Sociedad Geológica de España

GEOGACETA, 67, 2020

The lobe complex of the distal Almeria turbidite system: architecture and depositional history over the last 575,000 years

El complejo de lóbulo del sistema turbidítico distl de Almeria: arquitectura e historia deposicional durante los últimos 575 000 años

Belén Alonso[1], Óscar Llamosa[1], Gemma Ercilla[1], Ferran Estrada[1], Carmen Juan[1], David Casas[2] and Juan Tomás Vázquez[3]

[1] Instituto de Ciencias del Mar, CSIC, Passeig Marítim de la Barceloneta, 37-49, Barcelona, Spain. e-mail: belen@icm.csic.es, oscarllamosa@gmail.com, gemma@icm.csic.es, carmen.juanval@gmail.com

[2] Instituto Geológico y Minero de España, La Calera 1, 28760 Tres Cantos, Madrid, Spain. e-mail: d.casas@igme.es

[3] Instituto Español de Oceanografía, Málaga, Puerto Pesquero s/n, 2960 Málaga Spain. e-mail: juantomas.vazquez@ieo.es

ABSTRACT

This paper presents the stratigraphic architecture of the lobe complex (LC) of the distal Almeria turbidite system over the last 575 ka based on very high-resolution data (seismic parametric sub-bottom profiles, bathymetry and stable oxygen isotope core data). Its depositional architecture suggests the 575 ka oldest lobe represents a lobe system, which is essentially organized in vertical stacking of channel-levee/lobes. Their morpho-sedimentary characteristics point to: (i) this turbidite system roughly matches that of mixed sand-mud composition systems; and (ii) the lateral relocation of turbidites may be conditioned by factors such as the sediment load, the energy of gravity flows, related avulsion processes and the local morphological confinement. The detailed seismofacies analysis enabled the identification of channel-levee/lobes, mass-transport deposits and hemipelagites formed over the last 269 ka. Their lateral and vertical distribution suggests that an increased submarine canyon activity and mass-movements took place during lowstand stages (MIS 8, MIS 6, MIS 4 and MIS 2) whereas hemipelagic settling dominated during the highstand stages (MIS 7 and MIS 5).

Key-words: *channelized lobes, mass-transport deposits, turbidites, Alboran Sea.*

RESUMEN

Se presenta la arquitectura estratigráfica del complejo de lóbulo (LC) del sistema turbidítico distal de Almería de los últimos 575 ka basada en datos geológicos de muy alta resolución (perfiles sísmicos paramétricos, batimetría e isotopos estables de oxígeno). Su arquitectura deposicional sugiere que el lóbulo más antiguo (575 ka) está organizado por el apilamiento vertical de complejos de canal-dique/lóbulo. Sus características morfo-sedimentarias apuntan a: (i) su coincidencia con las de los sistemas mixtos de composición areno fangosa y que (ii) la reubicación lateral de los depósitos turbidíticos pudo estar condicionada por la carga de sedimento, la energía de los procesos gravitacionales, los procesos de avulsión y el confinamiento local. El análisis detallado de las sismofacies permite la identificación de lóbulos canalizados, depósitos de transporte en masa, y hemipelagitas formados durante los últimos 269 ka. Su distribución lateral y vertical sugiere que la actividad del cañón submarino y los movimientos en masa fueron mayores durante las etapas de bajo nivel del mar (MIS 8, MIS 6, MIS 4 y MIS 2) y la sedimentación dominante sería hemipelágica durante las etapas de alto nivel del mar (MIS 7 y MIS 5).

