Francesca Budillon, Massimo Magagnoli, Paolo Tommasi, Renato Tonielli, Fabrizio Zgur, Alessandra Avalle, Alessandro Conforti, Gabriella Di Martino, Lorenzo Facchin, Marcello Felsani, Sara Innangi, Antonio Mercadante, Roberto Romeo, Lorenzo Sormani, Gianpaolo Visnovic

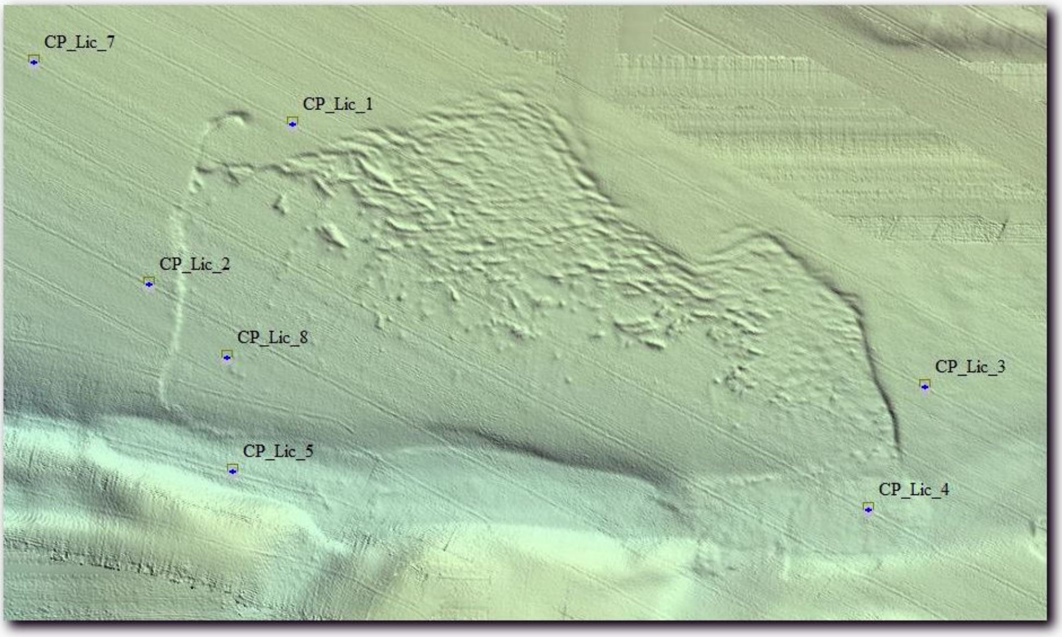
CRUISE REPORT

SAOS 2014
- Stability Assessment of an Open Slope -

Licosa submarine landslide survey

R/V URANIA

September, 2–10, 2014



Istituto per l'Ambiente Marino Costiero – Consiglio Nazionale delle Ricerche – CNR Napoli

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) – Trieste

Istituto di Geologia Ambientale e Geoingegneria – Consiglio Nazionale delle Ricerche – CNR Roma

With the technical support of Carmacoring s.r.l.

Area: Licosa offshore (Southern Tyrrhenian Sea – Italy, 40°08.166'; 14°44.438')

Abstract

The SAOS (Stability Assessment of an Open Slope) 2014 cruise was carried out in September 2014 (2nd-10th) on board R/V Urania, led by IAMC CNR (Naples) in collaboration with OGS (Trieste) and IGAG CNR (Roma), in the frame of Ritmare flagship-project activities. The cruise was aimed at the sampling of undisturbed stratigraphic succession of marine sediment in the surroundings of large slidescar along the slope of the South-eastern Tyrrhenian Sea to learn more on the mechanical and physical properties and pore water content of layers that are prone to fail. In low-gradient, open-slope settings, translational slides are the most frequent sediment failures phenomena and generate for the reduction of the shear strength or the liquefaction of weak layers, when dynamically solicited. This approach is essential to identify layers of regional extent that may compromise the stability of a large amount of sediment along the continental margin and thus representing potential geological hazard. To achieve these objective we employed a fall-controlled coring device, to retrieve mostly undisturbed sediment sections, high resolution swath echosounder, to implement residual maps of the slide scars at seabed and high resolution multichannel seismics, to verify the extension and the relevance of regional structural lineaments and their relation with recent deformation of superficial strata packages.

1. Introduction and aims of the research:

One of the most demanding aspects of the research on geomorphic processes in marine environment is to accomplish reliable numerical models of submarine slope stability. In low-gradient, open-slope settings, translational slides are the most frequent sediment failures phenomena (Camerlenghi et al., 2010) and generate for the reduction of the shear strength of weak layers when dynamically solicited. Thus, there is a growing need to learn more on the mechanical and physical properties and pore water content of marine sediment successions that are prone to fail. This approach is essential to identify layers of regional extent that may compromise the stability of a large amount of sediment due to their shear strength reduction or tendency to liquefaction. One of the most used approach, besides in situ piezocone measurements (CPTU: Cone Penetration testing), are laboratory tests for establishing mechanical properties of terrains by measuring density or unit weight, compressional wave velocities, grain-size, vane shear test, water content measurements, consolidation tests on cored sediment samples. These latter are propaedeutic to all other tests and should represent a necessary base-of-knowledge to approach any other subsurface geotechnical investigation.

The SAOS (Stability Assessment of an Open Slope) 2014 cruise was aimed to sample a stratigraphic succession of marine sediment, by coring procedures, in a sector of the South-eastern Tyrrhenian margin that is prone to fail. Recent extensive morpho-bathymetric surveys, aimed to cartographic purposes and geo-hazard prevention (Carg and Magic Project), have highlighted that at least four areas along the slope off Campania coast had failed in the last 200 ka. We have observed that the most common failure process is the translational slide above stratigraphic surfaces, widely occurring in the subseafloor (first 30 ms bsf). Specifically, the study area is off Licosa Cape where a about 30 kmq of a Late Pleistocene sediment succession failed about 11 ky BP (Trincardi et al., 2003; Bellonia et al., 2008; Iorio et al., 2014), leaving at the seafloor a slidescar 5-10 m thick (Fig.1).

To achieve the main objective of the cruise, i.e. to core mostly undisturbed stratigraphic sections of the failed sequence, we relied on a CP20 piston-core (10 cm diameter, 10, 15, 20 m long) of Carmacoring srl, that is suited to retrieve long cores by using free-fall or fall-controlling devices, with different configuration among head weight, length of free fall and length of tubes, in regards with lithology of the subsurface.

