Tectonic domains of the Betic Foreland System, SW Iberian Margin: Implications for the Gulf of Cadiz Contourite System

D. Duarte[1,2,*], C. Roque[3,4], Ng Zhi Lin[1], F. J. Hernández-Molina[1], V. H. Magalhães[2,4], E. Llave[5], F. J. Sierro[6]

[1]Dept. Earth Sciences, Royal Holloway Univ. London, Egham, UK (Debora.Duarte.2017@live.rhul.ac.uk)
[2]IPMA – Instituto Português do Mar e da Atmosfera, Lisboa, Portugal
[3]EMEPC – Estrutura de Missão para a Extensão da Plataforma Continental, Paço de Arcos, Portugal
[4]IDL – Instituto Dom Luiz, Campo Grande, Portugal
[5]IGME – Instituto Geológico y Minero de España (IGME), Madrid, Spain
[6]Dpto. de Geología, Univ. de Salamanca, Salamanca, Spain

*Debora.Duarte.2017@live.rhul.ac.uk

Introduction

Deep-water sedimentation is **influenced** by three variables – **tectonics**, **climate** and **sea-level changes** (e.g. Artoni et al., 2005; Leeder, 2011). Together, they control the distribution and architecture of sedimentary successions and, therefore, basin development.

The **SW Iberian Margin** (SWIM; **Fig. 1a,b**) occurs in an region of complex interplay between sedimentary, oceanographic and tectonic processes. The seafloor morphology is influenced by regional lithospheric movements, both during the **Mesozoic rifting** and the following **Eurasia-Nubia plate convergence** (Figueiredo, 2015; Pereira and Alves, 2013; Terrinha et al., 2009), and by local **diapiric processes** (e.g. Medialdea et al., 2009; Ramos et al., 2017).

The **Gulf of Cadiz Contourite System** (GCCS) developed in the SWIM, as consequence of the interaction of the **Mediterranean Outflow Water** (MOW) with the continental middle slope (**Fig.1b**). Being developed in a complex tectonic setting, it is a **key location** for exploring the **influence of tectonic activity** on **deep-water sedimentation**.