Palabras clave: *lóbulos canalizados, depósitos de movimiento en masa, turbiditas, Mar de Alborán.*

Geogaceta, 67 (2020), 31-34
ISSN (versión impresa): 0213-683X
ISSN (Internet): 0213-683X

Fecha de recepción: 1/07/2019
Fecha de revisión: 17/10/2019
Fecha de aceptación: 22/11/2019

Introduction

The present study is focused on the lobe complex (LC) of the distal Almeria turbidite system (ATS). It is located offshore Spain along the Almeria continental margin in the NE Alboran Sea (SW Mediterranean). The geological understanding of the ATS has benefited from progressive improvement of geophysical and deep-water sediment coring techniques (Alonso and Maldonado, 1992; Estrada *et al*., 1997; Alonso and Ercilla, 2003, García *et al*., 2006; Bozzano *et al*., 2009; Juan *et al*., 2016). However, the most recent evolution (late Quaternary) of the LC is not yet fully understood. This study presents a chronostratigraphy of 575 ka of the LC, and its depositional history.

Geological setting

The Alboran Sea is a partially landlocked marine basin (approximately 150 km wide and 350 km long, Dillon *et al*., 1980). Its regional active tectonic setting generates a complex seafloor physiography.

The ATS is mostly fed by the Andarax River. The architectural elements of the ATS consist of three tributary systems (Gata, Andarax and Dalias, Garcia *et al*., 2006), a long (60 km) and rectilinear submarine canyon with a sinuous to meandering thalweg (Fig. 1). The canyon evolves into a channel-levee complex at the base-of-slope (~ 1200 m deep) extending to 1600 m in depth (Alonso and Ercilla 2003). At a depth of about 1600 m, the LC begins to develop where the overbank of Almeria channel widens and the main leveed channel branches into distributary channels and distal fringes. This lobe extends to the Eastern Alboran Basin (1950 m deep; Fig. 1).

Data and methods

The data used consist of multibeam bathymetry, very high-resolution seismic sub-bottom profiles (parametric sub-bottom profiling systems Kongsberg Topas and Atlas Parasound), and ODP Site