Secondary objective of the cruise was to acquire high resolution seismic data in the first 1.5 s below the seabed, to verify the extension and the relevance of regional structural lineaments and their relation with recent deformation of superficial strata packages. To achieve this target we employed the multichannel acquisition system of OGS that includes a Mini Gi gun and a 300 m-long streamer with 96 channels.

Third objectives of the cruise was methodological and aimed to define the reliability of coring procedures by using free-fall or fall-controlled devices. Results have been verified primarily on board by comparing the real sediment compaction in twin cores (retrieved by using different methods) with a loop sensor core logger (Geotek) to check magnetic susceptibility peak-to-peak correlation of correspondent sedimentary layers.

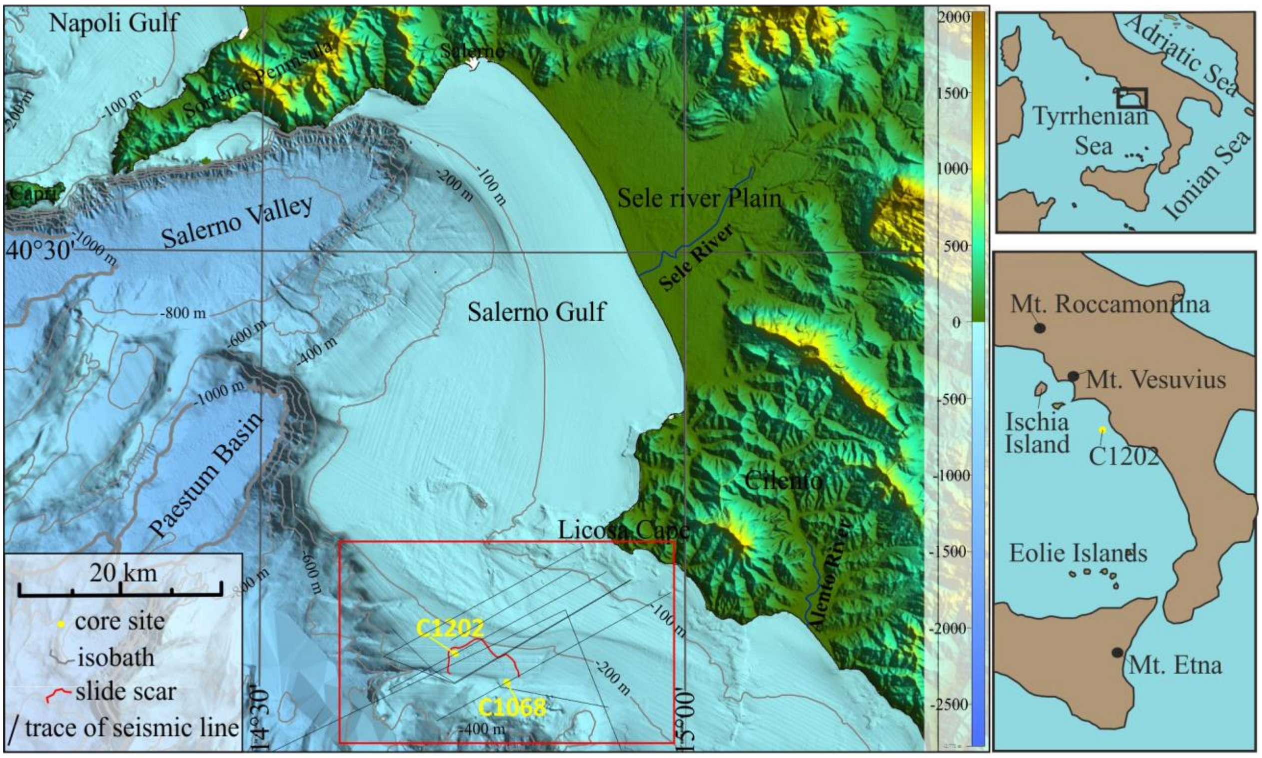


Figure 1 – Location map of the Licosa slide and the working area. Seismic line tracks and core sites refer to former data set

Corollary objectives of the cruise have been also:

- to complete the DEM of the area by surveying the distal depositional sector of the slide terrains at the mouth of the structural channel;
- to assess the seismic-stratigraphic relations between the landslide and the 5 km-distant giant pockmark area, by acquiring a grid of high resolution seismic data;
- to test the reliability of fall-controlled devices applied to the piston corer, to retrieve undisturbed sediment sections, compared to standard equipment by simple piston corer;
- compare the reliability of quick handle testing through various grain-sized deposits with lab-test results.

2. Working Strategies

As usually scheduled on board and for the sake of operators' safety, we have carried out sampling operations during the daily hours and seismic profiling at night. Four teams, in turns, operated at the seismic acquisition, coring operation, core splitting and lab testing, navigation control. Teams were as follows:

Table 1 - participants to SAOS 2014 cruise

Scientific staff	skill	institution
Francesca Budillon	Chief scientist	IAMC CNR - Napoli
Renato Tonielli	Resp. MBES/SBP acquisition	IAMC CNR – Napoli
Sara Innangi	MBES-Nav-SBP Chirp	IAMC CNR – Napoli
Gabriella Di Martino	MBES-Nav- SBP Chirp	IAMC CNR – Napoli
Marcello Felsani	MBES-Nav- SBP Chirp	IAMC CNR – Napoli
Alessandro Conforti	Lithostratigraphy	IAMCCNR - Oristano
Antonio Mercadante	Petrophysical analysis	IAMC CNR - Napoli
Paolo Tommasi	Resp. Geotechnical analysis	IGAG CNR - Roma
Alessandra Avalle	Geotechnical analysis	IGAG CNR - Roma
Roberto Romeo	Geotechnical analysis	OGS - Trieste
FabrizioZgur	Resp. Multichannel Seismic	OGS - Trieste
Lorenzo Facchin	Multichannel Seismic	OGS - Trieste
GianpaoloVisnovic	Multichannel Seismic	OGS - Trieste
Lorenzo Sormani	Multichannel Seismic	OGS - Trieste
Massimo Magagnoli	Resp. Coring operations	Carmacorings.r.l.
Benedetto Aiello	Coring operations	Carmacorings.r.l.
Daniele Ivani	Coring operations	Carmacorings.r.l.
Matteo Verocai	Coring operations	Carmacorings.r.l.

