosounder, spatial resolution

A multitude of glide planes characterizing the proximal Sahara Slide Complex, NW-Africa

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Weak sediment layers, that have a lower strength than adjacent units, can play a critical role in preconditioning submarine slopes for failure. Often these layers follow stratigraphic horizons. The Sahara Slide Complex affected about 50,000 km^2 of the northwestern African continental margin with slope gradients <6°. A remarkable characteristic of the proximal slide complex is, that failure occurred along six individual glide planes that are located at different stratigraphic depths. These glide planes can be mapped in sub-bottom profiler and seismic reflection data from the headwall area of the slide into the adjacent un-failed sections of the slope. In the latter areas, the glide planes are characterized by high-amplitude reversed polarity continuous reflections.

The stratigraphic unit that hosts the glide planes can be traced to DSDP Site 397, showing that the six glide plains were deposited since the late Pleistocene (~500 Ka). Considering their cyclic occurrence, timing of deposition over the last 500 ka, and similar seismic nature we discuss whether the six glide planes may be of similar genetic origin? In this case, their regular deposition might be controlled by the main (~100 ka) glacial/interglacial cycles in the Quaternary. Through examining sedimentary records from scientific ocean drilling along the northwestern African continental margin we search for stratigraphic layers with a cyclic deposition pattern that host the geotechnical properties to act as weak layers in large submarine landslides.

Keywords: Weak layers, Glide plane, Slope stability, Submarine landslide, Northwestern African continental margin

Seafloor morphology, offshore faulting and implications for submarine landslides in the Aegean

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The current study intends to provide a better understanding of submarine landslides triggering mechanisms in the Aegean Sea. Mapping, spatial distribution and structural analysis of submarine landslides, are correlated with active offshore faults and geomorphological characteristics of the seafloor with the aim to identify submarine slopes prone to failure and assess tsunami probability. Preliminary results of systematic research, based on processing and interpretation of swath bathymetry and seismic data, show that: Roughly 30% of the total surface of the Aegean's seafloor is steeper than 5% and up to 40% or higher. Roughly 90% of the seafloor is shallower than 1000 m. The steep slopes are oriented preferentially along NE-SW and NW-SE directions and are controlled by active faults. The majority of the observed slope failures occur at the shelf edge or the upper slopes. Shallower slope failures occur mostly off river mouths. The width of the scars does not exceed 4–5 km and the height does not exceed a few tens of meters. Maximum run-out distances are smaller than 20 km and the volume of the involved masses ranges between a few hundred m^3 and 0.5 km^3. Most of the observed slope failures are debris flows or slumps, while rock falls occur on very steep slopes free of sediments or on slopes of volcanic origin. The assessment of landslide risk zones in the Aegean region, which consists of dozens of inhabited islands, is necessary as submarine landslides are one of the most important potential marine geo-hazards in the region.

Keywords: submarine landslides, tectonics, geo-hazards, geomorphology, Aegean, slope stability, bathymetry

State of the art in the study of volcanic flank collapses

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Gravitational forces act on the steep and commonly unstable flanks of volcanoes. This can lead to flank deformation on a variety of temporal and spatial scales ranging from slow creep to catastrophic sector collapse. The catastrophic collapse of the volcano Anak Krakatau in the Sunda Strait (Indonesia) on 22 December 2018 caused a tsunami with >400 fatalities. The largest part of coastal and ocean island volcanoes, as well as the remnants of their past collapses, are often below sea level. Using examples from different volcanoes worldwide, we show how seafloor morphology, geophysical imaging, seafloor geodesy, and numerical modelling can help to reconstruct past flank collapses and to understand the present state of unstable volcano flanks. From these observations, we propose that flank collapse involves two processes that are potentially linked: large-scale slow flank sliding on a deep detachment (the interface to the pre-volcano basement) and catastrophic collapse of a fraction of the sliding flank along a shallower failure surface. Better understanding of this link is crucial for assessing the hazard associated with the numerous marine or coastal volcanoes worldwide that are known to have seaward-sliding flanks.