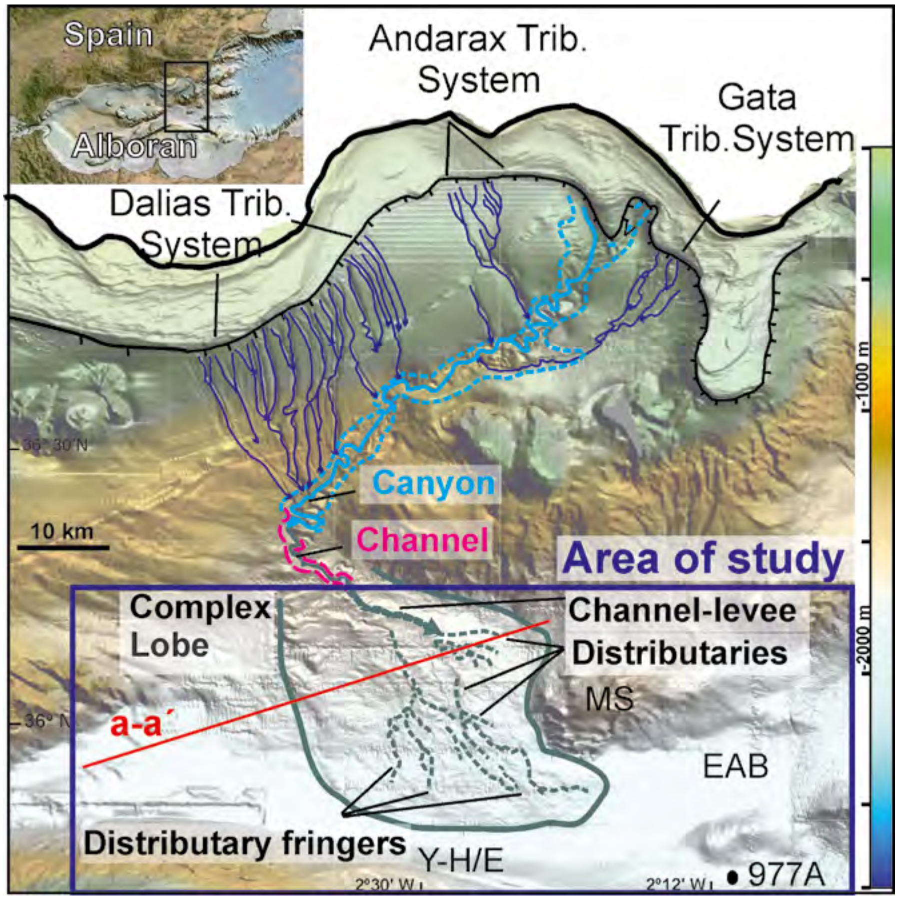

Fig. 1.- Bathymetric map of the Almeria margin showing the area of study, the main architectural elements of the ATS and location of ODP Site 977 (modified from Ercilla *et al.*, 2019). The red line refers to the location of Topas profile in figure 3. EAB: Eastern Alboran Basin, Y-H/E: Yusuf-Habibas Scarpment, MS: Maimonides Seamount, Trib.: Tributary.

Fig. 1.- Mapa batimétrico del margen de Almería mostrando el área de estudio, los elementos arquitecturales del ATS y la localización del sondeo de ODP 977 (modificado de Ercilla et al.*, 2019). La línea roja corresponde a la situación del perfil de Topas de la figura 3. EAB Cuenca oriental de Alborán, Y-H/E Escarpe de Yusuf-Habibas, MS Monte de Maimonides, Trib. Tributario.*

977 (de Kaenel *et al.*, 1999). Global Mapper GIS, IHS Kingdom Suite and previous measurements (oxygen isotopes and age dating) of this site were used.

Results

Seismic stratigraphy and architecture

Two seismic units, U1 and U2 (from older to younger) were identified over the last 575 ka.

Within each unit, three sub-units (U1a to U1c, and U2a to U2c) have been recognized. These sub-units are bounded by six reflectors, assigned as R1 to R6 from bottom up respectively (Fig. 2). A direct correlation between the reflectors R1 to R6, and the information from ODP Site 977 (depth, age, oxygen isotopes, and Marine Isotope Stages. de Kaenel *et al.*, 1999; von Grafenstein *et al.*, 1999; Martrat *et al.*, 2004), allowed us to define a chronostratigraphy of the above seismic units and subunits (Fig. 2). Channel-levee/lobes (Ch-l/l), mass-transport deposits (MTD) and hemipelagites within of these seismic units were identified.

Three Ch-l/l (Ch-l/l-1 to Ch-l/l-3, from older to younger) are well defined within the seismic unit U2 (sub-units U2a, U2b and U2c; Fig. 3) and composed of channel-fill deposits, levees and overbank deposits. The area, thickness and volume of each Ch-l/l are shown in figure 4. The MTD are described as lenticular bodies with very low amplitude chaotic facies and appear interfingered with Ch-l/l. Hemipelagites are characterized by laterally continuous, extensive and low- to mid-acoustic amplitude semitransparent to transparent facies.

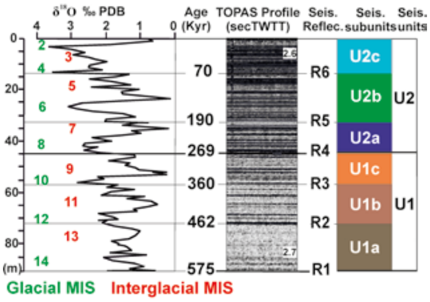

Fig. 2.- Chronostratigraphy of seismic (Seis.) units, subunits, seismic reflectors (Reflec.) and Marine Isotope Stages (MIS) of ODP Site 977.

Fig. 2.- Cronoestratigrafía de las unidades, subunidades sísmicas (Seis.), reflectores sísmicos (Reflect.) y estadios isotópicos (MIS) del sondeo de ODP 977.