2.1 Coring operations

The Carma® piston corer (PC) was operated on the broadside by means of two winches and a stinger support to recover the tubes (Fig. 2). The configuration of the PC was variable in weight (from 1250 kg to 1850 kg), length of tubes, length of the slack for controlling the high of free-fall; a trigger for releasing the PC has been armed as well. Three tests were made, using the "Angel descendent" control to reduce the speed of core penetration in sediments. This is needed to reduce deformation and sediment shortening and is becoming a compelling requirement by offshore companies. When using the AD device, however, a general reduction in penetration has been observed. Best results in terms of sediment recover were achieved in site Lic_2, where a 9,00 m of sediment were retrieved over a penetration of about 11 m below the seabed, using the free-fall configuration and 15 m-long tubes.

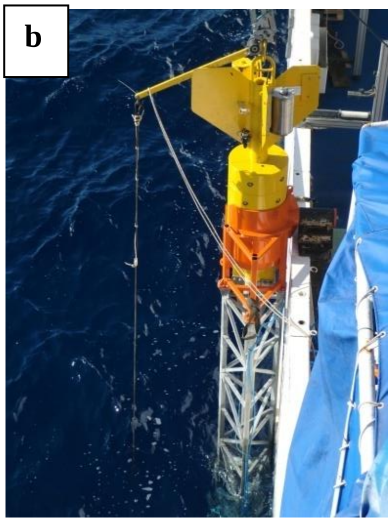
 

Figure 2 - The CP 20 a) during assembling operations and b) ready for use

Cored sites are:

Table 2 - list of cores, location (Lat, Long), depth and retrieved section

date	denomination	latitude	longitude	depth	retrieved section
04/09/2014	SAOS3	40°07.4789'	14°48.2654'	-240 m	5,05 m
04/09/2014	SAOS2	40°07.9258'	14°43.1636'	-259.5 m	8,20 m
05/09/2014	SAOS2_R	40°07.9269'	14°43.1648'	-259 m	9,00 m
05/09/2014	SAOS3_R	40°07.4784'	14°48.2651'	-241 m	7,26 m
06/09/2014	SAOS5	40°06.954'	14°43.737'	-302 m	5,35 m
06/09/2014	SAOS8	40°07.5468'	14°43.6944'	-270 m	6.57 m
06/09/2014	SAOS10	40°08.1662'	14°44.4382'	-233 m	6,70
07/09/2014	SAOS90	40°37.76'	14°42.38'	-104 m	7,71
07/09/2014	SAOS_2_ter	40°07.9271'	14°43.1641'	-259 m	4,17 m
08/09/2014	SAOS_AD	40°18.188'	14°16.319'	-673 m	7,60 m
08/09/2014	SAOS_FF	40°18.1885'	14°16.3197'	-672 m	9,30 m
08/09/2014	SAOS_PZ3	40°47.2455'	14°06.7041'	-99 m	3.8 m

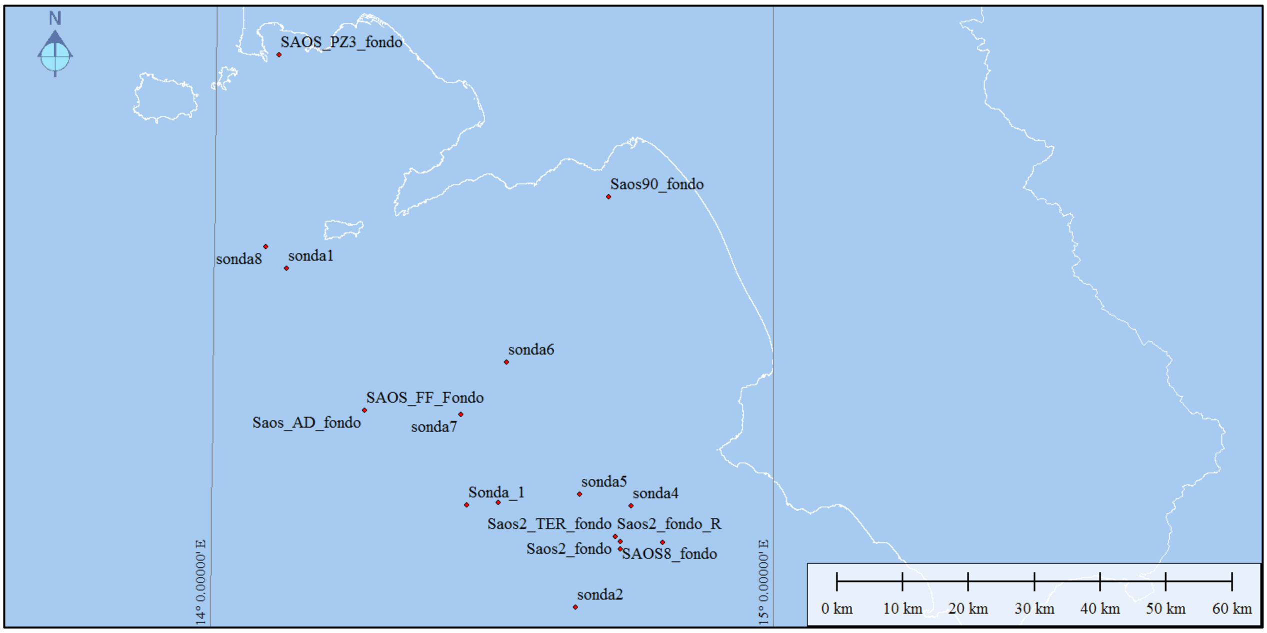


Figure 3 - map of core sites and CTD probes

On selected sites two or exceptionally three cores have been retrieved to allow multiple analysis in different laboratories and quick measurements on-board. About 9 m of cores were split on board (Fig. 3 a) and sub-sampled. On board analysis have included:

- Lithologic description
- S-wave velocity by a transceiver, signal amplifier and oscilloscope (Fig. 3 b)
- Magnetic susceptibility by a loop sensor core logger (Geotek) (Fig.3c)
- Sub-sampling for water content determination
- Shear strength by a Vane tester (Fig.3 b)
- Cohesion by a Fall cone

Figure 4 - a) core splitting; b) geotechnical measurements; c) magnetic susceptibility measurement by a loop sensor

Magnetic susceptibility is a powerful tool for peak to peak correlation of corresponding beds and thus suitable to verify core penetration and relative position of layers below the seabed. Twin cores have been therefore compared in terms of sediment shortening and penetrations (Fig. 5).

