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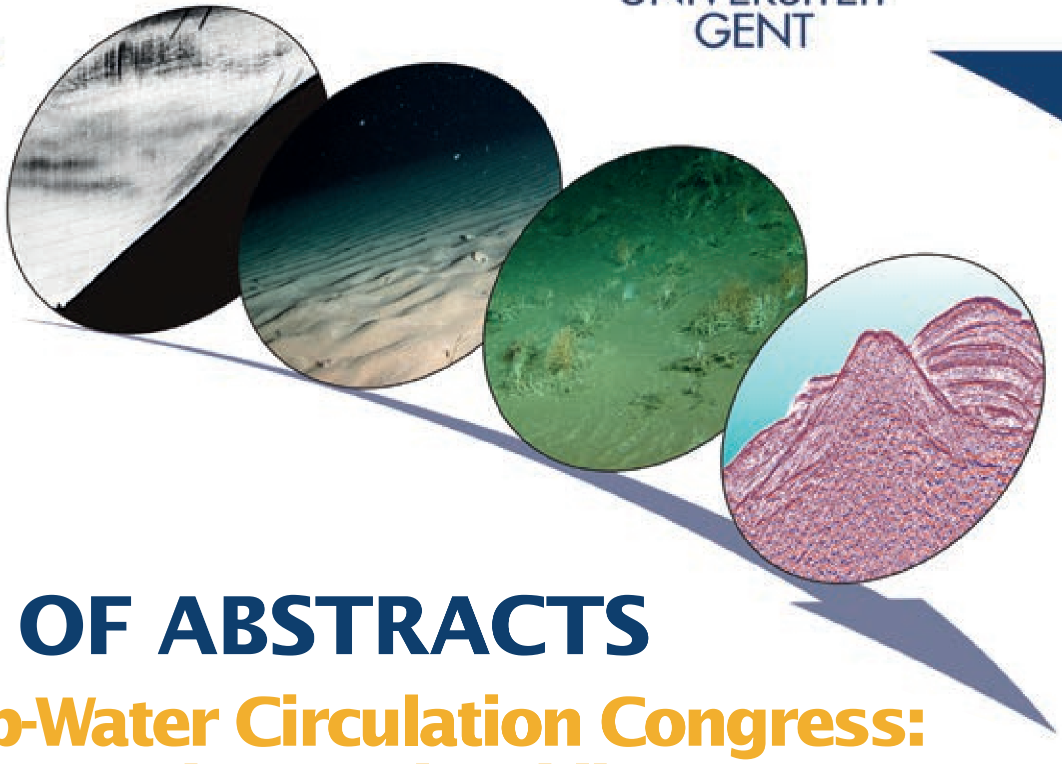

BOOK OF ABSTRACTS

2nd Deep-Water Circulation Congress: "The Contourite Log-book"

Ghent, Belgium
10-12 September 2014

Editors:
David Van Rooij & Andres Rüggeberg

VLIZ

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10-12 September 2014

International Conference

2nd "Deep-Water Circulation Congress": The Contourite Log-book

Book of Abstracts

VLIZ Special Publication 69

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Organising Organisations

Ghent University (Belgium)

VLIZ - Flanders Marine Institute (Belgium)

Royal Holloway, University of London (United Kingdom)

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

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Université de Liège (Belgium)

Supporting Organisations

FWO Vlaanderen – Flanders Research Foundation

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The City of Ghent

Introduction

Dear congress participant, on behalf of the Organising Committee of the 2nd Deep-Water Circulation Congress: The Contourite Log-book, I warmly welcome you to Ghent. During these 3 days, we will be able to offer you 6 exciting keynote lectures, 35 oral and 28 poster presentations, many of which will be presented by PhD students and early career scientists. We are much obliged to the members of the Scientific Committee for their assessment of these contributions, all present here in as extended abstracts in the official congress abstracts book. In total, 266 international scientists collaborated in the elaboration of all these abstract, covering topical areas all over the globe from shallow to deep (even ultra-deep) water depths. The contourite paradigm has thrived since its beginning in predominantly the Atlantic Realm, but it gradually has moved over to the other oceans and lakes of the world (Fig. 1).