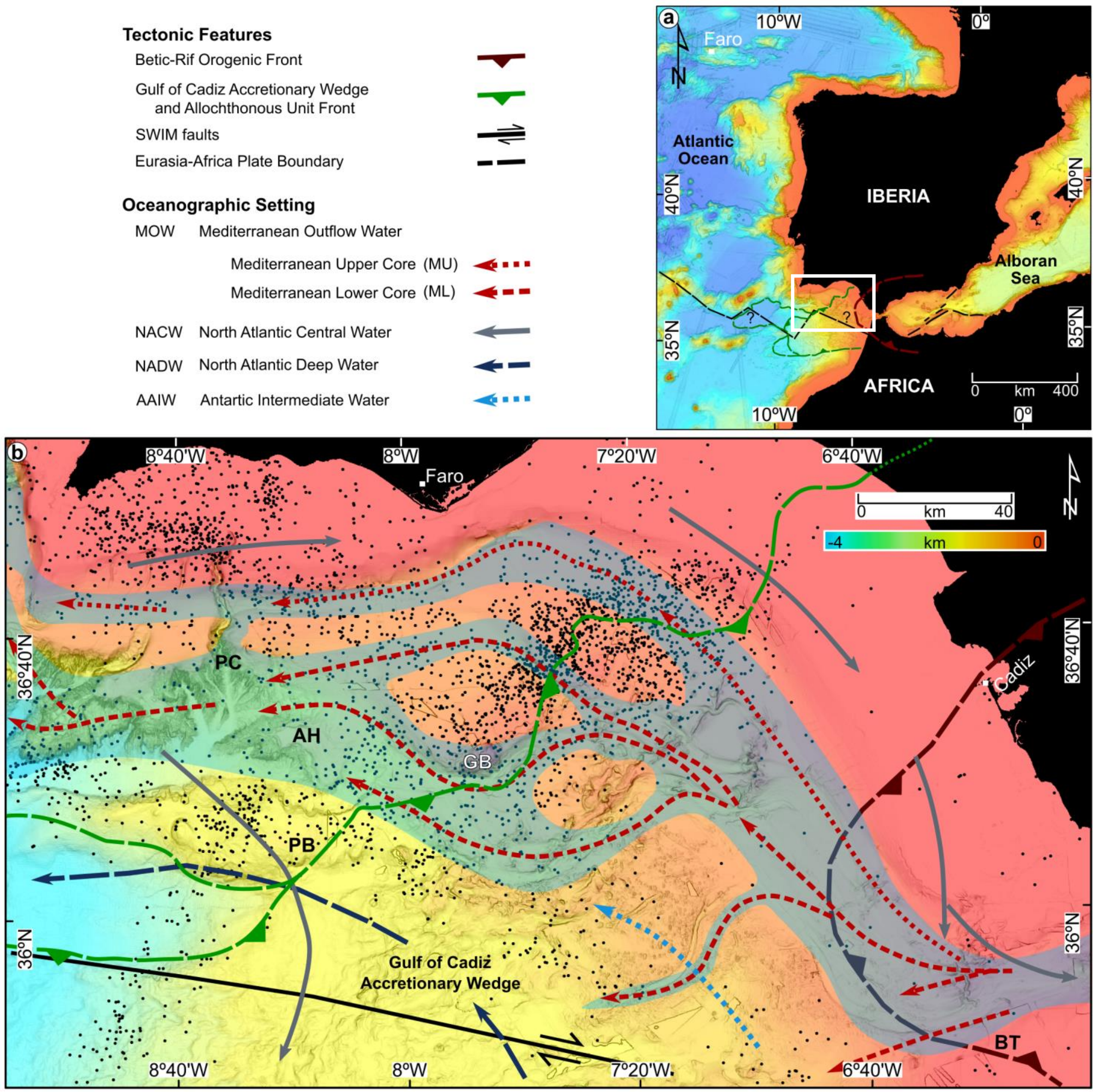


Fig.1 Geographic location of the SW Iberian Margin: **(a)** Regional setting, with the main tectonic structures. White rectangle show the study area; **(b)** Detailed map of the margin showing the main oceanographic and structural features. GB: Guadalquivir Bank, PB: Portimão Bank, AH: Albufeira High. Black circles show earthquake locations. Coordinate system: UTM-29N WGS84. Bathymetric data from the EMODnet Bathymetry Consortium, (2018).

Aims & Methods

This work aims to understand how inherited basin configuration and tectonic activity controlled the evolution of the GCCS.

This was achieved based on a tectonostratigraphic analysis of an extensive **2D multibeam seismic dataset** complemented by bathymetric and earthquake activity data.