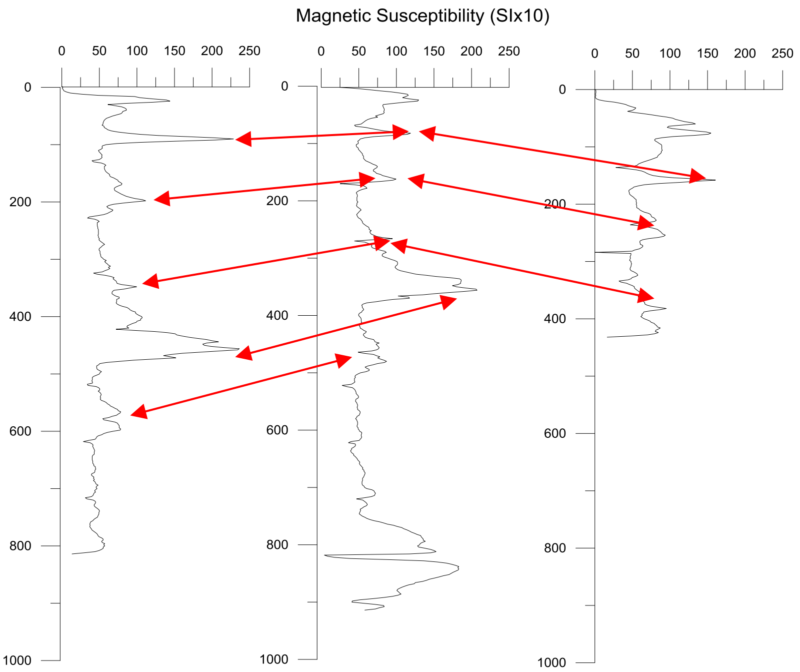


Figure 5 - plot of magnetic susceptibility in twin cores, retrieved with different configurations of the PC: a) free fall and 1.xx tons; b) free fall and xxx tons; c) fall-controlled and xxx tons

2.2 Seismic acquisition

The multichannel seismic survey aimed to investigate the first 1.5-1.8 s bsf, keeping a high resolution of records. Therefore the choice of the acquisition parameters was driven by the needing of a good compromise between resolving power - to fully discriminate the shallower reflectors and geometries- and penetration to possibly image the acoustic basement.

The source consisted of a single 60 cu.in Sercel-Sodera Mini GI gun fired in Harmonic Mode (30 G + 30 I). The shot point distance was set to 9.375 m, corresponding to a time interval of about 4.7 sec at a speed of 3.7 kn. Consequently, the record length was set to 3 seconds, with almost 2 sec. to the acquisition system automatic re-arm.

The compressed air was provided by a 3500 l/min (125 c.f.m.) BAUER compressor hosted within a standard TEU 20 container positioned on the back deck.

The source was towed at a depth of 1.5 m, with a ghost effect related first notch of about 500 Hz. The gun was activated by RTS Sure Shot gun controller triggered by the navigation system and then providing the recording system with the time break.

The navigation has been managed by the Teledyne Reson - PDS2000 software, configured to send the fire commands (fix) at 9.375 m shot point distance to trigger the gun controller.

The data were collected by a 96 channels, 300 m long Geometrics Geoeel digital streamer. With a 9.375 m shot point interval and a channel distance of 3.125 m, the maximum attainable fold coverage was 16 traces / CDP. The effective horizontal sampling (trace distance) in the stacked section was 1.56 m.

The streamer was towed at a depth of 0.5 - 1 m below the sea surface, with a ghost effect upper bounding the spectrum at about 700 Hz. The streamer was kept at a constant depth by a Digicourse levelling system, handling four birds as a whole. The general acquisition parameters are summarized in Table 3.

The data were recorded by a Geometrics CMX-T marine controller and stored in SEGD format within the acquisition workstation HD. Back up copies were real time stored on an external USB HD.

Table 3 - General acquisition parameters.

ACQUISTION PARAMETERS					
SOURCE		**STREAMER**		**RECORDING**	
Model	Mini GI-GUN Sercel	Model	Geoeel	Model	Geometrics
Volume	Single 60 cu.in.	Length	300 m	Sampling rate	0.5 ms
Gun Mode	30G+30I Harmonic	Ch. No.	96	Record length	3 sec
Shot Interval	9.375 m	Ch. Dist.	3.125 m	LC filters	3 Hz (LC);
Depth	1.5 m	Depth	0.5 - 1m	HC filters	Antialias
Pressure	140 atm.	Min off.	25 m		
SYNCHRONIZATION		Max off.	325 m		
Controller	RTS SureShot	Maxfold	16		
Aim Point	50 ms delay				

2.2.1. Quality Control

The SEG-D raw data were processed on a two dedicated workstation by means of GEDCO Vista Seisimager package. The quality control was performed on both the single shots and the whole profiles by screen display and plotting of the near trace sections.

The raw data were first transferred from the external USB back up HD to the processing workstation and loaded and reformatted by means of the Vista processing package. The overall quality of the raw data was first checked and single traces edited. Noisy traces, traces with transient glitches, or mono frequency signals were deleted; if present, polarity reversals were corrected. Brute stack sections were obtained by applying a conventional processing sequence, consisting of trace editing, wide band pass pre filtering, amplitude loss compensation, velocity analyses, and stack.