We are also proud that we were successful in continuing the efforts that have been made by the organisers of the first *Deep-Water Circulation Congress: Processes and Products*, organised in Baiona, Spain (16-18 June, 2010). After this (first?) period of 4 years, a major milestone in contourite research was passed with the execution of IODP Expedition 339, drilling the Cádiz Contourite Depositional System (Fig. 2). Also, this first congress has laid the base for a number of topical publications, renewed collaborations, international partnerships and projects of which the results will be presented within the upcoming days. We can only hope that this positive groundswell will continue towards a 3rd DWC in 2018.

Moreover, during this year, when the Marine Geology journal will celebrate its 50th anniversary, we can celebrate as well the first seminal paper on deep-sea currents, published by Heezen and Hollister in the first volume (2nd issue) of Marine Geology. Since then, a tremendous effort has been realized by numerous marine scientists to be able to better understand the story locked within the contouritic sequences. We are proud to announce that some of the papers presented during this congress will be further elaborated for a special “2DWC” issue of Marine Geology.

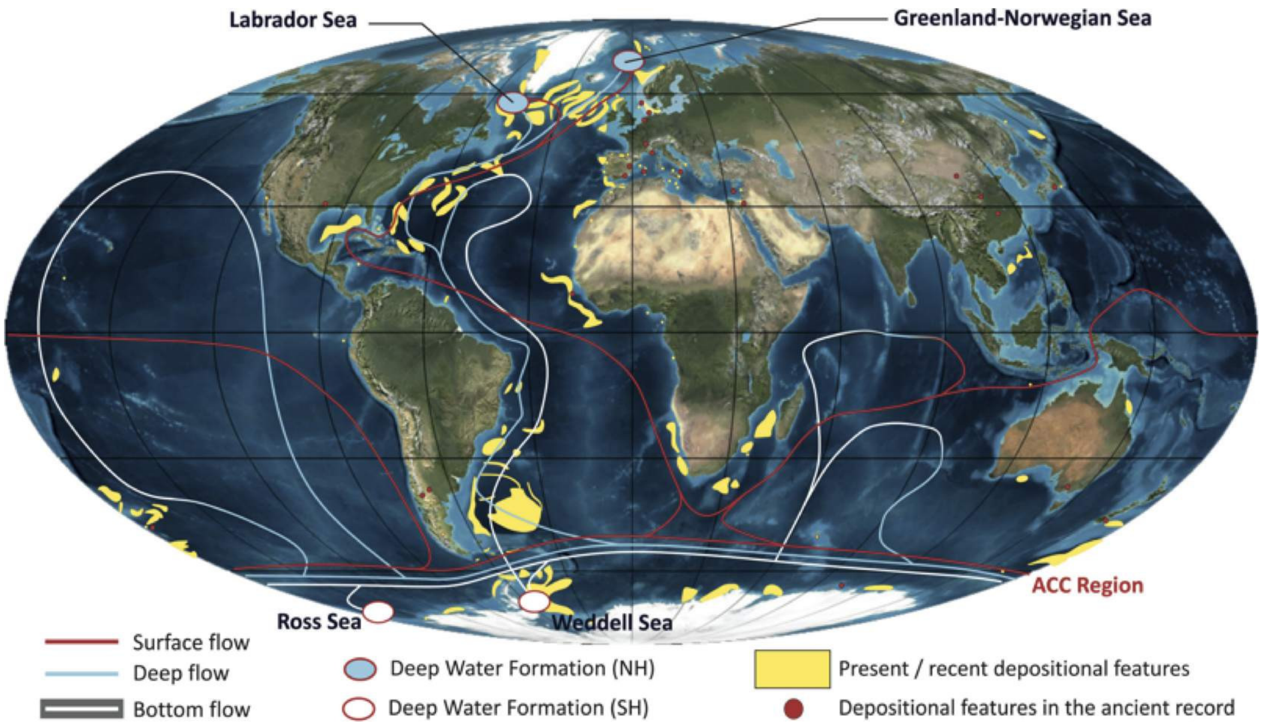

FIGURE 1. Global thermohaline circulation and occurrence of large contourite deposits in the present ocean basins (yellow areas) and in the ancient sedimentary record (black points), Rebesco et al. (2014)

This is why the 2nd Deep-Water Circulation Congress aims to focus within these three days on the "*Contourite Log-book*", with the intention to increase our ability to unveil and extract the temporal and lateral variability of palaeoceanographic processes. Based upon the submitted abstracts, we were able to focus on 4 topical sessions:

Session 1: "*The influence of contourite sedimentation on slope (in)stability*". Contourite deposits play a major role in the stability of continental margins. Especially on high latitudes their lateral and temporal variability may provoke mass movements. Additionally, some sets of diagnostic criteria between downslope and alongslope processes still can be improved. Therefore, this session is co-sponsored by the IGCP-585 E-MARSHAL project.