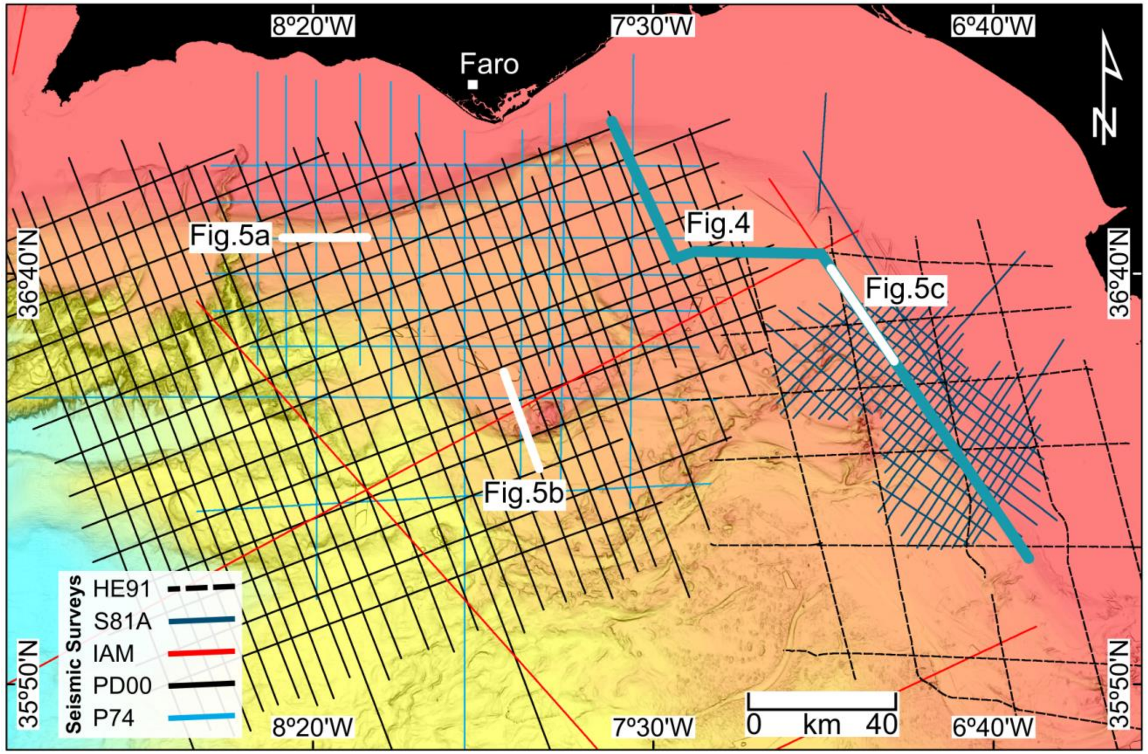
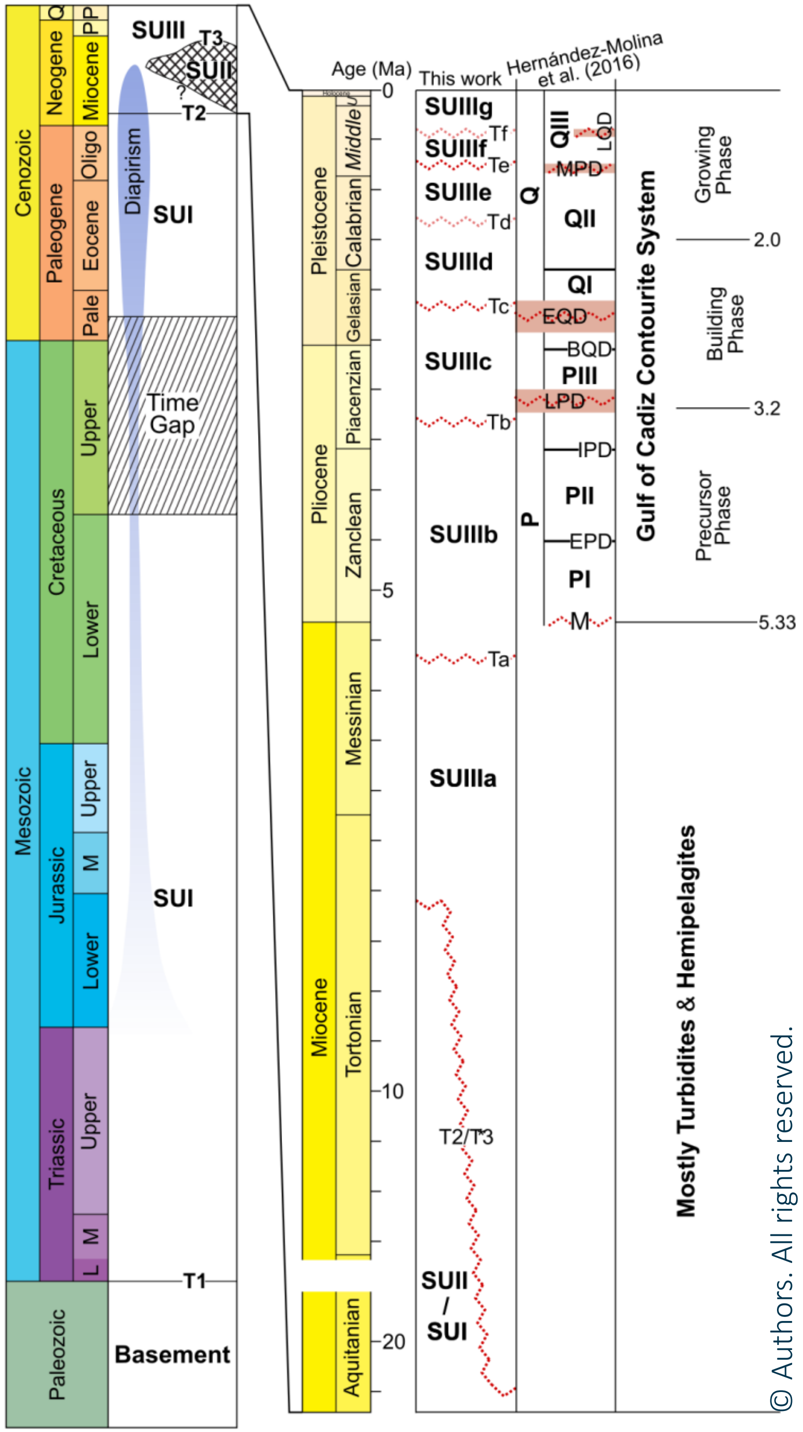


Fig.2 Dataset used in this work – 2D seismic surveys from TGS-Nopec (PD00-PDT00), Chevron P74, Repsol (HE91, S81A) and IAM. Coordinate system: UTM-29N WGS84. Bathymetric data from the EMODnet database (EMODnet Bathymetry Consortium, 2018).

Tectonostratigraphy

Fig.3 Chronostratigraphic chart and correlation between the tectonostratigraphic seismic units (SUI, SUII and SUIII) and discontinuities (T1 to T3/Ta to Tf) identified in this work and seismostratigraphic models for the Algarve Basin. The depositional systems are also shown.

M – Miocene-Pliocene Boundary, EPD – Early Pliocene Discontinuity, IPD – Intra Pliocene Discontinuity, LPD – Late Pliocene Discontinuity, BQD – Base Quaternary Discontinuity, EQD – Early Quaternary Discontinuity, MPD – Middle Pleistocene Discontinuity and LQD – Late Quaternary Discontinuity.



THE DRIFTERS RESEARCH GROUP

Tectonostratigraphy

- The Algarve, Doñana, Sanlucar and Cadiz basins developed in the foreland of the Betic-Rif Orogen.
- Three **regional tectonostratigraphic seismic units** (SUI to SUIII) were identified across the basins (**Fig.3** and **4**). They correspond to different phases of the SWIM tectonic evolution.