Keywords: marine geohazards, volcano flank collapse, submarine landslide, tsunami, flank instability

High resolution mapping of coralligenous bioconstructions offshore South-Eastern Sicily as a baseline for (bio)geomorphological studies in marine setting

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Coralligenous Bioconstructions (CB) include calcareous build-ups of biogenic origin that typify selected regions of the Mediterranean continental shelves, where they formed since the Holocene transgression. They can be from few to tens of meters large, displaying variable lateral continuity and thickness. Offshore Marzamemi (south-eastern Sicily, Ionian Sea) the occurrence of peculiar columnar-shaped CB have been documented in 2002, but their actual extension and distribution across the shelf was not known until recent time. The project "CresciBluReef: New technologies for knowledge and conservation of Mediterranean reefs" produced a new17 km^2 high-resolution bathymetric map using a R2Sonic2022 MBES, ground-truthed by ROV observations, that generated a good knowledge of the extension of CB in the region. The bioconstructions are preferentially distributed along selected depth ranges (from 30 to 40 m, and from 85 and 95 m of w.d.), with a good lateral continuity. The coupling of documented uplift rate (ca. 0.2 mm/yr since the Tyrrhenian time) and evidences reported in literature for Holocene relative sea-level curves, shows a good correlation between the distribution of CB and local and short stasis associated to the rapid Flandrian transgression. However, as revealed by the geomorphological map obtained by our study, a more in-depth investigation is needed to understand (1) the role of the inherited continental shelf landscape, shaped by previous low-stand periods, in creating favourable substrate for the settlement and growth of CB during the Holocene, and (2) the extent to which CB can in turn affect the evolution of present-day continental shelf landforms and landscapes.

Keywords: Coralligenous, marine bioconstructions, submarine geomorphology, seascape, marine DTM, sea-level changes, biogeomorphology

Towards high-resolution pseudo-3d imaging of seafloor pockmarks using dense echo-sounder profiles

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Seafloor depressions are common features observed on the ocean floor. Their shape and size can range from small, circular indentations (10s m) up to large, often irregularly shaped depressions (several kms in diameter). The origin of depressions is often attributed to focused fluid or gas seepage at the seafloor ('pockmarks') but remains ambiguous in many cases. Seismo-acoustic imaging allows the investigation of potential fluid-flow pathways and buried 'paleo' pockmarks. 3D multi-channel seismic surveys provide comprehensive insights of the imaged subsurface but the acquisition of 2D profiles is far more common. The lower frequencies (~20–1000 Hz) of traditional marine seismic sources (e.g., air guns or sparkers) provide deeper subsurface penetration at the expense of vertical resolution. In contrast, high-resolution imaging of shallow subsurface features can be conducted using hull-mounted, parametric sub-bottom profilers that are available on most larger research vessels. Higher frequencies (>1 kHz) and narrow acoustic beams provide very high vertical resolution in the decimeter range and small lateral footprints capable of resolving smaller structures than using conventional seismic. A recent voyage acquired an extensive grid of closely spaced (~25 m) 2D sub-bottom profiles over a dense pockmark field on the Chatham Rise, offshore New Zealand's South Island. Here we present a novel approach to create a pseudo-3D volume from high-resolution 2D profiles to enable detailed interpretation of buried pockmarks in the shallow subsurface. Pre-processing steps such as despiking, tide compensation, static and mis-tie corrections are applied to enhance data quality before interpolating empty traces in the output volume.