Session 2: "*The coupling between oceanographic processes and contourite sedimentation*". This session constitutes one of the challenges for future research; to better tie present-day physical oceanographic processes to the contourite deposits, with the aim to better understand past oceanic circulation. Therefore, topics are brought forward ranging between physical oceanographic studies, palaeoceanography on cores and seismic sections, as well as seismic oceanography.

Session 3: "*Contourite processes and deep-water ecosystems*". Contourite processes play a vital role in the initiation, maintenance and decay of deep-water ecosystems. Mostly, but not uniquely, this is related to cold-water coral reefs and mounds, where both systems seem to influence each other. This session is co-sponsored by FWO-ICA COCARDE II and ESF COCARDE-ERN (COld-water CArbonate Reservoir systems in Deep Environments).

Session 4: "*Advances in diagnostic criteria of contourite systems*". This largest session will focus on the advances and methods in (seismic) facies characterization of contourite systems, including shallow-water and lake contourites, as well as their economic relevance within hydrocarbon systems.

On behalf of the 2DWC Organising Committee, I wish you a most interesting and fruitful conference,

Prof. Dr. David Van Rooij
Chair of the 2DWC congress

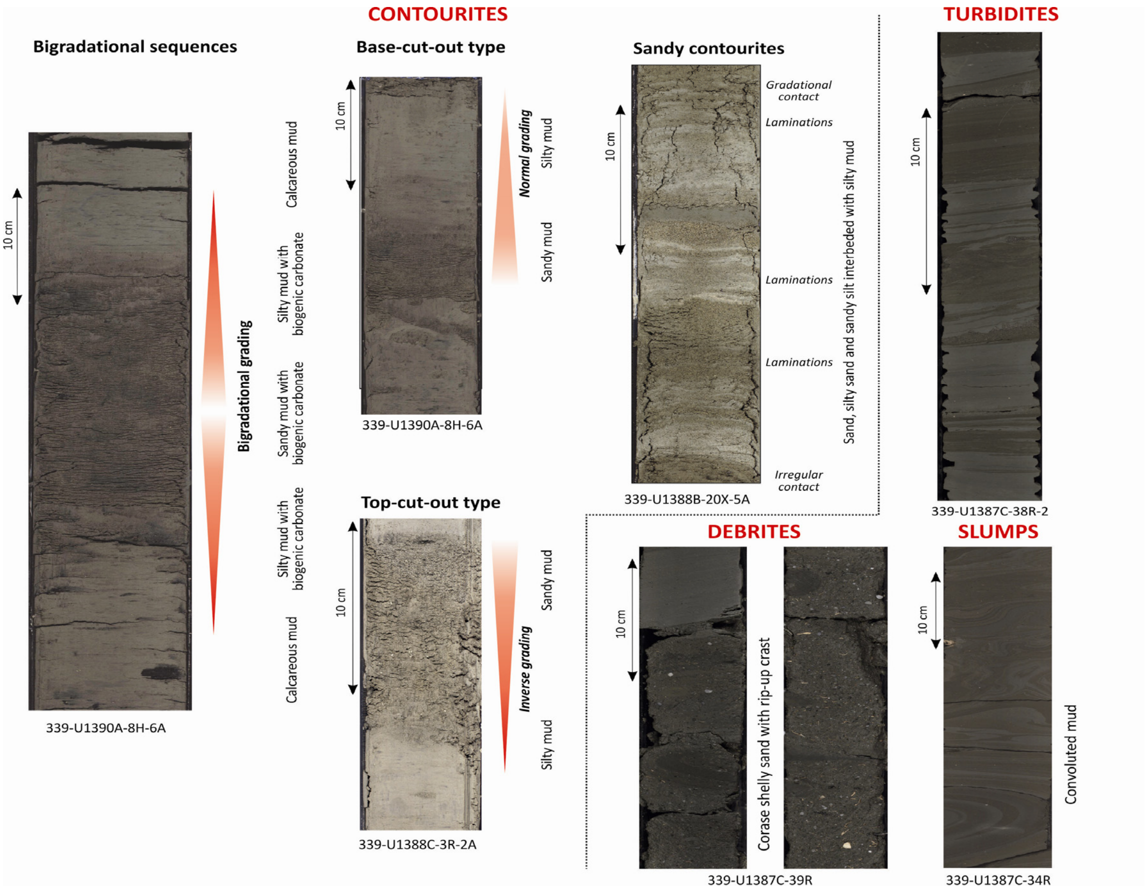

FIGURE 2. Contourites and associated facies, IODP Expedition 339, Gulf of Cadiz (Rebesco et al., 2014)

Members of the Ghent University co-ordinating team

- ***Conference chair:*** Prof. Dr. David Van Rooij
- ***ICT & website:*** Kurt Blom
- ***Administration:*** Wim Lievens, Marc Faure Didelle
- ***Logistical support:*** Thomas Vandorpe, Stanislas Delivet, Tim Collart, Kainan Mao

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Dr. Antje Voelker	*IPMA – Inst. Portugues do Mar e da Atmosfera, Portugal*

Special keynotes

- ***Dr. Michele Rebesco*** (*OGS, Triëste, Italy*) : Contourites and associated sediments controlled by deep-water circulation processes: state of the art and future considerations
- ***Dr. David J.W. Piper*** (*Geological Survey of Canada, Dartmouth, Canada*): Process, time and architecture: lessons from shallow contourites and their failures in the path of the Labrador Current
- ***Prof. Dr. Anna Wåhlin*** (*University of Gothenburg, Sweden*): The role of physical oceanographic processes in contourite sedimentation and how we can work together
