

PALEOSEISMOLOGY OF ACTIVE FAULTS BASED ON MULTISCALE SEISMIC IMAGING

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Abstract – The study of active structures offshore requires very-high resolution seismic imaging in order to observe the most recent layers below sea floor. In the other hand, high penetration methods are necessary to observe deeper reflections for understanding the evolution of the structure throughout the time. The aim of our study is to establish the seismic potential of the offshore segment of the Carboneras Fault, Eastern Betics, based on multiscale seismic imaging. Three different scale methods have been acquired and are compared here: very-high-resolution sub-bottom profiler TOPAS, very-high-resolution single-channel seismic (Sparker) and high-resolution multi-channel seismic. From seismic profiles, faulted Quaternary layers suggest that the Carboneras Fault is active. Sediment coring and dating analysis are used to consider ages for key reflectors observed in TOPAS profiles, and a change in the vertical slip-rate through the Quaternary is inferred.

Keywords – Carboneras Fault, Alboran Sea, active tectonics, multiscale imaging, high-resolution seismic

I. INTRODUCTION

Seismic data is commonly used to identify active faults, to study their seismic parameters, and to relate faulted horizons with the historical and instrumental earthquake record. High-resolution seismic reflection profiles (<3 km depth penetration and 2.5 m of vertical resolution) are excellent to investigate the tectonic setting identifying its faulting pattern. Very high-resolution seismic data (<100 m depth penetration and 15 cm of vertical resolution) images the uppermost portions of major faults and its seafloor surface ruptures, being useful to relate them with past earthquakes.

Seismic systems with different resolution and penetration are used to investigate active faults in the Southeastern Iberian Margin, where the compression between the African and Eurasian Plates is characterized by a moderate seismicity and a slow NW-SE convergence (4-5 mm/yr). However, some major events occurred in the past, such as the 1522 Almeria earthquake (Intensity IX), affecting large areas in the western Mediterranean. The Carboneras Fault Zone (CFZ), an onshore-offshore active sinistral strike-slip fault [1], has been proposed as an epicentral area according to evidence of seafloor ruptures in high-resolution acoustic and seismic data.

II. METHODS

Selecting a seismic source implies a trade-off between penetration, which demands lower frequencies (e.g. boomer, airgun, watergun), and resolution, which requires greater bandwidths (e.g. 3.5 kHz sounder, parasound, chirp) [2]. To image the geometry of the offshore segment of the CFZ with different scales of resolution and penetration, three seismic systems were selected: the airgun source, the sparker source and the chirp pulse source.

During the IMPULS survey carried out during spring 2006, a high-resolution multichannel seismic (MCS) system was implemented for the first time in the RV Hesperides and 46 high-resolution MCS profiles were acquired along and across the CFZ in water depths ranging from 100 to 1700 m. The source, a 10 m long air-gun array, was specially designed to enhance high frequencies, up to 300 Hz. To record the seismic data, a "GeoEel" digital streamer from Geometrics (California, USA) with 300 m of active section and 48 channels was used. The multichannel data, acquired at 1 ms sample rate, was processed at the Unidad de Tecnologia Marina (UTM-CSIC) processing laboratory. The flow sequence, after re-sampling from 1 to 2 ms and picking the top mutes, included a FK filter (between 20 and 200 Hz) to reduce spatial aliasing and a bandpass filter minimum phase (20-25-170-200 Hz). The NMO correction with a constant velocity of 1700 m/s due to the reduced length of the streamer was applied to the data. On preliminary seismic images, three main seismostratigraphic units were identified: Neogene basement, lower, and upper sedimentary units. An analysis of velocities from commercial seismic lines helped to assign the velocity range to each of the seismic facies for a Fast Explicit migration to better constrain the geometry.

Simultaneously, during the IMPULS cruise, a total of 60 profiles of high-resolution Simrad TOPAS (TOpographic PArametric Sonar) seismic profiler were ac-

quired in order to observe the shallowest geometry of the fault. The TOPAS PS18 is a high-resolution sub-bottom profiler with parametric effect. It uses a primary frequency of 18 kHz, and a secondary frequency of 1 to 6 kHz. The maximum vertical resolution obtained is 0.2 ms, and the bandwidth range from 4° to 6°. The selected source was a Chirp pulse wavelet with frequencies of 1.5 – 5 kHz. The trace length was 300 ms with a sampling frequency of 16000 kHz and a pass band filter of 2 kHz was applied.

