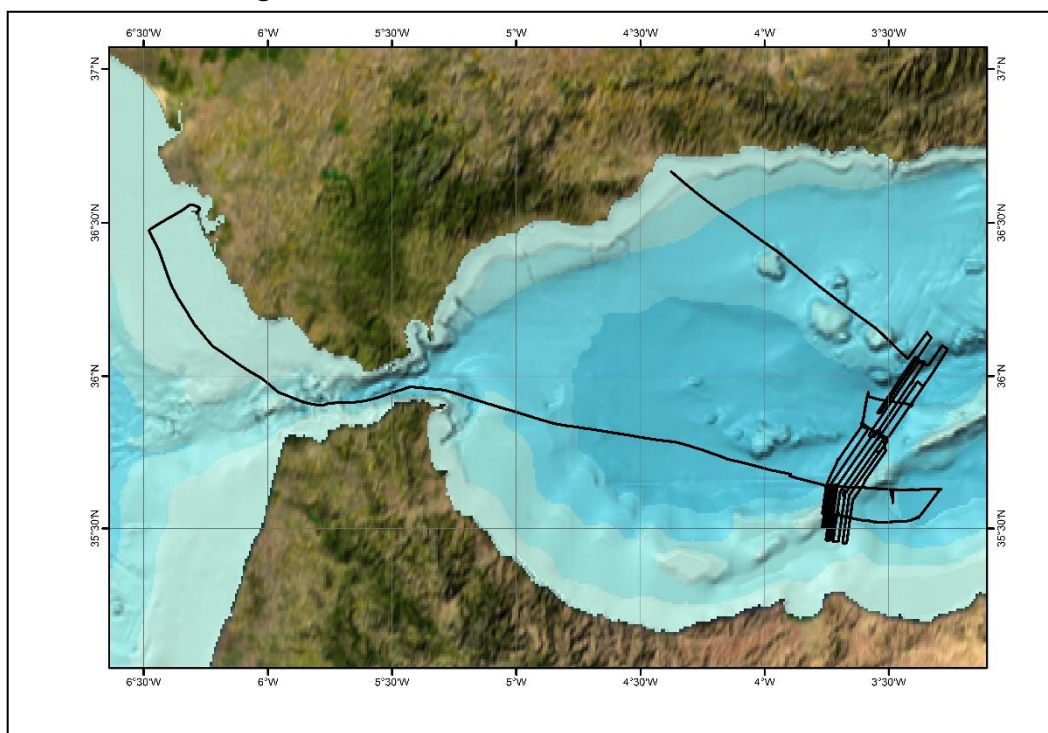


MINECO - IDRISI-2016 recovery cruise

***Quick response after Al-Idrissi Earthquake (Mw 6.3) in the
Alboran Sea (Ref. COC-DI-2016-05)***

Cruise Report

RV Angeles Alvariño, 5th – 10th December 2016



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This report has been written and compiled by Sergi Costa and Rafael Bartolomé, with the contributions of the scientific and technical cruise members on board the B/O Angeles Alvariño, hereafter referred as the Al-Idrissi Recovery cruise party (See section 2: Participants).

Acknowledgements

We acknowledge the Captain, Antonio Alvarez Minguez, the officers and the entire crew of the B/O Angeles Alvariño, for their professional work and operations during the cruise, which made possible the success of the Al-Idrissi Recovery cruise.

We deeply thank the UTM-CSIC technical acoustic Manuel Paredes, and the Remolcanosa Jorge and Carlos technicians for their efforts, guidance and assistance throughout the data collection, which ensured the quality of the marine geophysical data collected, presented in this report.

Thanks to the scientist Dr. Bill Booth for their help during the shifts.

Specially thanks to Susana Diez for his great experience and his echo sounder helpful file.

We also thank the members of the IEO and UTM-CSIC in Barcelona for the logistics, especially Jose Ignacio Diaz and Jordi Sorribas. We also acknowledge Pls of the Al-Idrissi Project (scientists Dra. Eulàlia Gràcia and Dr. Cesar Ranero) during the cruise planning and for her support and confidence in us before and during this cruise.

We gratefully acknowledge the financial support of the *Ministerio de Economía y Competitividad (MINECO)* in the form of working vessel days onboard the B/O Angeles Alvariño through the quick response action project.

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1. Introduction

The Idrissi-2016 recovery mission is a cruise to be performed in the framework of the Idrissi-2016 project: “Quick response after Al-Idrissi Earthquake (Mw 6.3) in the Alboran Sea: Monitoring of seismicity and mapping fault ruptures” (Ref. COC-DI-2016-05), which integrates research centers from Spain, Germany, and Morocco. The embarking port is Cadiz (Spain), 5th Dec 2016 and debarking port is Malaga (Spain) the 10th Dec 2016.

The Idrissi-2016 recovery cruise is part of a quick initiative to monitoring the seismicity and mapping fault ruptures after the Al-Idrissi Earthquake. A magnitude (Mw) 6.3 earthquake struck offshore of Morocco 50 km (31 mi) north-northeast of Al Hoceima on January 25 at a depth of 12.0 km. The shock had a maximum intensity of V (Moderate) and fifteen people were injured and some buildings were damaged; it also caused a blackout in the region.

The earthquake of January 25 2016, is the largest instrumentally recorded in the Alboran Sea. It was preceded by the January 21 earthquake of Mw 5.1 in the same epicentral area and has been followed by a series of aftershocks (over 2000) that have been migrating in the area along the time. The seismicity is not restricted to the southern Alboran Sea but events have occurred in northern Alboran, as the Mw 4.9, 31th January 2016, 20 km south of Adra, (Spain) and center of Alboran Sea (NW Alboran Island) as the Mw = 3.1, 27th February, at 10 km depth. Furthermore, the distribution of aftershocks indicates a length of rupture of about 40 km, higher than would correspond to its size (the typical breakdown of an earthquake of Mw = 7.0 is 30 km). These observations together can be interpreted as the earthquake has been able to break several adjacent segments of fault, and therefore, it is not ruled out that a major break might occur. Monitoring of seismicity in the area is not optimal due to the scarcity of nearby seismic land stations. Therefore, the OBS deployment to monitor seismicity and identify which fault segments have struck is mandatory.

In addition, the cruise has performed a simultaneously high-resolution mapping of active faults in the vicinity of the Al-Idrissi fault to detect possible changes in

the seafloor relief comparing the data acquired with previous bathymetry already available before the earthquake. We are the only group in Spain that has acquired marine data along the fault of "Al-Idrissi" pre-earthquake of Mw 6.3. In some segments, near (South) the epicenter, we have a bathymetry of ultra-high resolution acquired by autonomous underwater vehicles (AUV) during the SHAKE-2015 mission (IP: E. Gràcia) on-board the RV Sarmiento de Gamboa. Ultra-high resolution bathymetry after the earthquake acquired in the Al-Idrissi recovery mission (Fig. 5) at low speed (5 knots) and overlap between scans of 200% must be processed carefully to compare it with the previous acquired (pre-earthquake). The comparison will assess whether there have been breaks in surface or triggered mass movements.