- ***Prof. Dr. Dierk Hebbeln*** (*University of Bremen, MARUM, Germany*): Good neighbours in vigorous currents: contourites and cold-water corals
- ***Prof. Dr. Michel Hoffert***: (*Université Louis Pasteur, Strasbourg, France*): Manganese nodules: genesis, distribution and deep-water circulation
- ***Prof. Dr. Dorrik A.V. Stow*** (*Heriot-Watt University, Edinburgh, United Kingdom*): Contourites in the Gulf of Cádiz: new findings from IODP Expedition 339

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Project MOWER

Detailed programme

9 September 2014 (Day 0)

1800-1900: Ice Breaker reception at the Ghent City Hall

10 September 2014 (Day 1)

0800-0900 Registration and poster setup

0900-1000 Official opening session

1000-1100 Keynote presentation

M. Rebesco (OGS, Italy): "*Contourites and associated sediments controlled by deep-water circulation processes: state of the art and future considerations*"

1100-1130 Coffee break

1130-1230 Poster presentations (*short communications*)

1230-1400 Lunch break

1400-1500 Keynote presentation

D.J.W. Piper (Geological Survey of Canada, Canada): "*Process, time and architecture: lessons from shallow contourites and their failures in the path of the Labrador Current*"

1500-1600 ***Session 1:*** *The influence of contourite sedimentation on slope (in)stability (IGCP 585)*

1500-1515: ***Xinong Xie, Hui Chen, Yuhong Xie, Zhenfeng Wang, Yongchao Lu and Jianye Ren:*** *Spatial distribution of deepwater depositional systems and relationship with bottom currents on the northwestern lower slope of the Northwest Sub-Basin, South China Sea*

1515-1530: ***Elda Miramontes, Antonio Cattaneo, Gwenael Jouet, Sebastien Garziglia, Estelle Thereau, Arnaud Gaillot, Angelique Roubi and Mickael Rovere:*** *The Pianosa Contourite Depositional System (Corsica Trough, North Tyrrhenian Sea): stratigraphic evolution and possible role in slope instability*

1530-1545: ***Roberto A. Violante, F. Javier Hernández-Molina, I. Pastor Costa and Tilmann Schwenk:*** *Different styles in configuration of the contouritic drifts in the northern sector of the Argentine Continental Margin: implications in slope stability and geohazard*

1545-1600: ***Adam Creaser and F. Javier Hernández-Molina***: *Along- and down-slope process interactions in proximal channel-levee systems: Implications for hydrocarbon exploration*