In summer 2008, very high-resolution single-channel seismic (SCS) data were collected on the frame of the EVENT-SHELF experiment onboard the RV Garcia del Cid. Five profiles across the CFZ in the shelf were acquired to see the onshore-offshore link of the fault, where shallow water prevents a fine MCS image. It also provided accurate morphostructure images in the sub-surface and the upper geometry of the fault. The seismic system used was a "GEO-SPARK" source from GEO-RESOURCES company (Rotterdam, The Netherlands) able to acquire data with 30 cm of resolution up to 1.5 km water depth and with 400 m of penetration below seabed. A 6 kJ Sparker system was used, triggered every 2 s. The receiver was composed of 9 m long, 24 hydrophones single-channel streamer. The first processing of data implied a change of polarity because the system uses a negative electric discharge pulse in order to reduce the wear of the tips. The processing sequence continued with debias, minimum bandpass filter (350-1500 Hz), AGC (10 ms window), gain constant (1-3 dB depending of the profile) and spherical divergence to recover the loss of energy. Finally, an automatic or manual "swell filter" depending on the seafloor topography has been performed.

III. RESULTS AND CONCLUSIONS

Seismic profiles show a great variability of structures along the fault zone, in part due to the interaction between "en echelon" traces: positive flower structures can be observed at the shelf, southwards simple reverse faults block the gullies draining from the shelf, and complex compressive structures appear at the southern segment like pressure ridges slowly dimed towards the south and finally buried by hemipelagic sediments. The high-resolution IMPULS MCS profiles allow identifying up to 7 seismostratigraphic units above the Messinian unconformity. Correlations with ODP and commercial wells, together with sea level variation curves will provide estimate ages for the key reflectors delimiting those units, and will help to understand the evolution of the CFZ since the Miocene. Preliminary 0,04 mm/a dip-slip rates is obtained based on a approximately 112 m displaced reflector depicting the base of the Early Quaternary sequence (2,6 Ma).

TOPAS profiles show detailed stratigraphic information on the uppermost meters below the seafloor (80 to 100 m at an assumed sediment velocity of 1.5 km/s) providing a good control of recent activity over the Quaternary sedimentary architecture and depicting the shallowest geometries of the CFZ. Fault scarps and displaced reflectors evidence recent activity and a decrease of the fault activity towards the south, where Holocene sediments overlay the fault zone. From existing sediment core analyses from the Almería channel [3] sedimentation rates are calculated and slip rates can be obtained from TOPAS displaced reflectors. Profiles from the north segment of the fault shows a highly reflected horizon displaced 21 metres vertically suggesting a dip-slip rate of 0,14 mm/a for the Late Quaternary time. Similar dip-slip rate is obtained in another TOPAS profile along the CFZ. These are larger slip-rates than the ones obtained with MCS profiles since the Early Quaternary (0,04 mm/a) suggesting either an increase of the slip rate through the Late Quaternary or a change in the kinematics of the fault with an increase in dip-slip component.

SCS Sparker profiles clearly image the structures on the shelf and nearshore and will help to link onshore and offshore results and to better constrain the paleoseismic parameters for the entire CFZ.

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VERY HIGH-RESOLUTION SEISMO-ACOUSTICS IN THE STUDY OF SEAGRASSES. THE CASE OF POSIDONIA OCEANICA (MEDITERRANEAN SEA)

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Abstract - *Posidonia oceanica* is a coastal Mediterranean seagrass which accumulates in its subsurface large quantities of organic material derived from its roots, rhizomes and leaf sheaths embedded in sandy sediments. These organic deposits accumulate over thousands of years forming the matte, whose high content in organic carbon plays a major role in the global ocean carbon cycle. In this study, very high resolution seismo-acoustic methods were applied to image the subsurface features of a *P. oceanica* seagrass meadow at Portlligat (Cadaqués, Girona, Spain), in the NW Mediterranean Sea. Our findings yield fresh insights into the settling of the *P. oceanica* meadow in the study area, and define with unprecedented detail the potential volume occupied by the matte.