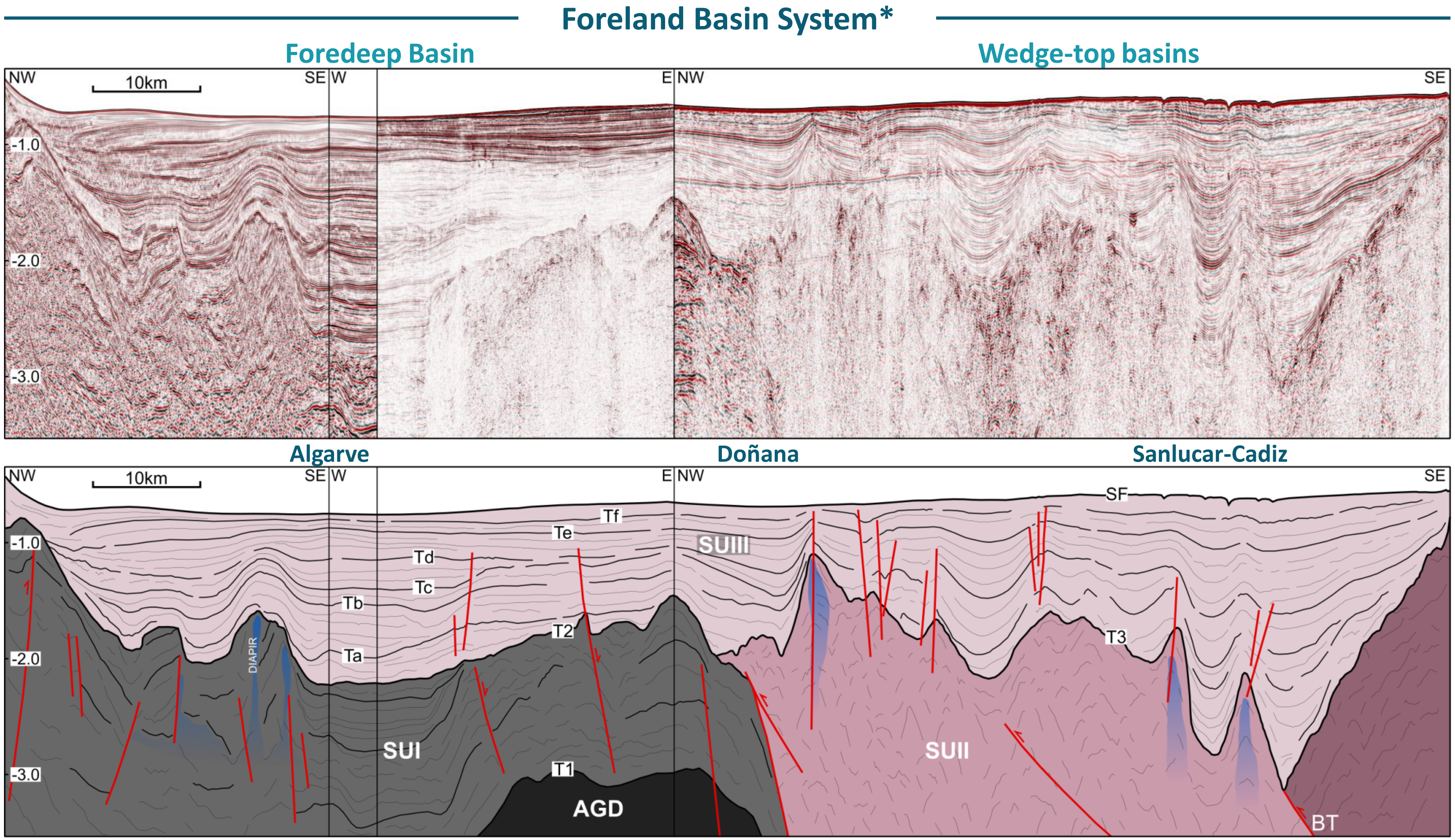


Fig.4 NW-SE cross-section based on composite seismic lines (vertical exaggeration of 10x). ADG – Paleozoic Basement Structural High. BT – Betics Front Thrust . **sensu* DeCelles and Giles, (1996)

SUIII

- Miocene-Quaternary Foreland Basin system.
- SUIII sub-units details in **Fig.3**.

SUII

- Accretionary wedge (GCAW) sediments.
- Deformed Triassic, Cretaceous, Palaeogene and Neogene rocks.

SUI

- Syn- and post-rift inverted margin.
- Folded Mesozoic and Palaeogene rocks.

Tectonic Structures

Three important tectonic structures were identified (**Fig.5**):

- the dextral strike-slip NW-SE **Gil Eanes Fault Zone** (GEF);
- NE-SW to ENE-WSW **Cadiz Fault** (CF);
- E-W to ENE-WSW **Albufeira-Guadalquivir-Doñana Basement High** (AGD).

Based on their location and orientation they were interpreted as being **inherited structures** from the **Mesozoic rift system** (e.g. Terrinha et al., 2013).