Discussion

Classification of lobes

The lobes of the distal ATS can be defined as attached ones taking into in consideration that the depositional architecture of the Almeria lobes begins at the mouth of the main leveed channel, in the absence of the channel lobe transition zone found in other turbidite systems (Fig. 4; *e.g.*, Shanmugam, 2016). This condition suggests a low efficiency system (*e.g.* Mutti, 1992). The architecture with a great variety of seismofacies that change in relatively short distance (few to tens of km) and the plan-view morphology of the lobes elements where the presence of sinuous distributary channels stand out, would indicate that this system roughly matches mixed sand-mud composition turbidite systems (Reading and Richards, 1994; Richards *et al.*, 1998).

Hierarchy of lobes

From a hierarchal point of view, we adopt the subdivisions of Mulder and Etienne (2010). The Almeria LC during the last 575 ka is essentially organized in vertical stacked of lobe systems. They occur where the seafloor is gentler to nearly flat (< 1°), which favours deposition of turbidity flows and the building of the mounded or semi-conical channelized bodies. The steeply confined setting created by the Maimonides Seamount to the east and the Yusuf-Habibas Escarpment to the south have conditioned the depositional architecture of the lobes to the scale of seismic unit, and resulted in a modified seismic stratigraphy and stacking patterns of hybrid deposits: MTD, Ch-l/l and hemipelagites.

Changes in lobe depositional pattern

The vertical and spatial distribution of Ch-l/l-1 to Ch-l/l-3 suggests changes in the deposition stacking pattern for the last 269 ka. A compensational stacking pattern occurred from 269 ka to 70 ka, with a general eastern migrating trend of the lobe system, in which the deposition of lobes within the U2 was controlled by the depressions created by ancient lobes developed within U1 and the sediment supply along the whole ATS. From 70 ka to present, the system evolves from a compensational to an aggradational then retrogradational stacking pattern (Fig. 4). The accumulation of MTD interfingered with Ch-l/l within U2 not only increased the load of sediments of unit U2 depocenter, but also may have played a significant role by reducing the accommodation space, thereby giving rise to a generally eastern lateral migration of the lobe system (Figs. 4 and 5).

The distribution of the lobes occurs in the partially-confined area of the Eastern Alboran Basin, where these deposits stack against the Habibas Escarpment of the Alboran Ridge but with variable confinement effects. It is higher for the deposits of the younger Ch-l/l of U2 than those developed within U1. The quasi-parallel trend of unit U2 depocenter with respect to the Alboran Ridge suggests that it constitutes a morphological barrier for sediment gravity flows feeding the lobes and hence for the deposition of their loads.

Sedimentary history over the last 269 ka

The sedimentary history of the LC over the last 269 ka can be synthesised into three main periods (1 to 3; Fig. 5). The occurrence of these periods has been controlled by the Milankovitch climate-driven sea-level cycles of 200 ka (4th order) and 100 ka (5th order).

Period 1 (269 ka to 190 ka): During the sea-level lowstand stage of glacial MIS 8 the Ch-l/l-1 was deposited occupying a relatively large area (450 km^2 and 11 km^3; Fig. 4). During this time, the high sediment supply favored the seaward advance and progradation of the Almeria margin feeding the turbidite system, and triggering the occurrence of gravity-instability processes. At the end of this period it predominates hemipelagic sedimentation covering the hybrid Ch-l/l-1 and MDT related to highstand stage of MIS 7. During this period, the semi-confined setting and paleo-topography conditioned the sediment distribution.

Period 2 (190-70 ka): During the lowstand stage of MIS 6 the Ch-l/l-2 was deposited occupying similar dimensions (300 km^2 and 9 km^3) to the previous one (Fig. 4). Lateral migration to the NE of these deposits would be related to the avulsion processes of the main channel and to the accommodation space. At the end of this period hemipelagites deposited above Ch-l/l-2 together with MTD associated with highstand sea-level during the MIS 5.