Keywords - Non linear seismo-acoustics, seagrasses, Holocene, Mediterranean Sea

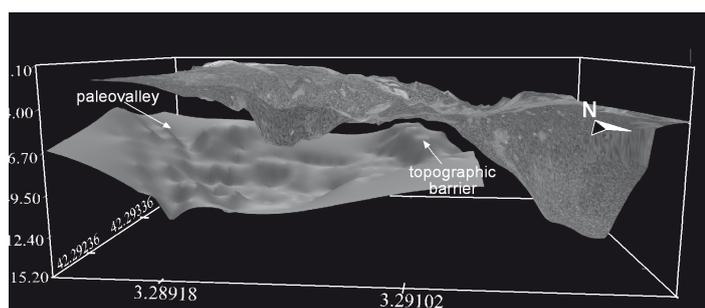
I. INTRODUCTION

Posidonia oceanica, a widespread Mediterranean seagrass, accumulates in its subsurface large quantities of organic material, named matte. The matte is mainly composed of detritus of the seagrass, derived from their leaves and organs, embedded in the surrounding sediments [1].

The organic fraction of the matte is preserved over thousands of years forming structures several meters thick [2]. This preservation results from the highly anoxic conditions in the matte and from the refractory nature of the detritus [2]. The high content in organic carbon of these deposits plays a relevant role in the global ocean carbon cycle. Although the distribution of *P. oceanica* has been widely assessed using acoustic methodologies, informations on its internal structure obtained with seismic methods are still very rare. In this study, very high resolution non-linear seismo-acoustic methods were applied to image the subsurface features of a *P. oceanica* seagrass meadow in the NW Mediterranean Sea (Catalonia, NE Spain). The main advantage of the non-linear parametric echosounders lies in their capability to generate low frequencies producing narrow beams with small footprints [3]. This differs substantially from the linear seismic systems, which require long pulses and large transducers to generate focused low frequencies [4].

II. RESULTS AND DISCUSSION

The parametric echosounder "Innomar SES 2000 compact" was used to acquire



75 seismo-acoustic records. The echosounder was characterized by a primary frequency of 100 kHz and secondary frequency ranging from 5 to 12 kHz. Pulse Repetition Rate was up to 30/sec and the beamwidth of $\pm 1.8^\circ$. *P. oceanica* meadow covers up to 60.000 m² of the Portlligat Bay. It mainly occurs in mounds, generating irregular seabed topography, with leaves measuring from 20 to up to 60 cm long (Figure 2a). Although the seismo-acoustic method proved to be reliable in imaging *P. oceanica* meadows at Portlligat, this instrumentation suffered from difficulties in associating the internal structure of the matte with a specific seismic facies. The gradation between plant detritus and sediments along the vertical structure of the matte (Figure 3b) scarcely provided high-enough contrasts of impedance to generate neat seismic reflectors. Its heterogeneous composition is a very high dispersive medium for acoustic energy, resulting in a marked decrease in the signal to noise (S/N) ratio. Despite these limitations, in many records it was possible to detect a strong reflector, from 2 to 6 m depth, that was interpreted as the initial substratum where the seagrass established for first time. A 3D bathymetric model of this substratum allowed us to reconstruct the palaeo-environment of the area prior to the settling of *P. oceanica*, which corresponded to a shallow coastal setting protected from the open sea. A core drilled in the meadow revealed the presence of a 6 m thick dense matte composed of medium to coarse sandy sediments mixed with plant debris and bioclasts. Radiocarbon datings revealed a constant accretion rate of the meadow of about 1.1 m/kyr. Very high-resolution marine geophysical techniques allowed us to accurately define the volume occupied by *P. oceanica* matte, which in the study area reaches up to almost 220,000 \pm 17,400 m³ (Fig.1).

III. CONCLUSIONS

The application of nonlinear seismo-acoustic technologies proved to be a powerful non-destructive method for highlighting the settling of coastal seagrasses in the Mediterranean Sea. Moreover, the new technological advances allowed in estimating the potential carbon retention of the *P. oceanica* meadows and better understand its relevance in the ocean carbon cycle.

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Fig.1: 3D view of the paleotopography of the matte substratum (lower gray layer) and of the actual seafloor in Portlligat Bay. Depth in meters.