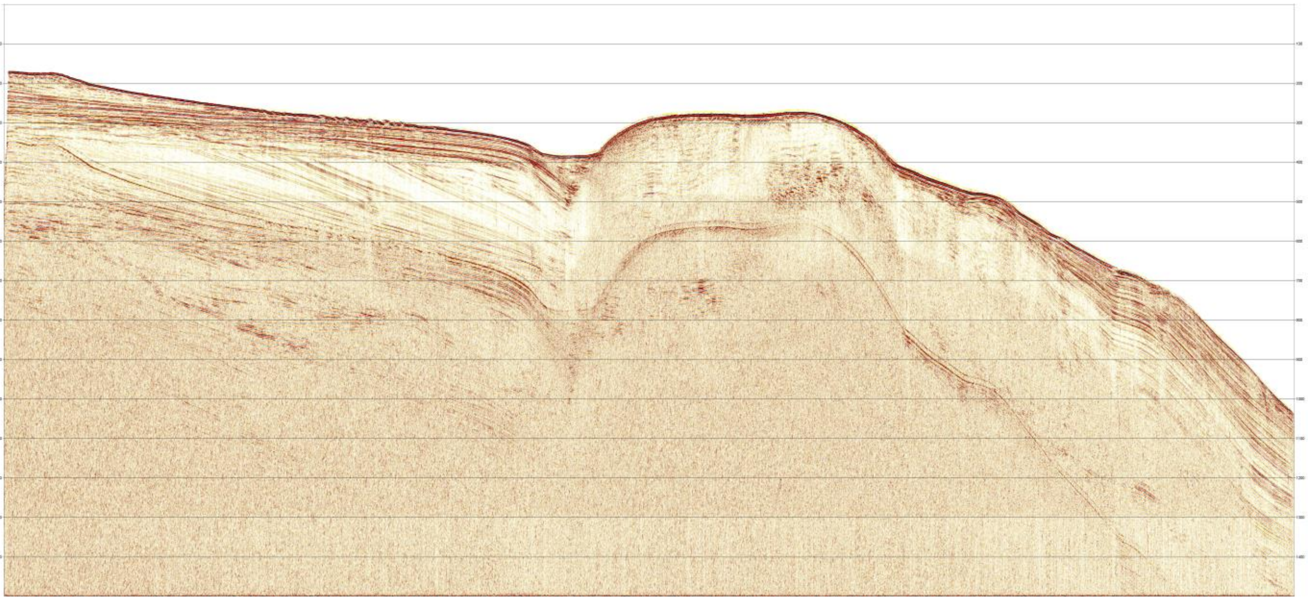


Figure 6–Brute stack of a multichannel seismic profile across the slide area.

Table 4 – Statistics of seismic acquisition

Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Long E
SAOS_06	SOL	03/09/2014	06.16	100	4616	039°59.2337'N	015°02.8803'E
	EOL	04/09/2014		4715		040°11.8784'N	014°37.4025'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_02	SOL	04/09/2014	03.34	100	2332	040°11.9796'N	014°43.6694'E
	EOL	05/09/2014		2431		040°00.2092'N	014°43.7308'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_01	SOL	05/09/2014	00.23	100	273	040°02.3458'N	014°45.4802'E
	EOL	05/09/2014		372		040°03.7213'N	014°45.4809'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_01A	SOL	05/09/2014	02.28	100	1754	040°03.0709'N	014°45.4800'E
	EOL	05/09/2014		1853		040°11.9329'N	014°45.4833'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E

SAOS_01W	SOL	05/09/2014	00:38	100		040°11.8094'N	014°45.4795'E
	EOL	05/09/2014		960		040°09.6454'N	014°45.4820'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_01WA	SOL	05/09/2014	02.21	100	3254	040°10.4112'N	014°45.4823'E
	EOL	06/09/2014		3353		040°02.2309'N	014°45.4803'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_04	SOL	06/09/2014	02.53	100	2070	040°00.3524'N	014°49.3120'E
	EOL	06/09/2014		2169		040°10.7979'N	014°49.2968'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_00	SOL	06/09/2014	07.25	100	5252	040°09.4203'N	014°39.0778'E
	EOL	07/09/2014		5351		040°35.7051'N	014°35.0629'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_09	SOL	07/09/2014	00.51	100	628	040°35.6704'N	014°34.3977'E
	EOL	07/09/2014		727		040°34.5623'N	014°38.2952'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_08	SOL	07/09/2014	02.31	100	1760	040°04.6577'N	014°54.9352'E
	EOL	07/09/2014		1859		039°56.3947'N	014°59.1303'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_07	SOL	07/09/2014	04.46	100	3314	039°59.2422'N	015°00.5705'E
	EOL	08/09/2014		3413		040°08.2650'N	014°42.2235'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_03	SOL	08/09/2014	04.11	100	2942	040°12.9174'N	014°47.2160'E
	EOL	08/09/2014		3041		039°58.0665'N	014°47.3619'E
Line Name		Date	Duration	Shot Point	Shot No.	Lat N	Lon E
SAOS_05	SOL	09/09/2014	04.02	100	2991	039°55.9114'N	014°50.5736'E
	EOL	09/09/2014		3090		040°11.0394'N	014°50.5474'E

2.3 MBES acquisition

The Multibeam Simrad EM 710 is hull mounted aboard the R/V *URANIA* and operates at 100 kHz. It provides bathymetric data with a swath width up to 150° generating 800 simultaneous high resolution beams. The acoustic footprint of the system varies in size with water depth, and the operational swath coverage as well.

Table 5 - Kongsberg EM 710 technical specifications

Frequency range	70 to 100 kHz
Max ping rate	30 Hz
Swath coverage sector	Up to 140 degrees
Min depth	3 m below transducer
Roll stabilized beams	±15°
Pitch stabilized beams	±10°
Yaw stabilized beams	±10°
Sounding patterns	Equiangular Equidistant High Density - Equidistant
Max depth	2000 m

CW transmit pulses	0.2 to 2 ms
Max coverage	2400 m

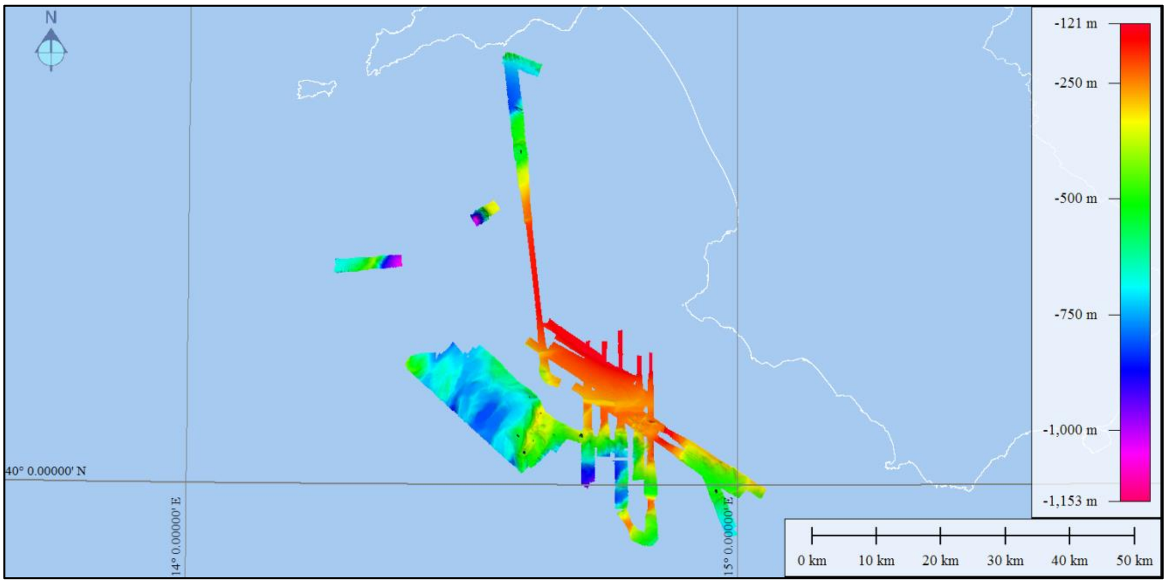


Figure 7 - coverage map of MBES acquisition during SAOS 2014 cruise.