Period 3 (70 ka to present): At the start of this period it took place the development of Ch-l/l-3, with smaller dimensions (180 km^2 and 3 km^3; Fig. 5) associated with the lowstand stage of MIS 4 and MIS 2; later hemipelagic deposition is dominant associated with the MIS 1. The marked decrease in dimensions of Ch-l/l-3 suggests a drop in the

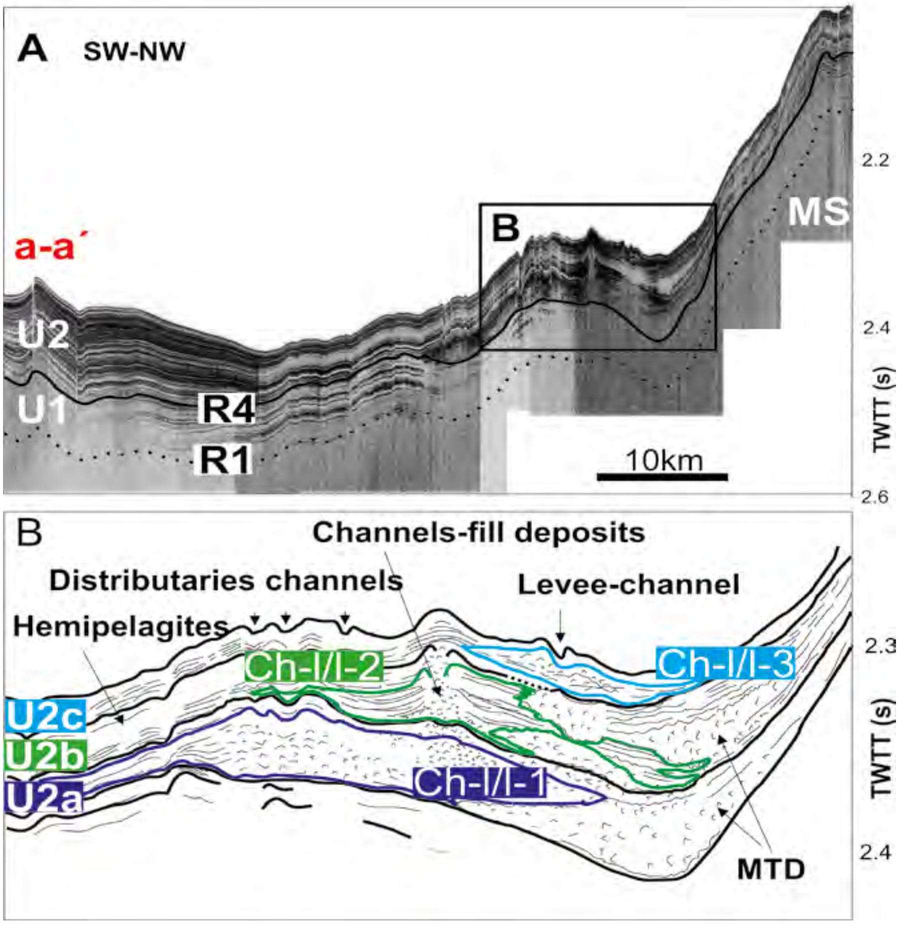

Fig. 3.- Topas seismic sub-bottom profile showing the seismic depositional bodies within the U2. Profile location in figure 1. MS: Maimonides Seamount, MTD: Mass Transport Deposits.

Fig. 3.- Perfil de Topas ilustrando los cuerpos símicos dentro de la U2. Localización del perfil en la figura 1. MS: Monte de Maimonides, MTD: Depósitos de Transporte en Masa.