1600-1630 Coffee break + *poster presentations Session 1*

1) ***Gemma Ercilla, Carmen Juan, Belén Alonso, Ferran Estrada, David Casas, Marga García, F. Javier Hernández-Molina, J. Tomás Vázquez, Estefanía Llave, Desirée Palomino, Marcel-lí Farran, Christian Gorini, Elia d'Acremont, Bouchta El Moumni Abdellah Ammar and the CONTOURIBER and MONTERA Teams:*** *Water mass footprints in uneven turbidite system development in the Alboran Sea*
2) ***Marga García, Belén Alonso, J. Tomás Vázquez, Gemma Ercilla, Desirée Palomino, Ferran Estrada, MªCarmen Fernández Puga, Nieves López Gonzalez and Cristina Roque:*** *Morphological characterization of contourite and mass-wasting recent processes at the Guadalquivir Bank Margin uplift, Gulf of Cadiz*

3) ***Kainan Mao*, Stanislas Delivet, David Van Rooij and Xinong Xie:** *Bottom currents influenced deep-water canyons in the northern of Baiyun Sag slope, South China Sea*
4) ***Eleonora Martorelli*, Alessandro Bosman, Daniele Casalbore, Francesco L. Chiocci, Federico Falcini, Pierpaolo Falco, Giannetta Fusco, Eleonora Morelli, Martina Pierdomenico:** *High-resolution seismic stratigraphy, multibeam bathymetry of the Capo Vaticano region (Tyrrhenian Sea) coupled with oceanographic data: interplay between alongslope bottom currents and downslope processes*

1630-1715 ***Session 1:*** *The influence of contourite sedimentation on slope (in)stability (IGCP 585)*

1630-1645: ***Katrien Heirman*, Tove Nielsen and Antoon Kuijpers:** *Down, across and along: sediment deposition and erosion on the glaciated southeast Greenland margin*

1645-1700: ***Giacomo Dalla Valle*, Fabio Trincardi and Fabiano Gamberi:** *Slope instability along a countorite-dominated margin in the Mediterranean Sea*

1700-1715: ***Mike Rogerson* and Stuart Fielding:** *Micropalaeontological Discrimination of Contourite and Turbidite Depositional Systems*

1800-2300 Conference dinner cruise

11 September 2014 (Day 2)

0830-0930 Keynote presentation

A. Wahlin (University of Gothenburg, Sweden): "*The role of physical oceanographic processes in contourite sedimentation and how we can work together*"

0930-1100 ***Session 2:*** *The coupling between oceanographic processes and contourite sedimentation*

0930-0945: ***Pere Puig*, Albert Palanques, Jacobo Martín, Marta Ribó, Jorge Guillén:** *Benthic storms in the north-western Mediterranean continental rise caused by deep dense water formation*

0945-1000: ***Antje H.L. Voelker*, Francisco J. Jimenez-Espejo, Andre Bahr, Gary D. Acton, Andreia Rebotim, Emilia Salgueiro, Ursula Röhl and Carlota Escutia:** *Mediterranean Outflow Water changes in the Gulf of Cadiz during the Mid-Pleistocene Transition – The role of insolation*

1000-1015: ***Antoon Kuijpers* and Tove Nielsen:** *High-energy contourite settings related to North Atlantic Deep Water flow*

1015-1030: ***Till J.J. Hanebuth*, Antonia L. Hofmann, Antje Lenhart, Ludvig A. Löwemark, Tilmann Schwenk and Wenyan Zhang:** *Short-term sediment dynamics on a contourite body (off NW Iberia), Part I: Rapid changes of bottom-flow intensity during the past 50ka deduced from a sediment-core transect*

1030-1045*:* ***Wenyan Zhang* and Till J.J. Hanebuth:** *Short-term sediment dynamics on a contourite body (off NW Iberia), Part II:The impact of hydrographic fronts as deduced from numerical modelling*

1045-1100: ***Gabriele Uenzelmann-Neben* and Antje Müller-Michaelis:** *High-resolution structure of the upper Western Boundary Undercurrent core shaping the Eirik Drift*