Our initiative is coordinated with the National Geographic Institute (IGN) that is in charge of the National Seismic Network on land. These data will be used together with the underwater network of OBS collected during the cruise. A letter of support to this survey has been written by the Director of the National Seismic Network of the IGN (Dr. Emilio Carreño).

2. Participants

2.1 Scientific and technical personnel

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3. Geological Setting

Geodynamics of the SE Iberian Margin

Active deformation in the south-eastern Iberian Margin is revealed by earthquake focal mechanisms derived from moment tensor inversion, covering both onshore and offshore regions (Stich et al., 2003; Bufo et al., 1995). In the Eastern Betic Shear Zone (EBSZ) and the Alboran Sea, strike-slip faulting dominates (e.g. Stich et al., 2003) as corroborated by geological and geophysical data (e.g. Grimison and Chen, 1986, Sanz de Galdeano, 1990; Gràcia et al., 2006) (Fig. 1). Most of the shortening between Iberia and Africa is absorbed in southeastern Iberia along the EBSZ, which is formed by the Bajo Segura, Carrascoy, Alhama de Murcia/Albox, Palomares and Carboneras faults. The area shows moderate to low seismicity. To the north of this system, the Crevillente fault shows also some seismicity on its eastern and southern part, where the Mula and Bullas earthquakes occurred. A number of historical large earthquakes occurred along EBSZ, such as the Torrevieja (1829, I=X), Vera (1518, I=IX) and Almería (1522, I=IX with possible submarine epicenter) earthquakes, which prove the earthquake and tsunami potential of the system.

The southern termination of the EBSZ corresponds to the Carboneras fault (CF), characterized by a transpressional sinistral slip with estimated cumulated displacements of 35-40 km since the Burdigalian and 18 km since the Late Tortonian (Montenat et al., 1990) based on apparently displaced volcanic rocks. The observed onshore-offshore segmentation allowed suggesting that the fault is capable of generating up to Mw 7.4 earthquakes (Gràcia et al., 2006).

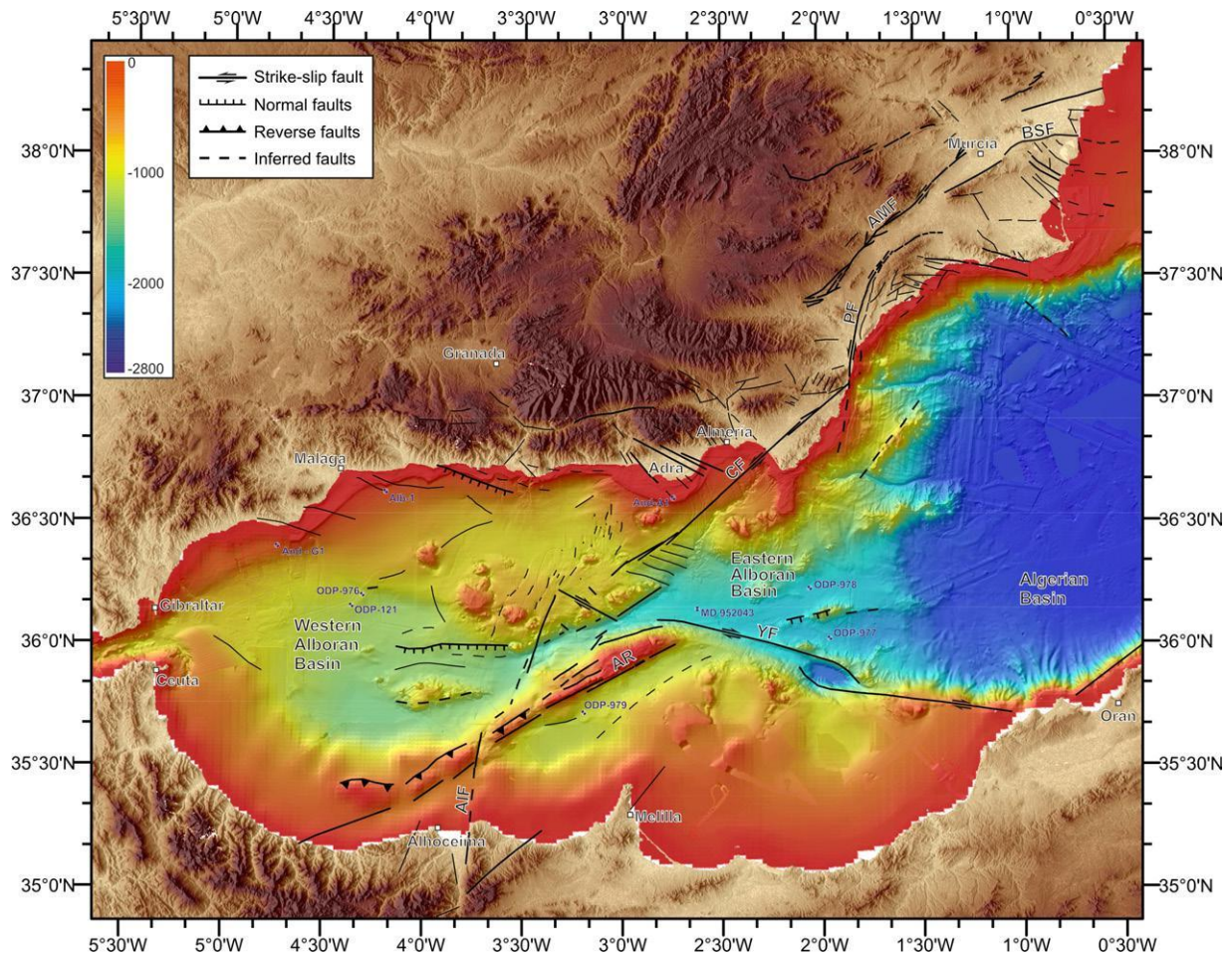


Figure 1. Interpretative structural map of the Eastern Betics Shear Zone (EBSZ) and Alboran Sea based on MCS results (e.g. Comas et al., 1999; Mauffret et al., 2004; Gràcia et al., 2006; Martínez-García et al., 2010). BSF: Bajo Segura Fault; AMF: Alhama de Murcia Fault; PF: Palomares Fault; CF: Carboneras Fault; YF: Yussuf Fault; AR: Alboran Ridge; AIF: Al-Idrissi Fault. Bathymetry is the MediMap compilation (MediMap et al., 2008).