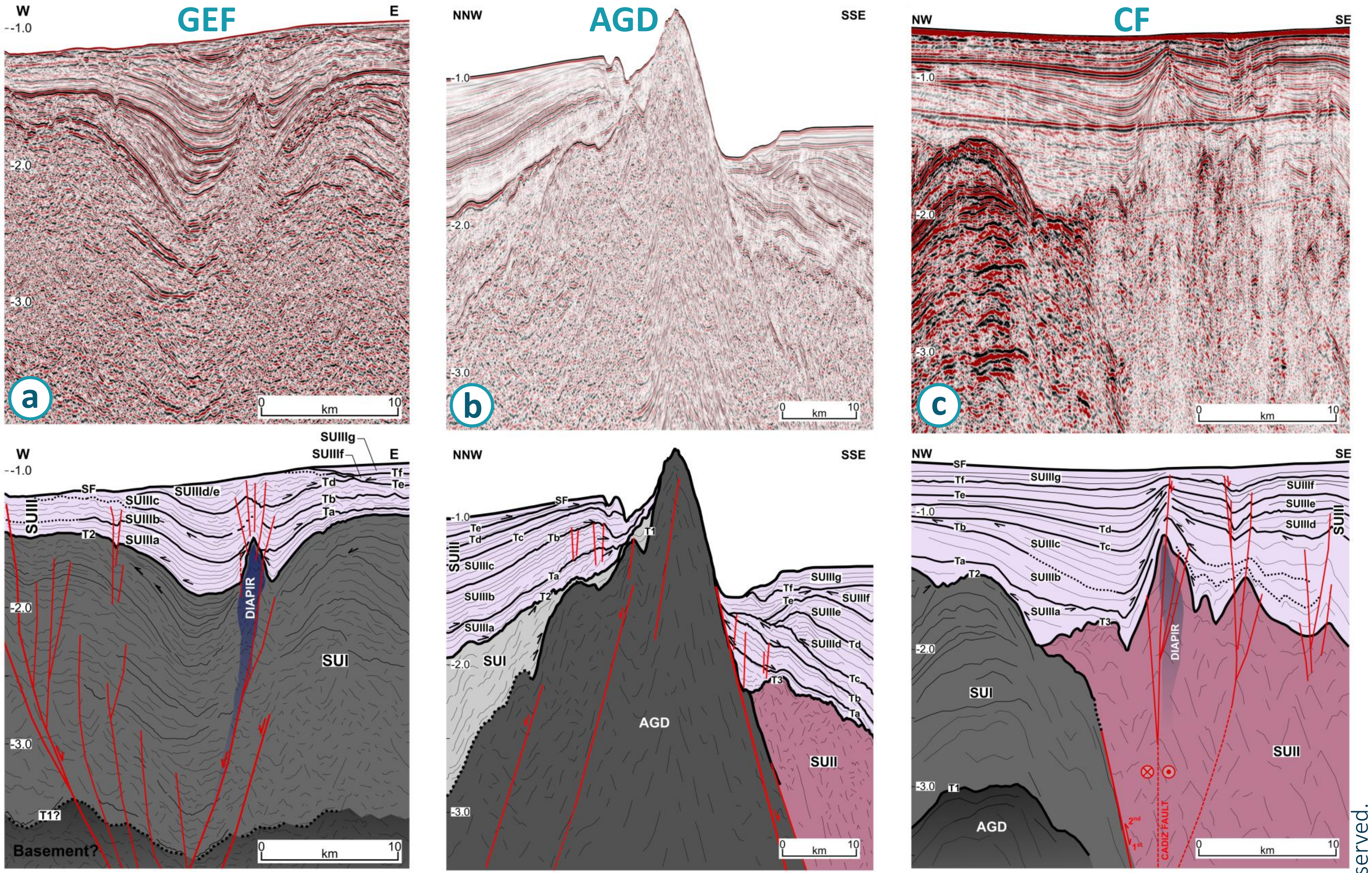


Fig.5 Seismic sections and interpretation from lines **(a)** P74-20 – GEF, **(b)** IAMGC3 – CF and **(c)** PD00-824 – AGD. Seismic units (SUI and SUIII), sub-units (SUIIIa to SUIIIg) and the identified unconformities (T2 and Ta to Tf) are shown. Vertical exaggeration of 10x. Profiles location is given in **Fig. 1c**.

- **Complex structure**, wide zone of brittle and ductile deformation;
- Deforms **SUII**, **SUIII** and probably the **basement**;
- Negative **flower structure** (strike-slip) + **dip-slip**.

- Elongated morphostructural high;
- **Triangular** features in cross-section, wit high amplitude, **chaotic** internal facies, bounded by normal faults.

- Deforms **SUII**, **SUIII** and probably the **basement**;
- Negative **flower structure** (strike-slip) + **minor dip-slip**;
- **Control** the location of the Guadalquivir **Diapiric Ridge** (GDR).

THE DRIFTERS RESEARCH GROUP

SWIM Tectonic Domains

The margin's evolution was strongly **influenced** by the **tectonic structures** (GEF, CF and AGD). Together with **regional tectonic** and **paleoceanographic processes**, they controlled the growth pattern of the Miocene-Quaternary deposits of the foreland basin system (**SUIII**).