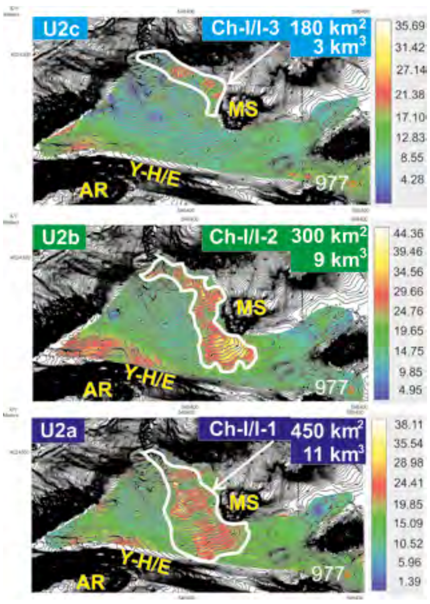

Fig. 4.- Isopach map (in metres) of the three subunits (U2a, U2b and U2c) and the three Ch-l/l. AR: Alboran Ridge, Y-H/E: Yusuf-Habibas Scarpment, MS: Maimonides Seamount. Location of ODP Site 977.

Fig. 4.- Mapa de isopacas (en metros) de las tres subunidades (U2a, U2b, U2c) y los tres Ch-l/l. AR: Dorsal de Alborán, Y-H/E: Escarpe de Yusuf/Habibbas, MS: Monte submarino de Maimonides. Localización del sondeo de ODP 977.

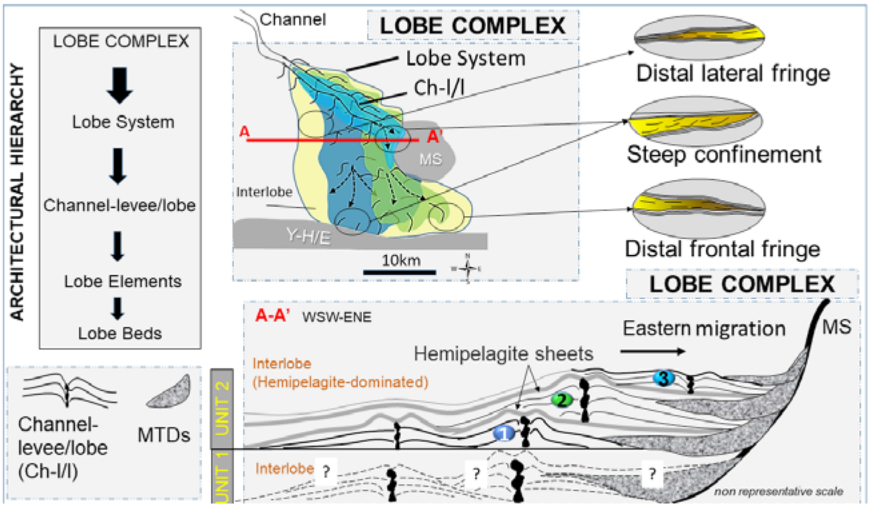

Fig. 5.- Schematic configuration of the internal architecture of the LC of the distal ATS over the last 575 ka. The lobe system shows a general eastern migration trend from unit 1 and different fringe pinch-out configurations. MS: Maimonides Seamount, Y-H/E: Yusfuf-Habibas Escarpment, MTD: Mass Transport Deposits. 1 to 3 refer to Channel-levee/lobes.

Fig. 5.- Configuración esquemática del LC del ATS distal de los últimos 575 ka. El sistema de lóbulo muestra aproximadamente una migración desde la unidad U1 y diferentes configuraciones en las terminaciones de lóbulo. MS: Monte de Maimonides, Y-H/E: Escarpe de Yusuf-Habibas, MTD: depósitos de movimiento en masa. Los números 1 al 3 indican el Canal-dique /lóbulo.

turbidite activity within the system. This landward migration has been observed in other turbidite systems in the Alboran area (Alonso and Ercilla, 2003). Such a change could be linked to the relative decrease in land sediment input. Also, a variation in the hinterland sediment source (e.g., lateral migration of rivers mouth) linked to glacio-eustatic changes, a decrease of margin gradients, and a gradual basin filling and onlap would govern this landward migration (Alonso and Ercilla, 2003).