Cumulative dip-slip rates were calculated based on vertical displacements identified on MCS profiles and estimation age of offset horizons. Tentative dip-slip rates of 0.10-0.16 mm/yr for the last 128 kyr and a strike-slip rate of 1.3 mm/yr based on left-laterally offset gullies have been obtained. Information of individual events could be determined based on the onland data, where paleoseismic studies showed that the CF is seismogenic (Moreno et al., 2016). Five sites have been analyzed on land (geomorphology, microtopography, geophysics, trenching and dating), and evidence a minimum of 6 paleo-earthquakes since the mid-Pleistocene. The 3 younger events occurred in the last 40 ka suggesting a mean recurrence of 13 ka for this period.

In the cruise, we aimed to explore a relevant fault system located south of the Carboneras Fault: the Al Idrissi Fault (AIF, Fig. 1). This 150 km long NNE-SSW trending fault located SW of the Alboran Ridge, may be a source of large events such as the 1994 Al Hoceima Mw 6.0 earthquake and the January 25, 2016 Mw 6.4 at sea.

4. Objectives of the Al-Idrissi recovery cruise

The cruise goals and research objectives have been defined after discussion within the research groups, as well as with the German scientists and technicians listed in point “2. Participants”. This is the second and concluding cruise of the project Idrissi-2016 project.

The two objectives of the Idrissi-2016 recovery cruise are:

1) to recovery the 12 Ocean Bottom Seismometers (OBS) deployed on the ocean floor during the oceanographic mission Idrissi-2016 accomplished on September 2016. The OBS will have been acquiring earthquake data occurring in the area during 3 months under the sea. Seismic data will determine the shallow and deep crustal structure and plate geometry of the convergent system giving rise to earthquakes as the Mw 6.3 occurred on January 25th 2016, specially along the Al Idrissi fault, possibly the responsible of the geological hazards that threaten the region.

The tracking chart for the OBS recovery is shown in Figure 8 - chart of Idrissi-2016 recovery cruise. The data will be later processed and analyzed in detail onshore to construct models of the tectonic features and the seismic velocity structures and properties of the crust and upper mantle. This model will help to relocate the earthquakes in the future and will be of paramount importance to define the active areas of the margin.

2) Together with the OBS deployment, a detailed bathymetry survey of the Al Idrissi fault will be performed along the fault using hull-mounted echo sounders on the vessel. In addition, the data acquired will allow improving our knowledge on the tectonics, faults parameters, and landslides to define the most significant geological hazards, including large earthquakes and rarely tsunamis.

5. Methods

The following methodology was used during the Al-Idrissi recovery cruise:

Bathymetric survey

During the Al-Idrissi recovery cruise, we used on board the B/O Angeles Alvariño a multibeam echosounders KONGSBERG EM710. It is mounted on the hull of RV “Angeles Alvariño”. The system emits a frequency range between 40 to 100 kHz. It operates at depths between 100 to 2800 m. Swath-bathymetric and backscatter data are simultaneously acquired. The acquisition may generate grids between 25-100 m cell-size depending on water depth and data redundancy. Hull mounted.

Wide-angle refraction seismic data (OBS network)

Wide-angle refraction seismic (WAS) data allow obtaining seismic velocity distribution of the sediments, crust, and the upper mantle. The velocity models are used to discriminate the crustal thickness, locate and define the geometry of the geological discontinuities, and differentiate among the types of rocks forming the crust, as well as the presence of fluids/melt. The seismic signal is produced by natural earthquakes occurring in the area. 11 of the German pole of 12 OBS has been recovered 3 months later of their deployment.

6. Cruise plan and navigation

During the Al-Idrissi recovery survey, 876 nautical miles of swath-bathymetry limited to 400-1800 m depth range (Fig. 2) were acquired in the SE Iberian margin. Moreover, 11 of the 12 seabed devices (OBS) have been collected from the seafloor.