Based on these observations, the SWIM was divided into **four tectonic domains** – **A**, **B**, **C** and **D** – with **different structural** and **seismological characteristics** (**Fig.6**).

Separated by… CF, AGD, GEF

Tectonic Domains	Characteristics
Domain A	- Aseismic zone. - **Gentle seafloor**, with smooth relief. - **Diapirs** outcrop in the **north** of the domain.
Domain B	- High number of seismic events. - **Intense diapirism** → controlled depocentre evolution.
Domain C	- **Flexural subsidence**, in response to the tectonic loading caused by the Betics Orogen, led to the **increment of accommodation space** (Pliocene-Quaternary).
Domain D	- **Small accommodation space** or sedimentary input. - Uplifted area, between the Atlantic and Tethys rifting domains (Pereira and Alves, 2013).

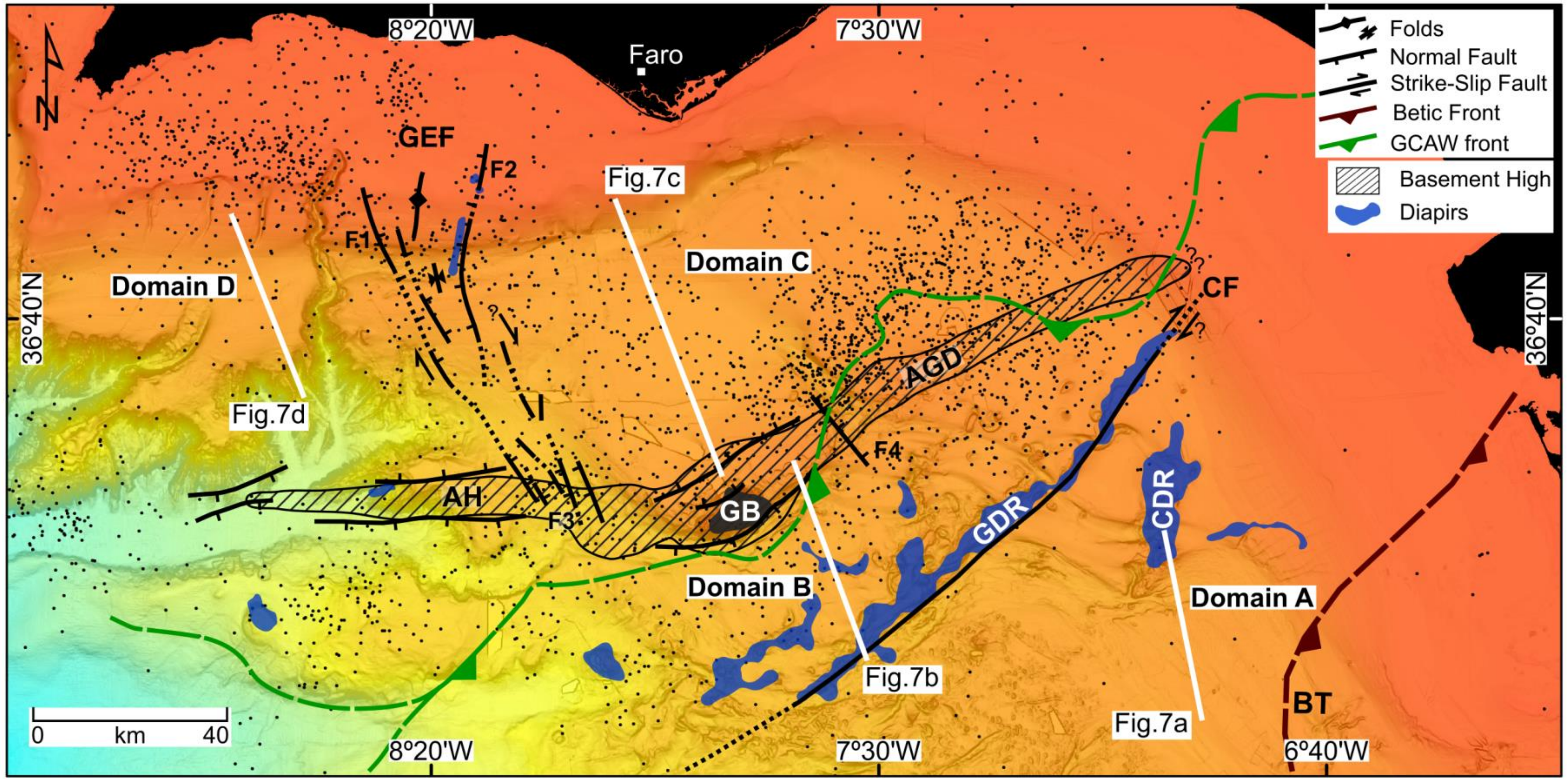


Fig.6 **Tectonic Domains of the SWIM**. Back dots: earthquake epicentres. AGD: Albufeira-Guadalquivir-Doñana Structural High, GB: Guadalquivir Bank; AH: Albufeira High, GEF: Gil Eanes Fault, CF: Cadiz Fault, BT: Betic Front Thrust, GDR: Guadalquivir Diapiric Ridge, CDR: Cadiz Diapiric Ridge.