1100-1130 Coffee break + *poster presentations Session 2*

5) **Carmen Juan, Gemma Ercilla, F. Javier Hernández-Molina, Ferran Estrada, Belén Alonso, David Casas, Marga García, Marcel-lí Farran, Estefanía Llave, Desirée Palomino, *J. Tomás Vázquez*, Teresa Medialdea, Christian Gorini, Elia D'Acremont, Bouchta El Moumni, Abdellah Ammar and the**

CONTOURIBER, MONTERA and MOWER Teams: *(Paleo)circulation models in the Alboran seas during the Pliocene and Quaternary*

6) ***Belén Alonso, Nieves López-González, Grazziela Bozzano, David Casas, Gemma Ercilla, Carmen Juan, Ferran Estrada, Marga Garcia, J. Tomás Vázquez, Isabel Cacho, Desirée Palomino, Elia d´Acremont, Bouchta El Moumni, MONTERA and MOWER Teams:*** *Djibouti Ville Drift (SW Mediterranean): Sedimentation and record of bottom-current fluctuations during the Pleistocene and Holocene*
7) ***Samuel Toucanne, Gwenael Jouet, Emmanuelle Ducassou, Maria-Angela Bassetti, Bernard Dennielou, Charlie Morelle Angue Minto'o, Marjolaine Lahmi, Nicolas Touyet, Karine Charlier, Gilles Lericolais and Thierry Mulder:*** *A 130,000-year record of Levantine Intermediate Water flow variability in the Corsica Trough, western Mediterranean Sea*
8) ***F. Javier Hernández-Molina, Dorrik A.V. Stow, Carlos A. Alvarez-Zarikian, Gary Acton, André Bahr, Barbara Balestra, Emmanuelle Ducassou, Roger Flood, José-Abel Flores, Satoshi Furota, Patrick Grunert, David Hodell, Francisco Jimenez-Espejo, Jin Kyoung Kim, Lawrence Krissek, Junichiro Kuroda, Baohua Li, Estefania Llave, Johanna Lofi, Lucas Lourens, Madeline Miller, Futoshi Nanayama, Naohisa Nishida, Carl Richter, Cristina Roque, Hélder Pereira, Maria Fernanda Sanchez Goñi, Francisco J. Sierro, Arun Deo Singh, Craig Sloss, Yasuhiro Takashimizu, Alexandrina Tzanova, Antje Voelker, Trevor Williams and Chuang Xuan:*** *Onset of Mediterranean Outflow into the North Atlantic*
9) ***F.Javier Hernández-Molina, Estefania Llave, Benedict Preu, Gemma Ercilla, A. Fontan, M. Bruno, Nuno Serra, J.J. Gomiz, Rachel Brackenridge, F.J. Sierro, Dorrik A.V. Stow, Marga García, Carmen Juan, N. Sandoval, and A. Arnaiz:*** *Contourite processes associated with the Mediterranean Outflow Water after its exit from the Gibraltar Strait: Global and conceptual implications*
10) ***F. Javier Hernández-Molina, Anna Wåhlin, M. Bruno, Gemma Ercilla, Estefania Llave, Nuno Serra, G. Roson, Pere Puig, Michele Rebesco, David Van Rooij, D. Roque, C. González-Pola, F. Sanchéz, Maria Gómez, Benedict Preu, Rachel Brackenridge, Carmen Juan; Dorrik A.V. Stow:*** *Oceanographic processes and products around the Iberia continental margin: a new multi-disciplinary approach?*
11) ***Estefania Llave, F. Javier Hernández-Molina, Gemma Ercilla, Christina Roque, David Van Rooij, Marga García, Rachel Brackenridge, Carmen Juan, Anxo Mena, Gloria Jané, Dorrik A.V. Stow:*** *Deep water circulation around the Iberian continental margin: state of art and future implications*
12) ***Dries Van den Eynde, Matthias Baeye, Michael Fettweis, Frederic Francken, Lieven Naudts and Vera Van Lancker:*** *Sediment plume monitoring in the Clarion-Clipperton Zone*
13) ***Quentin Dubois-Dauphin, Christophe Colin, Hiske Fink, Dierk Hebbeln, David Van Rooij, Norbert Frank:*** *Nd isotopic composition of present and Holocene water masses from the Gulf of Cadiz and the Alboran Sea*
14) ***Andres Rüggeberg, Sascha Flögel, Jacek Raddatz and Christian Dullo:*** *Seawater density reconstruction of intermediate waters along the European continental margin*