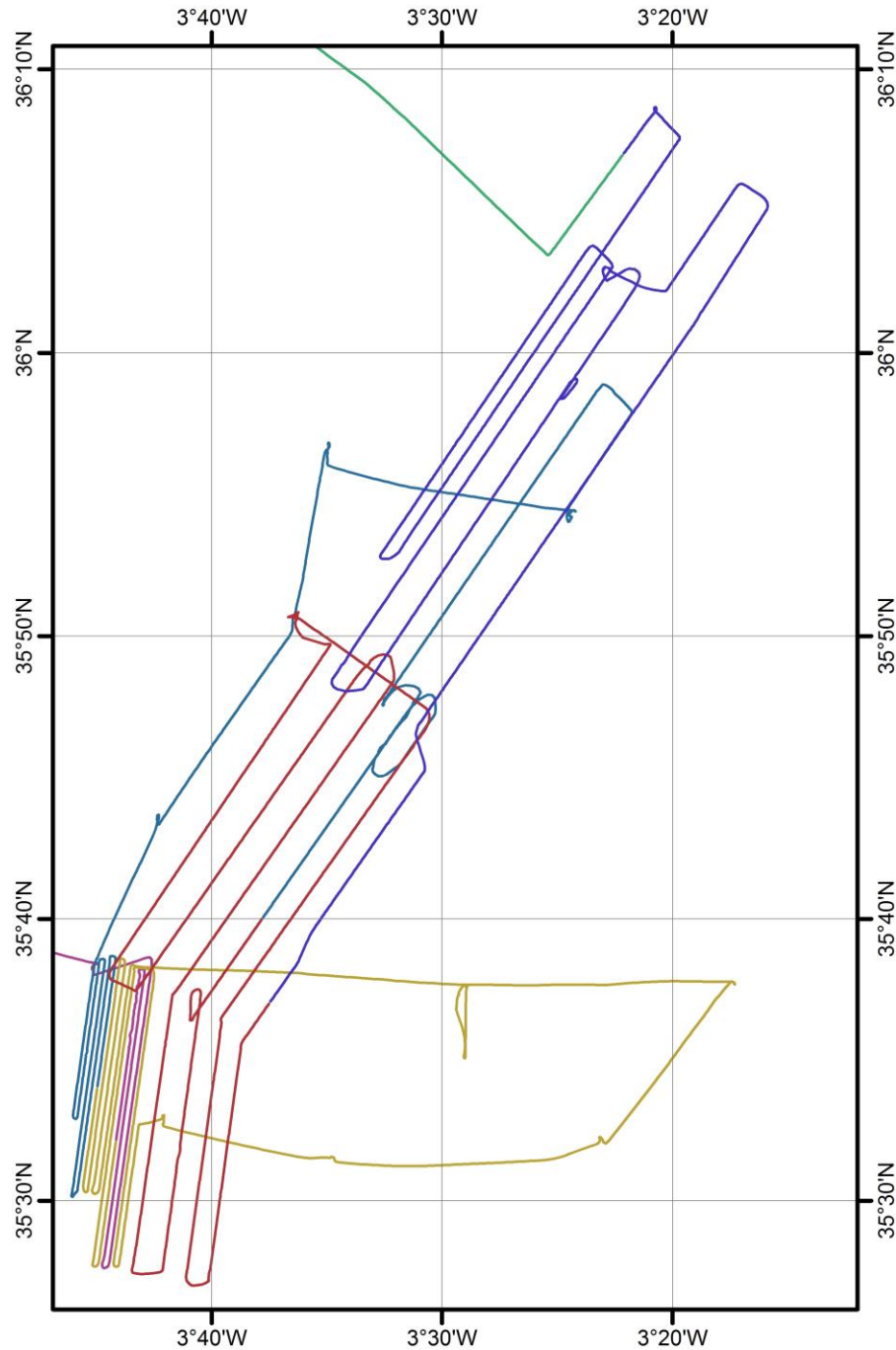


Figure 2: Navigation track of the Al-Idrissi recovery cruise

DATE	Length_(NM)
04/12/2016	9.35
05/12/2016	234.01
06/12/2016	138.89
07/12/2016	129.47
08/12/2016	140.39
09/12/2016	146.33
10/12/2016	78.44
TOTAL nautical miles	876.88

Table I: *Navigation in nautical miles every day and total*

We acquired 1950 km² of bathymetry and backscatter, including 130 km² of high-resolution bathymetry in the epicentral area, at low speed of 5 knots. We distinguished three different zones of investigation, named Zone A, Zone B and Zone C (Fig. 3). Zone A is the epicentral area acquired at ~ 5 m resolution; B and C) are the central and north fault segments that have been scanned at ~ 20 m resolution. See Figure 4 for details about the overlap between scans of bathymetry

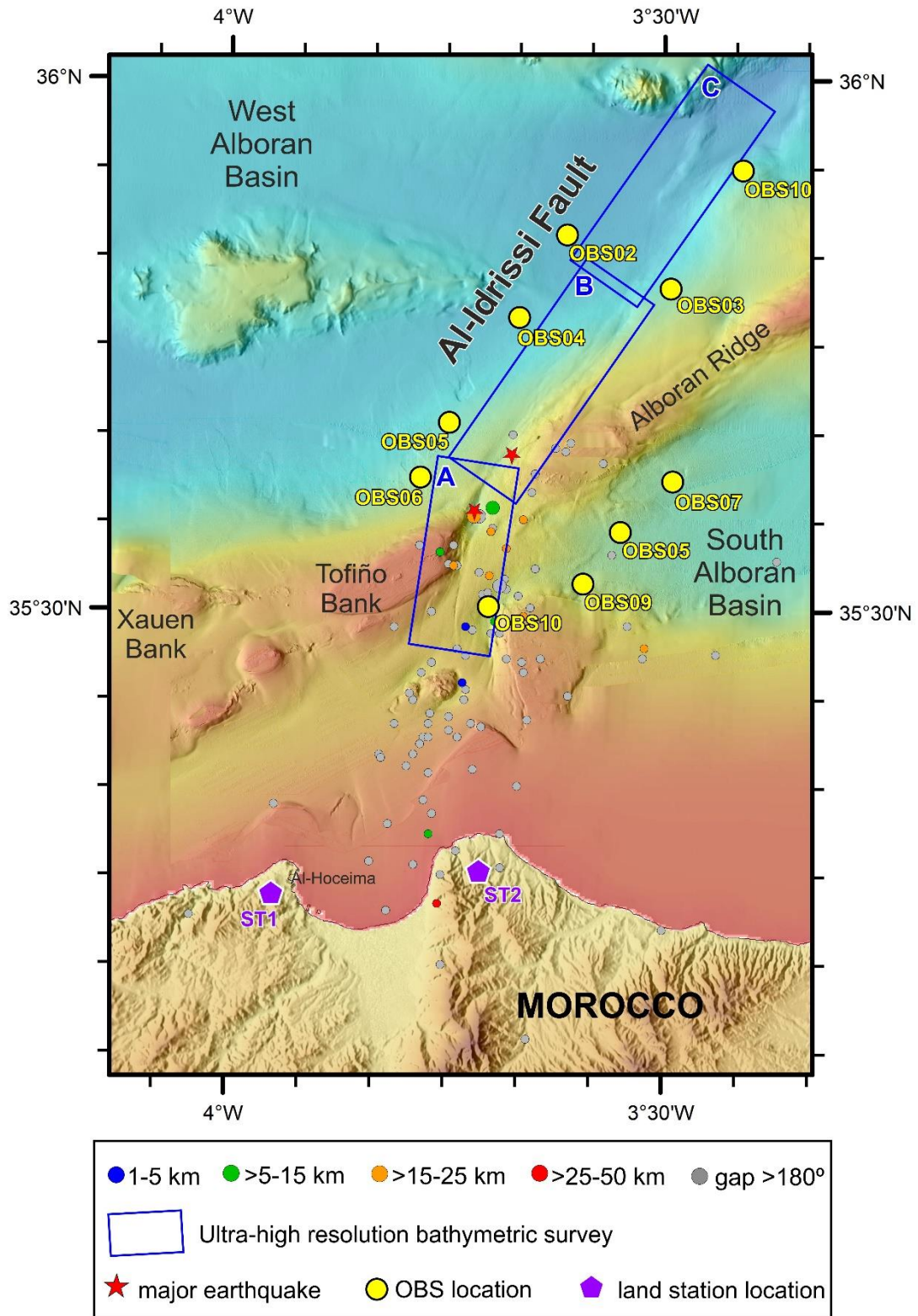


Figure 3: Al-Idrissi recovery survey plan, with yellow circles representing the OBS locations recovered. Blue rectangles are the areas surveyed with Multibeam echosounder. Note the trace of the Al-Idrissi fault along the blue

boxes.