Conclusions

The seismic chronostratigraphy of the LC of the distal ATS allowed the recognition of a succession of two main seismic units, U1 and U2 (from older to younger), deposited over the last 575 ka. The three well-defined Ch-l/l identified within unit U2 deposited over the last 269 ka are intercalated with MTD and hemipelagites. The depositional architecture reveals vertical and lateral variations of the seismic units, which were mainly conditioned by sea-level fluctuations, sediment supply and paleo-topography. Finally, this work provides new insights to calibrate deep-water facies models in complex tectonic and partially confined settings. This newly recognized very high-resolution seismic stratigraphy also represents an important modern analogue data to improve deep subsurface reservoir models for the oil and gas industry.

Acknowledgments

We wish to thank to A. Puga and F. Bohoyo for reviewing this paper. This work was supported by the FAUCES Project (CTM2015-65461-C2-R; MINECO/FEDER).

References

Alonso, B. and Ercilla, G. (2003). *Marine Petrology Geologist* 19, 1225-1240.

Alonso, B. and Maldonado, A. (1992). *Geo-Marine Letters* 12 (2/3), 137–143.

Bozzano, G., Alonso, B., Ercilla, G., Estrada, F. and García, M. (2009). In: *External Control on Deep-Water Depositional Systems* (B. Kneller, W.D. McCaffrey, O.J. Martinsen, Eds.), SEPM Special Publications No 92, 199-206.

de Kaenel, E., Siesser, W.G. and Murat, A. (1999). In: *Proceedings of the Ocean Drilling Program*, Scientific Results (R. Zahn, M.C. Comas, A. Klaus, Eds.), College Station, TX (ODP), 161, 159-183.

Dillon, W.P., Robb, J.M., Greene, H.G. and Lucena, J.C. (1980). *Marine Geology* 36, 205-226.

Ercilla, G., Juan, C., Periáñez, R., Alonso, B., Estrada, F., Casas, D., Vázquez, J.T., D'Acremont, E., Gorini, Ch., El Moumni, B., Do Couto D. and Valencia, J. (2019). *Deep Sea Research I* 144, 1-16.

Estrada, F., Ercilla, G. and Alonso, B. (1997). *Tectonics* 283 (1-4), 423-442.

García, M., Alonso, B., Ercilla, G. and Gracia, E. (2006). *Marine Geology* 226 (3-4), 207-223.

Juan, C., Ercilla, G., Hernández-Molina, F.J., Estrada, F., Alonso, B., Casas, D., García, M., Farran, M., Llave, E., Palomino, D., Vázquez, J.T., Medialdea, T. Gorini, CH., El Moummi, B. and Ammar, A. (2016). *Marine Geology* 378, 292-311.

Martrat, B., Grimalt, J.O., López-Martínez, C., Cacho, I., Sierro, F.J., Flores, J.A., Zahn, R., Canals, M., Curtis, J.H. and Hodell, D.A. (2004). *Science* 306 (5702), 1762-1765.

Mulder, T. and Etienne, S. (2010). *Sedimentary Geology* 229 (3), 75-80.

Mutti, E. (1992). *Turbidite sandstones*. Instituto di Geologia University di Parme, co-published with Agip, 276 p.

Reading, H.G. and Richards, M. (1994). *AAPG Bulletin* 78 (5), 792-822.

Richards, M., Bowman, M. and Reading, H. (1998). *Marine and Petroleum Geology* 15 (7), 689-717.

Shanmugam, G. (2016). *Journal of Palaeogeography* 5 (2), 110-184.

von Grafenstein, R., Zahn, R., Tiedemann, R. and Murat. A. (1999). In: *Proceeding of the Ocean Drilling Program, Scientific Results* (R. Zahn, M.C. Comas, A. Klaus, Eds.), College Station, TX (ODP), 161, 469-479.