SWIM Tectonic Domains: imprint on Sedimentary Processes

The GCCS **depositional** and **erosional features** show **different characteristics** for each of the **tectonic domains** previously recognised (**Fig.8**).

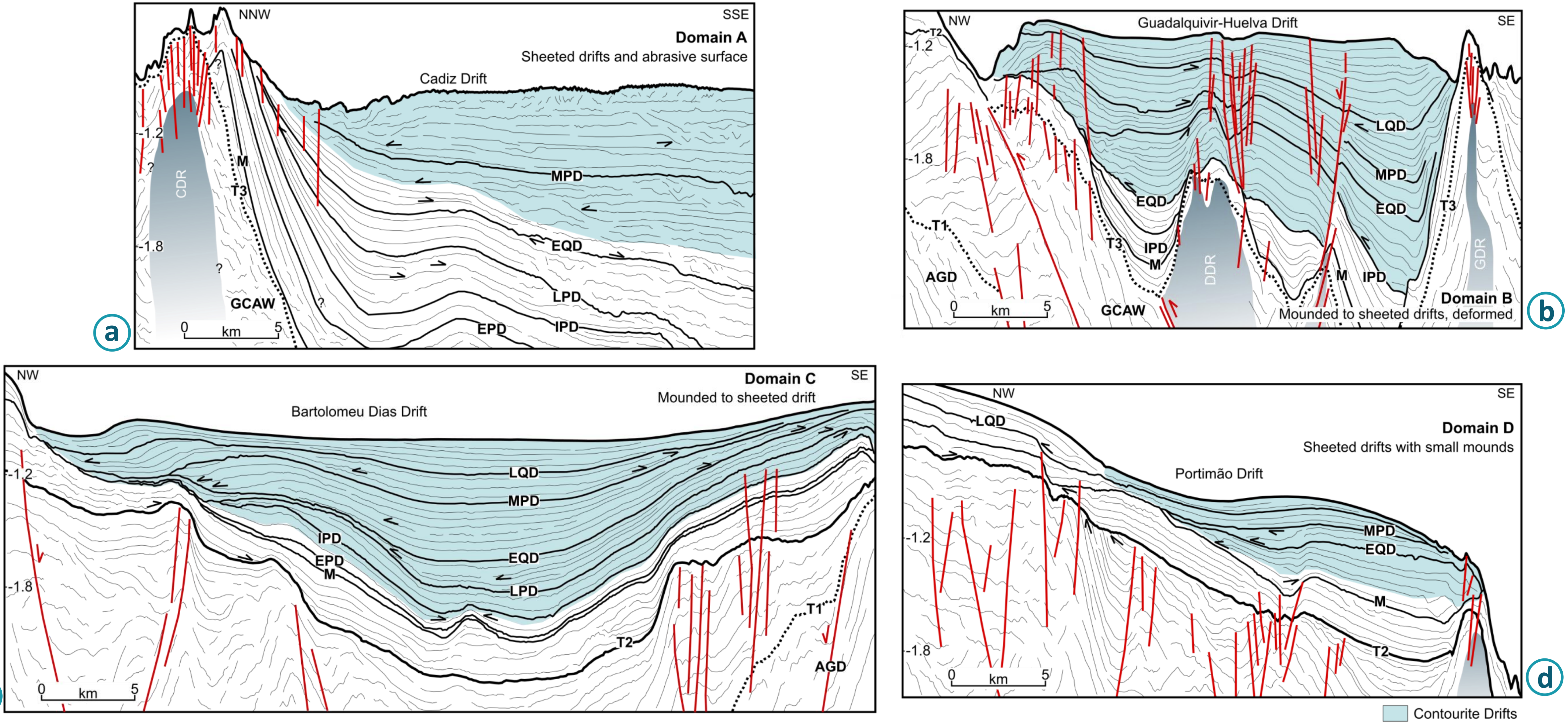


Fig.7 Seismic lines showing the contourite drifts in each of the tectonic domains. Seismostratigraphic interpretation of Hernández-Molina et al., (2016) for the contourite drifts is shown (LQD, MPD, EQD, LPD, IPD, EPD and M; see **Fig.3**).