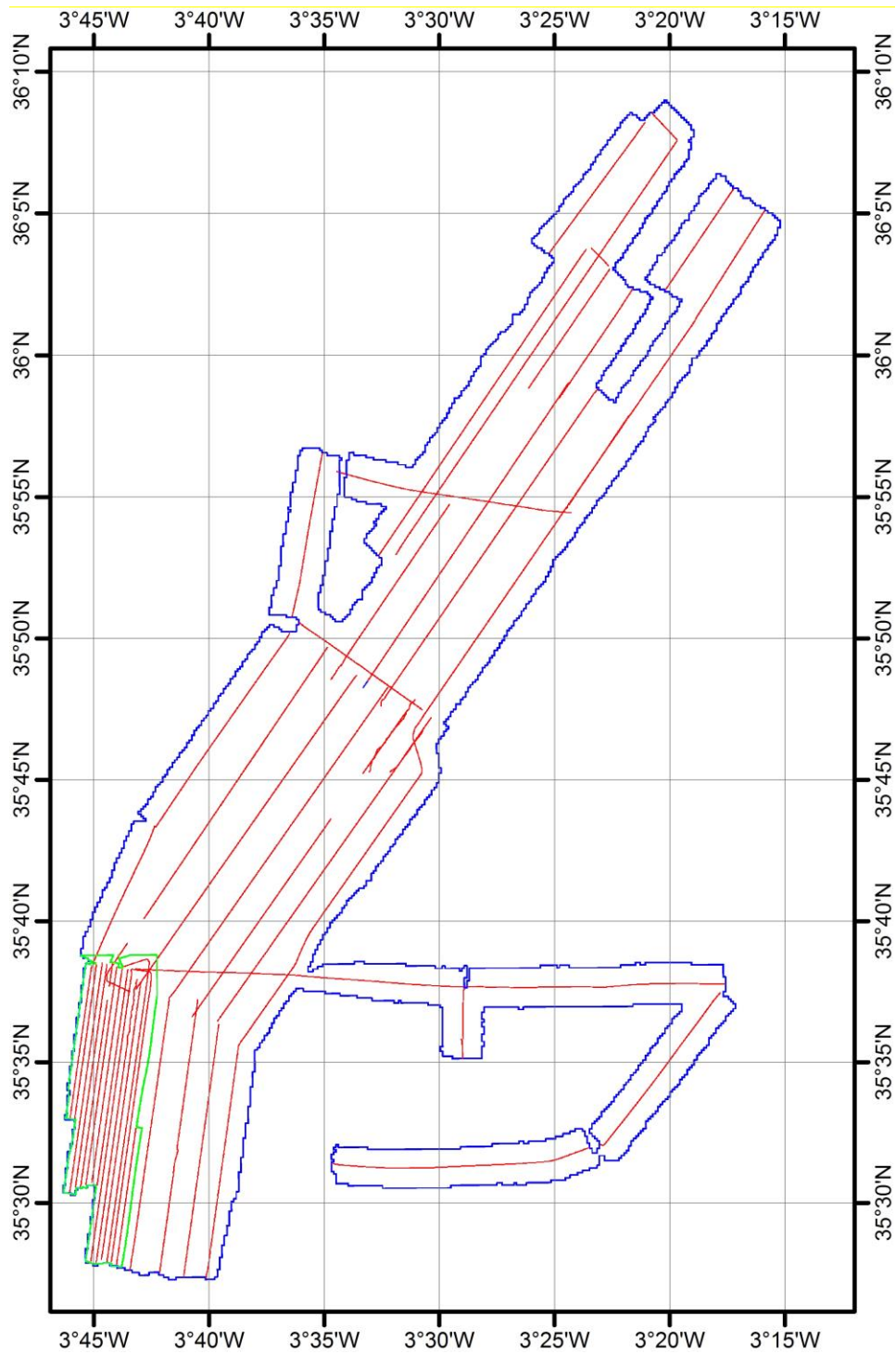


Figure 4: Navigation map of the bathymetry survey in the 3 study areas investigated during the Al-Idrissi recovery cruise. Zone surveyed included: A) epicentral area ~ 5 m resolution; B and C) central and north fault segments at ~

20 m resolution. Note the different overlapping between track lines.

7. Swath-bathymetry and acoustic backscatter

During the Al-Idrissi recovery cruise, we used the multibeam echosounder KONGSBERG EM710. It is mounted on the hull of RV “Angeles Alvariño”. The system emits a frequency range between 40 to 100 kHz. It operates at depths between 100 to 1800 m. Swath-bathymetric and backscatter data are simultaneously acquired, including water column. Acquisition coverage may generate grids between 5-20 m cell-size depending on water depth and data redundancy.

All the area surveyed along the fault is shown in Figure 5. Data has not been processed on-board, but the high-quality of the data despite the rough weather during the survey (average 2m of sea waves). Profile velocity sound in the water column has been acquired one a day and has been applied to the whole dataset.

The echosounder has been calibrated by SIMRAD company before the survey. We worked with a maximum 30-35° aperture of beams, but coverage is lower than the previously estimated of 3x depth by the company. Then, more lines of acquisition have been interpolated in the survey plan, and therefore more time spent for the same coverage.

Two major problems arise during the acquisition:

- 1) The file used by the CARIS multibeam processing software that includes the main characteristics of the echosounder, and given to us by the IEO, had a bad format/values. Susana Diez from the UTM-CSIC provides a new file that correctly worked in the software. Once the correct file was used, overlapping between lines was perfect.
- 2) The surface water velocity value acquired by the hull-mounted echosounder sensor was noticeably different from the one obtained by the profiler SVP. We used a CTD to distinguish which of the two was the correct value. SVP and CTD were in agreement, so we used the value of the SVP during acquisition instead of the echosounder sensor.

Maps showed in this report include the importation of the raw data, previously corrected by the motions of the vessel (roll, pitch, yaw and heave). Bathymetric data were interpolated at nodes of a regular-spacing grid of 3 and 20 meters to obtain final DTMs with both resolutions (Fig. 5 and 6). Sound velocity profiles have been applied to the whole dataset during acquisition.

Acoustic backscatter data and water column were acquired with the EM710 multibeam echosounder as well. Reflectivity data and water column processing have not been carried out, but a check of data files have been performed to ensure the acquisition of the data.