The Seafloor Information System software was used for recording bathymetric data; the software receives data from the Differential GPS system and from the motion sensor in order to perform a real-time correction of bathymetric records for ship position and attitude. During acquisition some parameters, such as *nadir angle* and *pulse lenght,* can be modified in order to improve data quality; a velocity sound probe placed near multibeam transducers provided the real-time sound speed for the *beam steering* and a SeaBird 911plus CTD was lowered through the water column every 6 - 8 hours to provide the sound velocity profile useful to compute the water layer refraction coefficients.

2.3.1 Preliminary results of MBES acquisition

About 400 km^2 of bathymetric data have been acquired between 200 m and 1100 m of depth and a 10 m x 10 m grid size cell DTM was generated (Figg. 7 and 8).

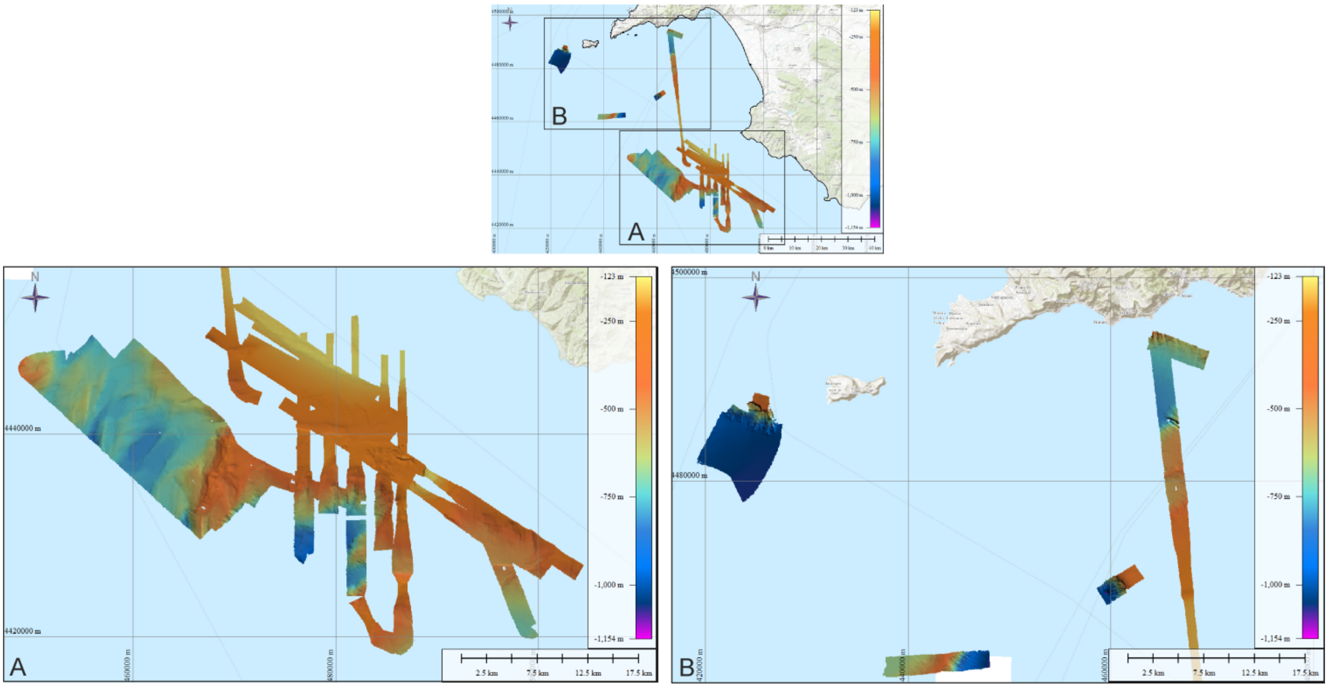


Figure 8 - Digital Terrain Model of study area

Besides bathymetric data, the Multibeam EM 710 produce backscatter data, therefore a seabed acoustic map was generated using a 2,5 x 2,5 m cell grid size (Fig. 12); finally an overlapping map showing acoustic seafloor response and bathymetric data was created (Fig. 9).