1130-1230 ***Session 2:*** *The coupling between oceanographic processes and contourite sedimentation*

1130-1145: ***Lara F. Pérez, F. Javier Hernández-Molina, Federico D. Esteban, Alejandro Tassone, Alberto R. Piola, Andrés Maldonado, Emanuele Lodolo:*** *Contourite Terraces in the Middle-Slope of the Northern Scotia Sea and Southern Atlantic Ocean: Palaeoceanographic Implications*

1145-1200: ***D. Calvin Campbell:*** *Comparison of large contourite drifts in the western North Atlantic*

1200-1215: ***Volkhard Spiess:*** *The Impact of the Agulhas Current System on Sedimentary Systems at the Southeast African Margin - Shallow, Mid- and Deep-Water Contourite Formation*

1215-1230: ***Quentin Dubois-Dauphin, Christophe Colin, Lucile Bonneau, Jean-Carlos Montero-Serrano, Dominique Blamart, David Van Rooij, Norbert Frank:*** *Millennial-scale influence of southern intermediate component water into the North-east Atlantic during the last 40 kyr*

1230-1400 Lunch break

1400-1500 Keynote presentation

D. Hebbeln (University of Bremen, MARUM, Germany): "*Good neighbours in vigorous currents: contourites and cold-water corals*"

1500-1600 ***Session 3:*** *Contourite processes and deep-water ecosystems*

1500-1515: ***Hiske G. Fink, Claudia Wienberg, Ricardo De Pol-Holz and Dierk Hebbeln:*** *Development of Mediterranean cold-water coral ecosystems since the late glacial*

1515-1530: ***David Van Rooij, Thomas Vandorpe, Stanislas Delivet, Dierk Hebbeln, Claudia Wienberg, Ines M. Martins and the Belgica COMIC, MD194 Gateway and MSM36 MoccoMebo shipboard scientific parties:*** *Buried cold-water coral mound provinces and contourite drifts along the Eastern Atlantic margin: controls, interactions and connectivity*

1530-1545: ***Veerle A.I. Huvenne, Lissette Victorero Gonzales, Dominique Blamart, Edwige Pons-Branchu, Mark N. Mavrogordato, Douglas G. Masson, Claudio Lo Iacono, Russell B. Wynn:*** *The Darwin Mounds, N Rockall Trough: how the dynamics of a sandy contourite influenced cold-water coral growth*

1545-1600: ***Ludivine Chabaud, Elsa Tournadour, Emmanuelle Ducassou, Thierry Mulder, John Reijmer, Gilles Conesa, Jacques Giraudeau:*** *The modern carbonate contourite drift of the Little Bahama Bank: a geophysical, sedimentological and biostratigraphic study*

1600-1630 Coffee break + *poster presentations Session 3*

15) ***Inês Martins, João Vitorino, Thomas Vandorpe and David Van Rooij:*** *A Physical Oceanography contribution to understand the processes affecting El Arraiche Mud Vulcano field (NW Moroccan Margin)*
16) ***Loubna Terhzaz, Naima Hamoumi, Lotfi El Mostapha, David Van Rooij, Silvia Spezzaferri, Agostina Vertino and Jean-Pierre Henriet:*** *Preliminary results of a sedimentological study of carbonate mounds and cold-water corals from Brittlestar Ridge I and Cabliers site*
17) ***Claudio Lo Iacono, Lissette Victorero Gonzalez, Veerle A.I. Huvenne, David Van Rooij, Eulàlia Gràcia, Cesar Ranero and the GATEWAYS Cruise Party:*** *Morphology and shallow stratigraphy of the West Melilla and Cabliers CWC Mounds (Alborán Sea). Preliminary insights from the GATEWAYS MD194 Cruise*
18) ***Tim Collart, Kerry Howell, Heather Stewart, Jean-François Bourillet, Estefania Llave, Dominique Blamart and David Van Rooij:*** *Using cold-water coral mini-mounds as analogue for giant mound growth: assessment of environmental drivers and anthropogenic impact*
19) ***Desirée Palomino, Juan-Tomás Vázquez, José Luis Rueda, Luis Miguel Fernández-Salas, Nieves López-González, Víctor Díaz-del-Río:*** *Seabed morphology and bottom water masses related to benthic habitats at the Cristóbal Colón diapir (NW of the Guadalquivir ridge, Gulf of Cádiz)*