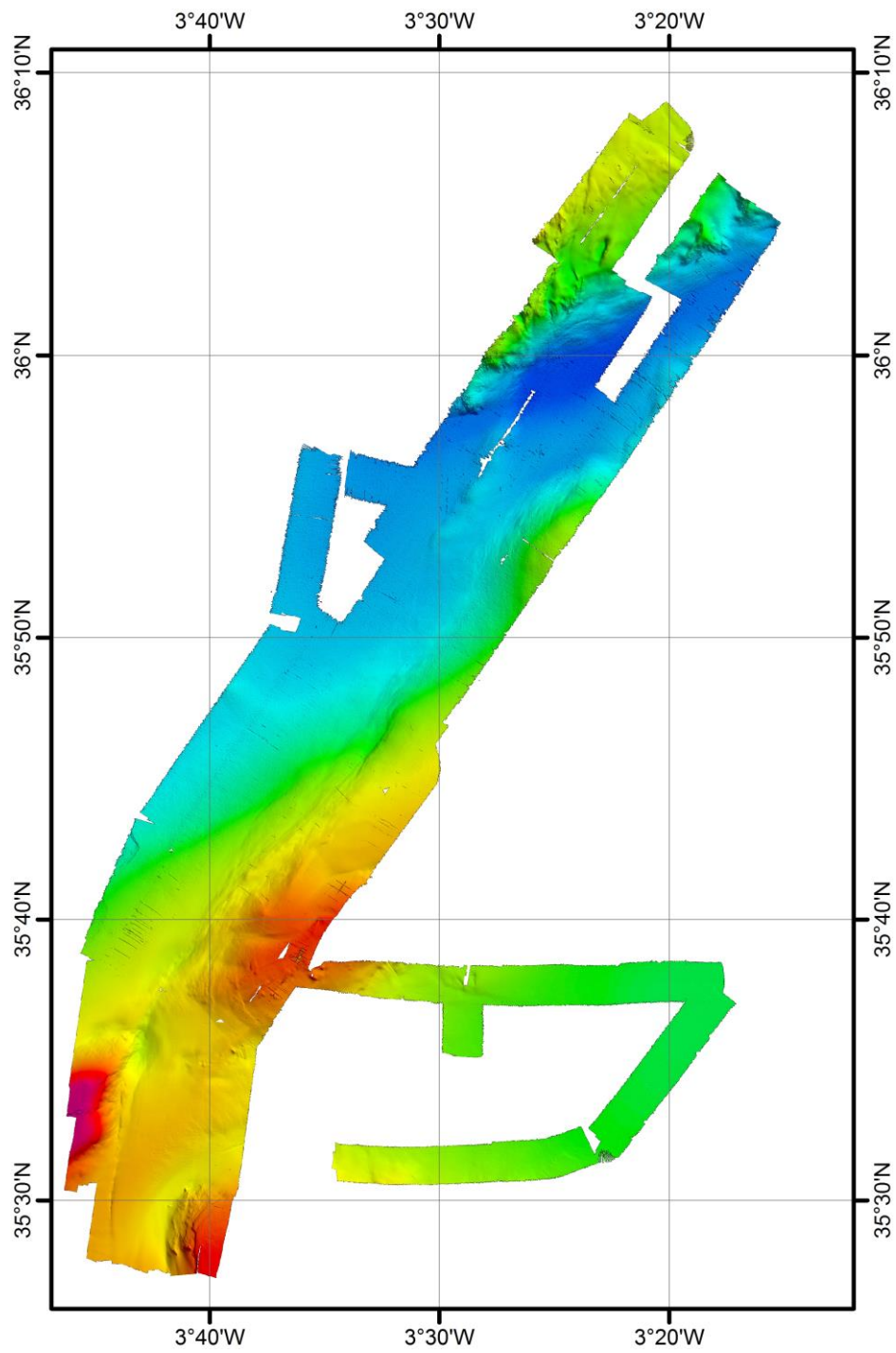


Figure 5: Dataset acquired during the recovery cruise at 20-m grid space

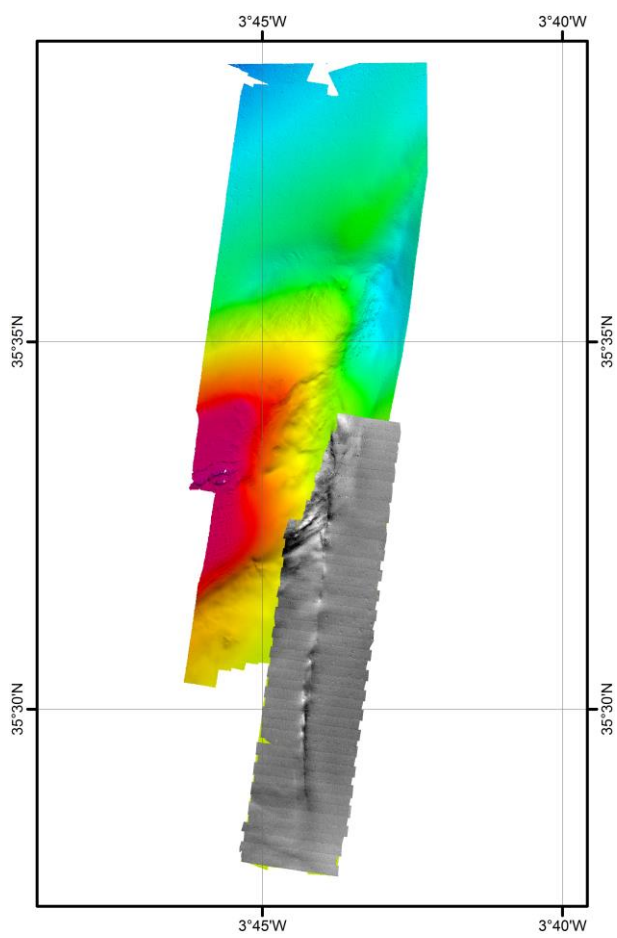
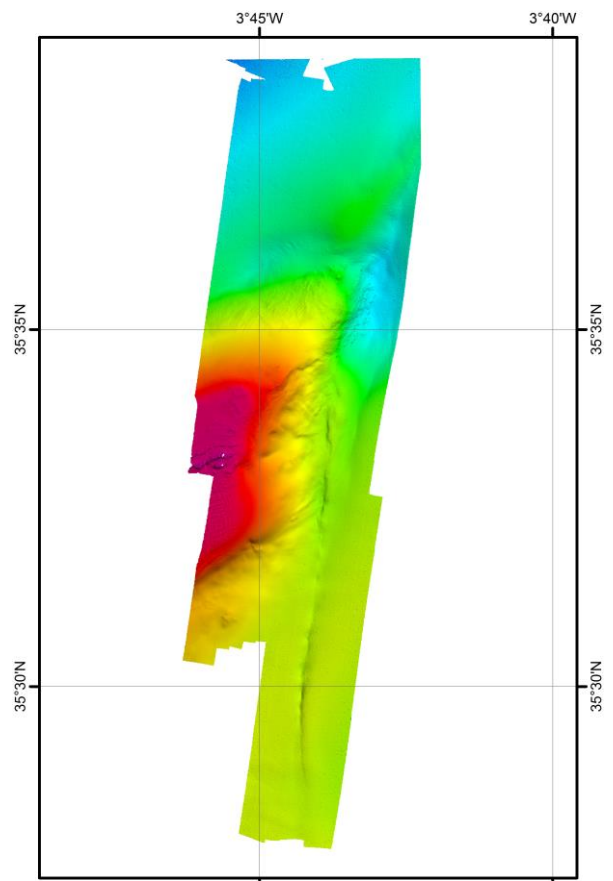


Figure 6: up) Dataset acquired at 3m grid space in the southern part of the Al-Idrissi Fault (Zone A). Down) the same dataset with AUV 1-m grid space superimposed. Note that no big differences in topography can be distinguished between both datasets, pre and after the earthquake of Mw 6.4, January 2016.