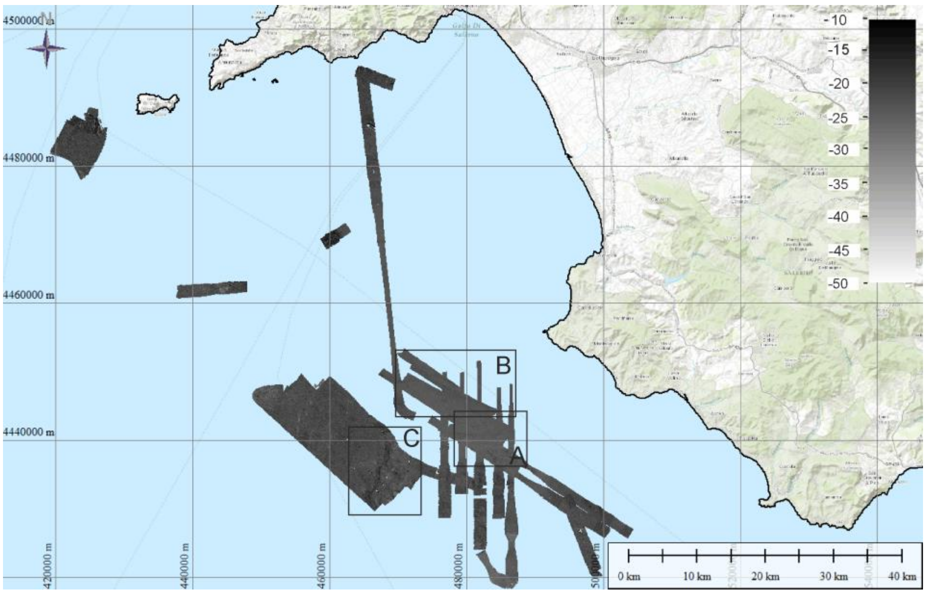


Figure 9 - Seafloor backscatter map

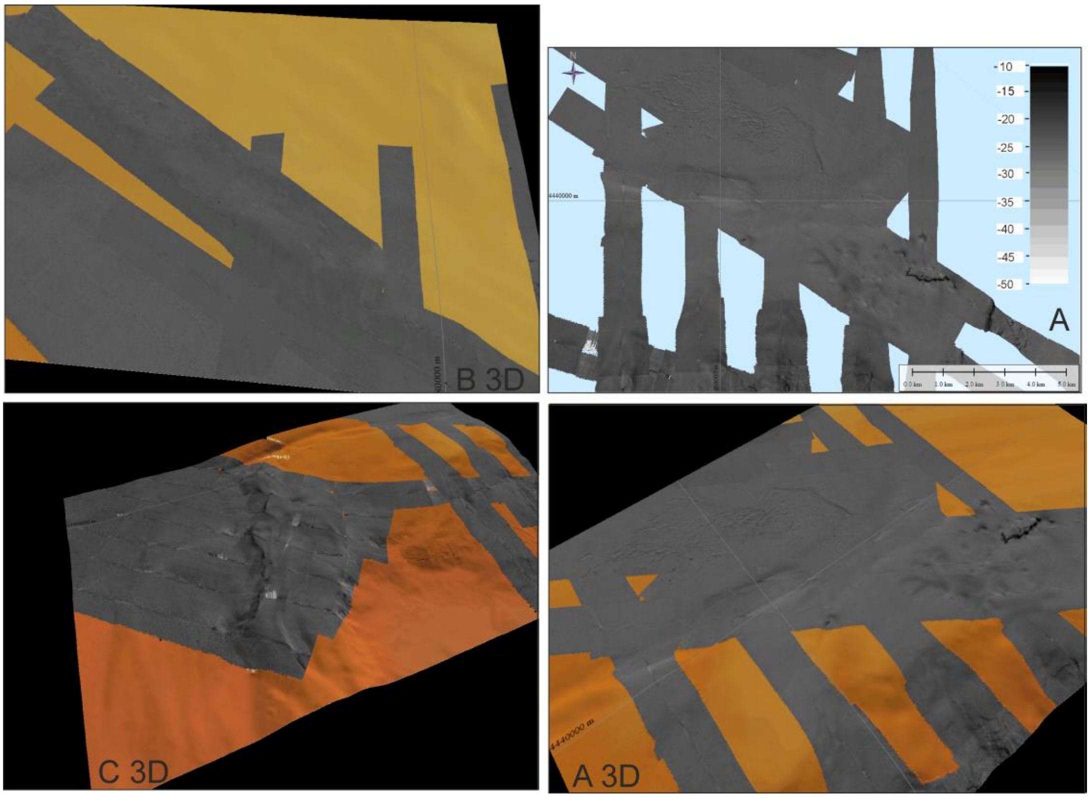


Figure 10 - Bathymetric and backscatter mosaic integration; frames of 3D images are in fig. 9

2.3.2 Water column acquisition

A short acquisition of water column data has been tentatively made above a sub-circular depressed area, located at -1000 m in the Salerno Gulf. This feature, resting at the base of the slope (Fig. 11), is about 100 meters deep and 1 km wide and can be interpreted as a giant pockmark connected to the slidescar of the Posidonia Slide (Budillon et al., 2014). The aim of the acquisition was to verify the state of activity of the pockmark and to check for possible fluid seepages.

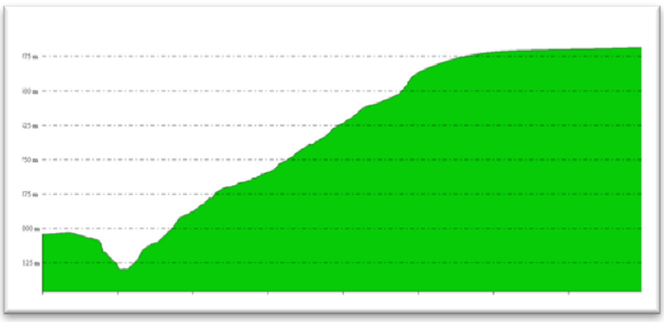


Figure 11 - Profile view of the giant pockmark at the foot of the upperslope

At a first examination, water column data did not evidence any fluid seepage

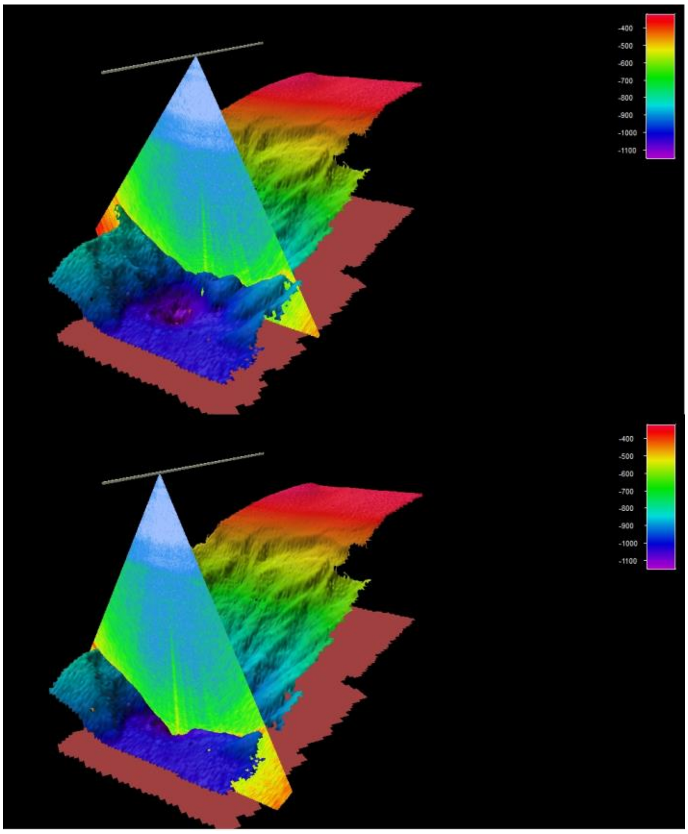


Figure 12 - Water column acquisition above a giant pockmark connected to the slidescar of the Posidonia slide

2.4 Acquisition of Subbottom Chirp profiles

The Chirp sonar DATASONIC CHIRP II CAP6600 employed is hull-mounted aboard the R/V URANIA and operates generating a FM swept pulse with a frequency band of 2±7 kHz as a source signal.