Keywords: pockmarks, seafloor depressions, pseudo-3D, sub-bottom profiler, sediment echosounder, interpolation

Anchoring by high-tonnage vessels: a global driver of seabed damage

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With the SARS-CoV-2 coronavirus came what media has deemed the "port congestion pandemic". Since it began, thousands of ships have been reported waiting outside heavily congested ports relying on anchoring gear to hold fast. While the shipping industry is known to contribute to air, water and noise pollution, the physical impact of shipping practices, such as anchor use on the seafloor, has received much less attention. With a regional survey using high-resolution (1 m) bathymetry data of a comparatively low congestion port in New Zealand-Aotearoa, we demonstrate that high-tonnage ship anchors excavate the seabed by up to 80 cm and the associated impacts are preserved for at least 4 years. This is the first characterisation of the intensity and extent of damage to the seafloor and benthic environment caused by high-tonnage ship anchoring. We demonstrate that the observed seabed damage is attributed to high-tonnage passenger and cargo vessels. Anchor use in port regions has significantly changed the structure of the seafloor, with downstream impacts on benthic habitats and ecosystem functions. Extrapolating these findings to a global scale, we estimate that between 6,000 and 20,000 km^2 of coastal seafloor is adversely affected. With the predicted increase in global marine traffic, a less destructive method of managing high-tonnage vessels awaiting port calls is necessary to mitigate the impact of maritime activities on chemically and biologically important shallow marine environments.

Keywords: Anthropogenic impact, maritime operations, seabed damage, anchoring, repeat multibeam mapping, benthic ecology/biogeochemistry

The underwater landslide archives of Aotearoa/New Zealand: Documenting occurrence or preservation bias?

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Documenting and characterising ancient submarine landslide features is fundamental to understanding their distribution and frequency through time. Such information is critical to assess modern hazard potential of submarine landslides. The availability of marine geophysical data spanning ~1,200 km along the eastern Aotearoa/New Zealand provides an excellent basis to map regional trends in landslide occurrence, and better constrain the causes of submarine landslides. Expansive and high-quality bathymetry data have already been used to catalogue >2,200 submarine landslides to understand potential geomorphic and tectonic controls on their emplacement. Of those landslides mapped in bathymetry data, only 1% showed evidence of a preserved Mass Transport Deposit (MTD), and most (68%) landslide scars occur within submarine canyon systems. This suggests that the preservation of MTD in the geological record is rare, and that submarine canyons may be more prone to failure. We present and compare surface landslides with the complementary subsurface database that documents MTD in all available seismic reflection data. Data were collated from >30 marine surveys, encompassing >43,000 km of seismic lines. The subsurface dataset reveals >700 individual observations of MTD, with initial results showing preferential preservation within basin structures and on open continental slopes. The disconnect between the distribution of surface and subsurface MTD suggests the number of MTD preserved in the subsurface likely represents a gross underestimate of landslide occurrence in the geological record. Furthermore, we pose the question: do regional observations of submarine landslide occurrence reflect true tendencies of slopes to fail, or does preservation bias muddy the waters?

Keywords: Submarine landslides, marine hazards, multibeam data, seismic reflection data, mass-transport deposit

How do bottom currents control the development of moats and their associated contourite drifts?

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The interaction of sedimentary systems with oceanographic processes in deep-water environments is still not well understood, despite its importance for improving paleo-reconstructions, and for understanding source-to-sink sediment transport. Moats are elongated depressions formed by bottom currents, that are oriented along slope and typically found along continental slopes or seafloor irregularities. They are associated with bottom current driven sediment deposits (contourite drifts) along one of the moats sides. The aim of this study is to improve our understanding of how moats and their associated mounded drifts are formed. We analysed the morphology and stratigraphy of moats in different parts of the world ocean. The median width of moats is 2.3 km, relief is 50 m and the relief-width ratio is 0.02. Most (78%) moats show an aggradational stacking pattern. Thus, on average (at present day) most moats are not erosive but rather less sediment is deposited compared to the drift alongside. Coriolis force has a great influence on the wind and ocean circulation, but it seems to have only a small influence on the moat morphology, which is strongly controlled by the morphology of the slope. We found that at a steeper slope, the drift is also steeper. Possibly, steep slopes focus and narrow the main core of the current. The gradient of speed between inside and outside the moat (i.e. on the contourite drift) is higher in a narrow core of a current. We suggest that narrow current cores at steep slopes lead to a higher drift angle.

Keywords: Contourite system, Ocean current, Sediment transport, Sediment processes, Deep-water environment, Seismic data, Bathymetry

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