Although the data before and after the earthquake do not show great differences at this stage of processing and analysis, a noticeable escarpment (Fig. 7) has been found west of the earthquake epicenter re-localized by Dr. Ingo Grevemeyer (unpublished data).

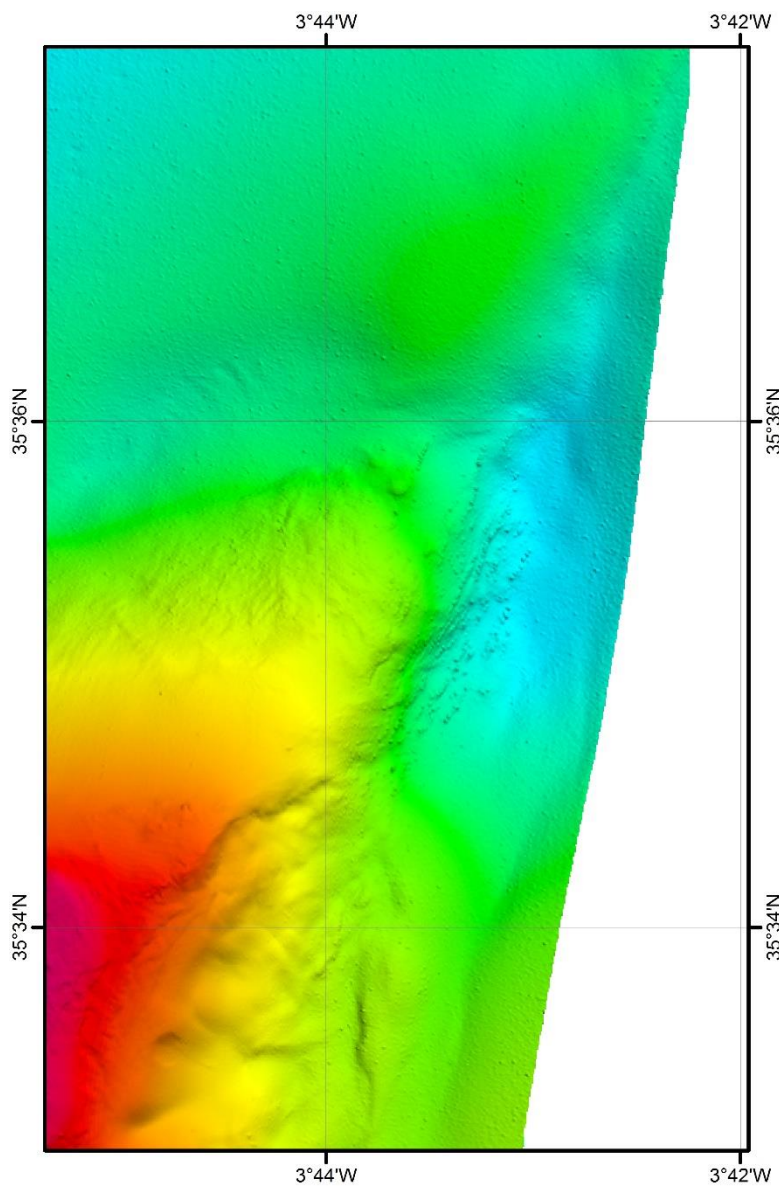


Figure 7: *Detail of the multibeam echosounder DTM around the epicenter of the Mw 6.4 2016 earthquake re-localized by Dr. Ingo Grevenmeyer (unpublished data). Note the different roughness to the north and south of the escarpment, that might indicate recent motion.*

8. OBS recovering

Ocean Bottom Seismometers/Hydrophones (OBS/H) are instruments that are attached to the seafloor and do not hang above it. OBS consist of a hydrophone and a seismometer that record the water and seafloor vibrations produced by natural sources (earthquakes) in the area. These data are used to obtain information on the sub-seafloor structure and on the source characteristics. We will use a total of 12 OBS, the maximum number that will be recording at the seafloor at the same time, belonging to the German Institute GEOMAR (Table II). The OBS include a frame constituted by two aluminum cylinders containing the acquisition electronics and batteries, as well as foam structure for floatation and recovery aids such as a flag and an anchor for OBS diving. Flag and antenna were not incorporated; therefore, the recovery was only possible during daylight.

The OBS is recovered from the deck with the aid of a crane, after staying at sea-bottom from September 2016 to Dec 2016. OBS is free with the aid of a seaboard acoustical release. Then ascends to the surface at a velocity of ~50 m/min. Depending on deployment depth and sea conditions the recovery time can vary between 0.5 to 1 hour.

We have recovered during the cruise 11 of the 12 OBS deployed in September 2016 onboard the RV Sarmiento de Gamboa (Fig. 8). OBS 4 was theoretically released from the seafloor, but after the first communication never appeared on the sea surface and never communicate again. One day later of his release, we try again in the same area to free it from the anchor, but we never get any answer from the device.

Latitude	Longitude	# OBS	DEPTH (m)
36.049	-3.37817	OBS 01	1102
35.94716	-3.58267	OBS 02	1527
35.90783	-3.4045	OBS 03	1072
35.84717	-3.60567	OBS 04	1481
35.72767	-3.70517	OBS 05	1311
35.67833	-3.89533	OBS 06	1101
35.6405	-3.75	OBS 07	890
35.55033	-3.70117	OBS 08	566
35.5295	-3.57933	OBS 09	838
35.628	-3.48333	OBS 10	1001
35.5375	-3.38667	OBS 11	1101
35.6295	-3.29083	OBS 12	1142

Table II: Coordinates and depth of the OBS recovered during the survey. In red, the OBS that has not been recovered.