The survey lines were mostly acquired within the swath mapping survey and along the track of multichannel seismic, using a pulse width ranging from 5 up to 10 ms and the multi-pinger mode, in order to provide the best reachable vertical and horizontal resolution on the investigated depth. Additional profiles have been acquired on specific shallow geological targets to complete our data set of stratigraphic data in the area (Fig. 13)

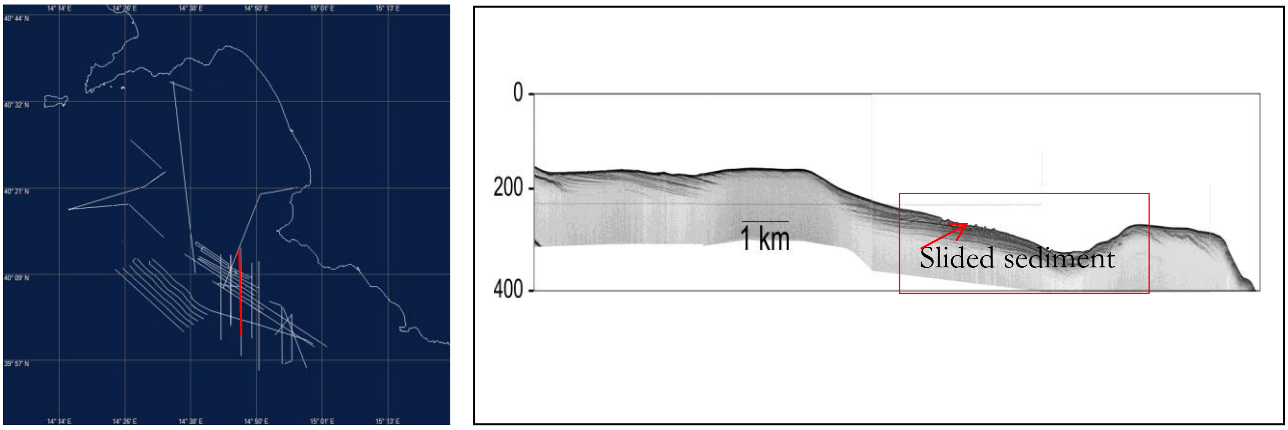


Figure 13–a) navigation track of Subbottom chirp seismic profiles, in red the track line of fig. 13b profile; b) a Subbottom Chirp profile across the shelf margin prograding wedge, the Licosa Slide, an intraslope relief

3. Weather conditions

Fair weather condition during the whole cruise made possible working activities to be run h24 without any interruption.

4. Data gathering

No relevant technical failure at the instrumentation affected the data acquisition.

The team of cruise SAOS 2014

Acknowledgments

The cruise was financially supported by Progetto Bandiera RITMARE. Scientific aims and activities have been in the framework of the 4.1.2 Action "Avanzamento metodologico nella definizione delle pericolosità naturali in mare profondo", led by Angelo Camerlenghi of OGS, Trieste.

We are very grateful to Master Mr. Emanuele Gentile and the whole crew of R/V Urania, for their collaborative attitude, skillfulness and professional competence.

Therefore, we warmly thank: Emanuele Gentile (Master), Gerardo Salvemini (Chief mate), Vincenzo di Candia (Second mate), Salvatore Di Leva (Deck cadet), Marino Montis (Chief engineer), Mariano Manfredi (First assistant engineer), Procolo G. Corcione (Engineer), Santi Simone Ferro (Engineer cadet), Alessio Cesari (Electrotechnical Officer), Ciro Di Crescenzo (Electrotechnical Officer cadet), Luigi Mastronardi (Bosun), Alfredo Baluardo (Seaman), Carlo Cirillo (Seaman), Vito Tatulli (Stewart), Michele Armenia (Chief cook), Stefano Cozzolino (Cook), Sergio Borriello (Ship's boy).

References

Bellonia A., Budillon F., Trincardi F., Insinga D., Iorio M., Asioli A., Marsella E. (2008). Licosa and Acciaroli submarine slides, Eastern Tyrrhenian margin: characterisation of a possible common weak layer. Rendiconti *online* Soc. Geol. It., Vol. 3, 83-84.

Budillon F., Cesarano M., Conforti A., Pappone G., Di Martino G., Pelosi N. (2014) Recurrent superficial sediment failure and deep gravitational deformation in a Pleistocene slope marine succession: The Poseidonia Slide (Salerno Bay, Tyrrhenian Sea). In S. Krastel et al. (eds.), Submarine Mass Movements and Their Consequences, Advances in Natural and Technological Hazards Research 37, 273-283.

Camerlenghi A., Urgeles R., Fantoni L. (2010) A Database on Submarine Landslides of the Mediterranean Sea. In Mosher D.C. et al. (eds.), Submarine Mass Movements and their consequences, Advances in natural and Technological Hazard Research, 28, 503-508.

Iorio M., Liddicoat J., Budillon F., Incoronato A., Coe R. S., Insinga D.D., Cassata W., Lubritto C., Angelino A., Tamburrino S. (2014). Combined palaeomagnetic secular variation and petrophysical records to time-constrain geological and hazardous events: an example from the eastern Tyrrhenian Sea over the last 120 ka. Global and Planetary Changes, 113, 91-109.

Trincardi F., Cattaneo A., Correggiari A., Mongardi S., Breda A., Asioli A. (2003) – Submarine slides during sea level rise: two examples from eastern Tyrrhenian margin. In Locat J. Mienert J. (Eds.), Submarine Mass Movements and their consequences, Kluver Acad. Publ., Dordrecth, The Netherlands, 469-478.

Trincardi F., Field M.E. (1992) - Collapse and flow of lowstand shelf-margin deposits: an example from eastern Tyrrhenian Sea, Italy. Mar. Geol., 105, 77-94.