THE DRIFTERS RESEARCH GROUP

SWIM Tectonic Domains: imprint on Sedimentary Processes

Separated by…

Tectonic Domains	Characteristics	Contourite System
Domain A	- Aseismic zone. - **Gentle seafloor**, with smooth relief. - **Diapirs** outcrop in the **north** of the domain.	- Abrasive surface. - Sheeted drifts.
CF		
Domain B	- High number of seismic events. - **Intense diapirism** → controlled depocentre evolution.	- Sheeted and deformed sheeted drifts. - Paleo-mounded drifts against AGD. - Network of erosive channels.
AGD		
Domain C	- **Flexural subsidence**, in response to the tectonic loading caused by the Betics Orogen, led to the **increment of accommodation space** (Pliocene-Quaternary).	- Mounded-sheeted drifts (~50km wide, 75km long and max. thickness of 1.75s TWT). - Main depositional sector of the GCCS.
GEF		
Domain D	- **Small accommodation space** or sedimentary input. - Uplifted area, between the Atlantic and Tethys rifting domains (Pereira and Alves, 2013).	- Small sheeted drifts (10-15km wide and ~50km long and max. thickness of 1.45s TWT).

Structural elements identified as main controls to the evolution of the GCCS

- **Tectonic subsidence or uplift**

Flexural subsidence create accommodation space.
Contrariwise, drifts are not very extensive in uplifted areas, where the accommodation space is limited.

- **Presence of structural obstacles**

Mounded drifts geometries near important structural obstacles.
If the seafloor is gentle, sheeted drifts are developed as a consequence of a weak and wide non-focused MOW.

- **Fault-related depressions**

Contourite channels locally developed along the GEF and F4 faults → influence of fault-generated seafloor morphology (e.g. depressions resulted from the negative flower structures in the GEF southern sector).

THE DRIFTERS RESEARCH GROUP

Conclusions

- This work demonstrates the **inherited tectonic structures** and the **margin paleo-topography** are the **major elements controlling the initiation and the development of the contourite system**. The SWIM morphology was shaped by the regional tectonic processes – that conditioned the gateways' evolution and the diapiric activity – and by the paleoceanography – MOW circulation – throughout the Miocene-Quaternary.

- It was established that **drifts** characteristics (e.g. size and geometry) are **dependent on tectonic-controlled depositional space**, at a basin-wide scale. The presence of **structural obstacles** represents a major controlling factor in drift evolution **imposing** the **development of mounded geometries** where important structural obstacles conditioned the current circulation.

- Consequently, these results emphasize the **importance of taking tectonics into account for contourite systems evolutionary models**. It can be a guide for forthcoming works, where deep-water systems develop in active settings or in areas with important inherited topography (e.g. the Argentinian-Uruguayan margin).

Acknowledgements

D.D. thanks the FCT (Fundação para a Ciência e a Tecnologia) - the Portuguese Science Foundation through the PhD grant SFRH/BD/115962/2016. The research studies are conducted in the framework of 'The Drifters Research Group' of the Department of Earth Sciences, Royal Holloway University of London (UK). The bathymetric data used in this work is from the European Marine Observation and Data Network (EMODnet) Bathymetry Project (http://www.emodnet.eu/bathymetry).

References

Artoni et al. (2005) Climatic Controls on Sedimentation in Late Miocene Cortemaggiore Wedge-Top Basin (Northwestern Apennines, Italy), in: Lacombe et al. (Eds.), Thrust Belts and Foreland Basins: From Fold Kinematics to Hydrocarbon Systems. Springer, Berlin, pp. 431–456; **DeCelles and Giles, (1996)** Foreland basin systems. Basin Res; **EMODnet Bathymetry Consortium, (2018)** EMODnet Digital Bathymetry (DTM 2018); **Figueiredo (2015)** Neotectonics of the Southwest Portugal Mainland: Implications on the Regional Seismic Hazard. Universidade de Lisboa; **Hernández-Molina et al. (2016)** Evolution of the gulf of Cadiz margin and southwest Portugal contourite depositional system: Tectonic, sedimentary and paleoceanographic implications from IODP expedition 339. Mar. Geol. 377, 7–3; **Leeder (2011)** Tectonic sedimentology: Sediment systems deciphering global to local tectonics. Sedimentology 58, 2–56; **Medialdea et al. (2009)** Tectonics and mud volcano development in the Gulf of Cádiz. Mar. Geol. 261, 48–63; **Pereira and Alves, (2013)** Crustal deformation and submarine canyon incision in a Meso-Cenozoic first-order transfer zone (SW Iberia, North Atlantic Ocean). Tectonophysics 601, 148–162; **Ramos et al. (2017)** Extension and inversion structures in the Tethys–Atlantic linkage zone, Algarve Basin, Portugal. Int. J. Earth Sci. 105, 1663–1679; **Terrinha et al. (2009)** Morphotectonics and strain partitioning at the Iberia-Africa plate boundary from multibeam and seismic reflection data. Mar. Geol. 267, 156–174; **Terrinha et al. (2013)** A Bacia do Algarve: Estratigrafia, Paleogeografia e Tectónica, in: Dias, R., Araújo, A., Terrinha, P., Kullberg, J.C. (Eds.), Geologia de Portugal. Vol. II: Geologia Meso-Cenozóica de Portugal. Escolar Edirora, Lisboa.

Follow us on Twitter @DriftersRHUL