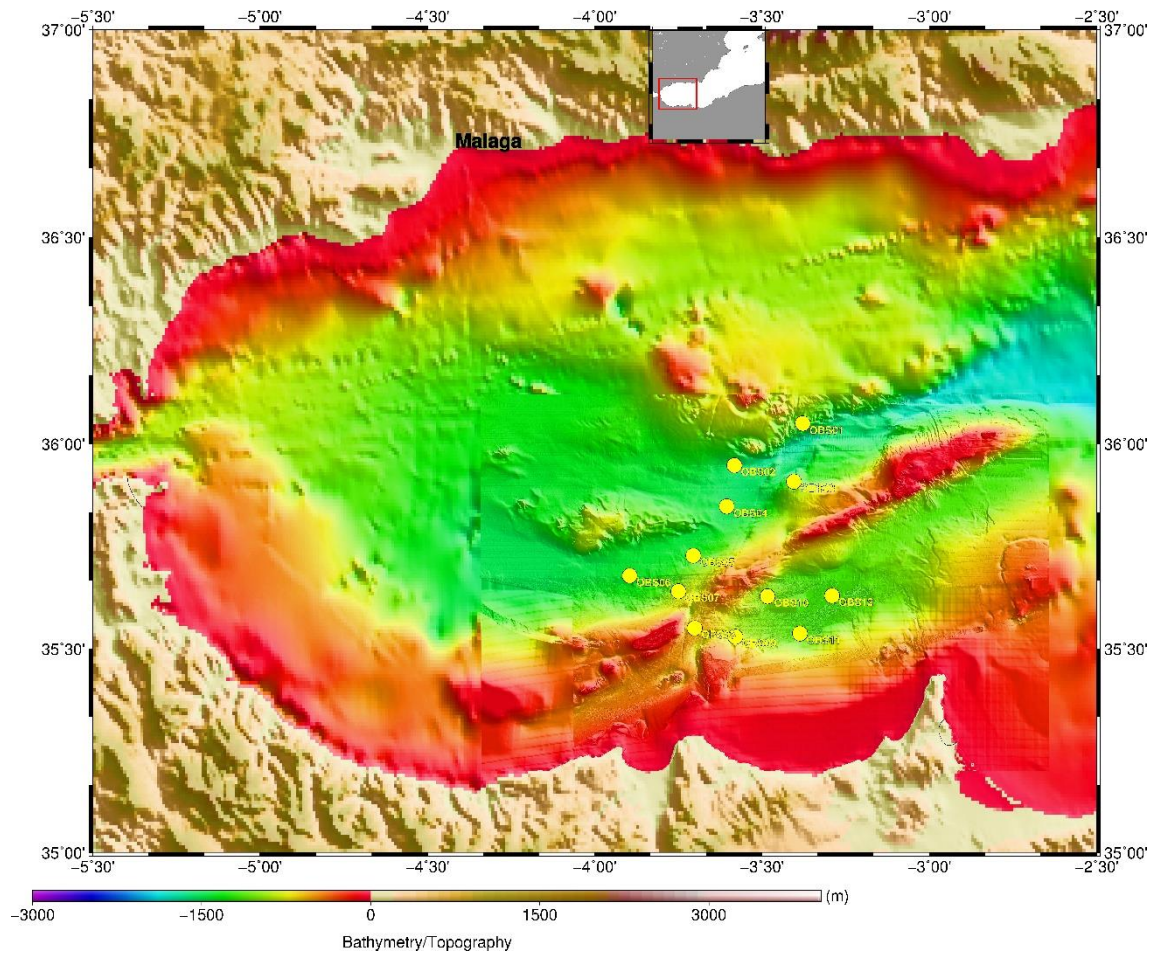


Figure 8: OBS location map of the 12 OBS deployed in September 2016 onboard the RV Sarmiento de Gamboa. We recovered 11 from 12 OBS during the Al-Idrissi recovery survey.

9. Time Calculation

We present here in table III the time calculation of the activities done during the cruise onboard the B/O Alvariño between 5th to 10th Dec 2016. We have included transits, travel distances between OBS and time dedicated to bathymetry acquisition in yellow.

OBS deployment						REAL DATE
Distance (km)			time (h)	Elapsed time (days)	time (days)	
268		Transit Cadiz-OBS06	14.5	0.6	0.602952	05/12/2016 0:00
	OBS6	Recovery OBS06+ crane	1.0	0.6	0.042500	05/12/2016 16:31
14		Transit OBS06-OBS07	0.8	0.7	0.031497	05/12/2016 17:16
	OBS7	Recovery OBS07+ crane	0.8	0.7	0.034769	05/12/2016 18:06
		CTD + batymetry	15.5	1.4	0.645833	06/12/2016 9:36
13.5		Transit OBS07-OBS08	0.7	1.4	0.030373	06/12/2016 10:20
	OBS8	Recovery OBS08+ crane	0.7	1.4	0.029552	06/12/2016 11:02
13.5		Transit OBS08-OBS09	0.7	1.4	0.030373	06/12/2016 11:46
	OBS9	Recovery OBS09+ crane	0.8	1.5	0.033657	06/12/2016 12:35
15		Transit OBS09-OBS11	0.8	1.5	0.033747	06/12/2016 13:23
	OBS11	Recovery OBS11+ crane	0.9	1.6	0.037948	06/12/2016 14:18
15		Transit OBS11-OBS12	0.8	1.6	0.033747	06/12/2016 15:06
	OBS12	Recovery OBS12+ crane	0.9	1.6	0.038503	06/12/2016 16:02
17		Transit OBS12-OBS10	0.9	1.7	0.038247	06/12/2016 16:57
	OBS10	Recovery OBS10+ crane	0.9	1.7	0.036003	06/12/2016 17:00
		CTD + batymetry	14.5	2.3	0.604167	07/12/2016 7:30
23		Transit to OBS05	1.2	2.4	0.051746	07/12/2016 8:44
	OBS5	Recovery OBS05+ crane	1.0	2.4	0.041312	07/12/2016 9:44
17.5		Transit OBS05-OBS04	0.9	2.4	0.039372	07/12/2016 10:40
	OBS4	Recovery OBS04+ crane	1.1	2.5	0.043951	07/12/2016 11:43
14		Transit OBS04-OBS02	0.8	2.5	0.031497	07/12/2016 12:29
	OBS02	Recovery OBS02+ crane	1.1	2.6	0.044676	07/12/2016 13:33
20		Transit OBS02-OBS03	1.1	2.6	0.044996	07/12/2016 14:38
	OBS03	Recovery OBS03+ crane	0.9	2.6	0.037762	07/12/2016 15:32
18		Transit OBS03-OBS01	1.0	2.7	0.040497	07/12/2016 16:31
	OBS01	Recovery OBS01+ crane	0.9	2.7	0.038133	07/12/2016 17:26
		CTD + batymetry	55.0	5.0	2.291667	10/12/2016 0:26
118		Transit to Malaga	6.4	5.3	0.265479	10/12/2016 6:48
566.5		total hours=	126.6		5.274955	
		Days=	5.3			

Table III: Time calculation plan of the activities performed during the Al-Idrissi recovery cruise.

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