20) ***Cecilia Laprida, Graziella Bozzano, Ricardo Garberoglio and Roberto A. Violante:*** *Late Cenozoic fossil cold-water coral concentrations and mounds on the Argentine continental margin, Southwest South Atlantic*

1630-1730 ***Session 4:*** *Advances in diagnostic criteria of contourite systems*

1630-1645: ***Stanislas Delivet, David Van Rooij, Bram Van Eetvelt and Xavier Monteys:*** *Seismic geomorphological reconstructions at Goban Spur: Implications for Plio-Pleistocene MOW bottom current variability*

1645-1700: ***Marta Ribó, Pere Puig, David Van Rooij, Araceli Muñoz and Roger Urgeles:*** *Large sediment waves on the Gulf of Valencia continental margin (NW Mediterranean): internal structure and evolution*

1700-1715: ***Dmitry Borisov, Ivar Murdmaa, Elena Ivanova and Oleg Levchenko:*** *Giant Mudwaves in the NW Argentine Basin (South Atlantic)*

1715-1730: ***Graziella Bozzano, Roberto A. Violante and José Luis Cavallotto:*** *Clean and well sorted sands in the deep Argentine Basin (SW Atlantic): the role of the Antarctic Bottom Water*

1800-2100 Visit of the Filliers distillery

12 September 2014 (Day 3)

0830-0930 Keynote presentation

M. Hoffert (Université Louis Pasteur, France): "*Manganese nodules: genesis, distribution and deep-water circulation*"

0930-1100 ***Session 4:*** *Advances in diagnostic criteria of contourite systems*

0930-0945: ***Till J.J. Hanebuth, Michele Rebesco, M. Grave, A. Özmaral, Renata G. Lucchi and the CORIBAR Team:*** *The Kveithola Drift (western Barents Sea): Preliminary results from the CORIBAR Cruise*

0945-1000: ***Oleg Levchenko, Victoria Putans and Dmitry Borisov:*** *Contourites in the Middle Caspian Sea?*

1000-1015: ***Hui Chen, Xinong Xie, Yeqiang Shu, Dongxiao Wang, David Van Rooij, Thomas Vandorpe, Kainan Mao, Ming Su:*** *Deep-water depositional characteristics and relationship with bottom currents at the intersection of Xi'sha Trough and Northwest Sub-Basin, South China Sea*

1015-1030: ***Luisa Palamenghi, Hanno Keil, Stephan Steinke, Tim Freudenthal, Mahyar Mohtadi, Volkhard Spiess:*** *Interaction between South China Sea deep circulation and the northwestern Pearl River Mouth Basin*

1030-1045: ***Federico Falcini, Eleonora Martorelli, Ettore Salusti and Francesco L. Chiocci:*** *Diagnostic analysis of contourite drifts and contour currents around small-scale topographic features: some examples from the Italian Seas (Mediterranean Sea)*

1045-1100: ***Thomas Vandorpe, David Van Rooij, Henk De Haas and Inês Martins:*** *Obstacle-related contourite drifts in the El Araiche Mud Volcano field, Southern Gulf of Cadiz*

1100-1130 Coffee break + *poster presentations Session 4*

21) ***Shunshe Luo, Youbin He, Qiqi Lv, Mingli Xi, Yuanquan Zhou:*** *Trace Element Characteristics and Sedimentary Environmental Significance of the Lower Ordovician Contourites in Northern Hunan, China*

22) ***J. Tomás Vázquez, Desirée Palomino, M. Carmen Fernández-Puga, Luis-Miguel Fernández-Salas, Eugenio Fraile-Nuez, Teresa Medialdea, Olga Sánchez-Guillamón, Luis Somoza and the SUBVENT***

team: *Seafloor geomorphology of the Passage of Lanzarote (West Africa Margin): Influences of the oceanographic processes*

23) **Cédric Tallobre, Pierre Giresse, Lies Loncke, Germain Bayon, Maria-Angela Bassetti, Mirjam Randla, Roseline Buscail, Xavier Durrieu de Madron, François Bourrin, Stéphane Kunesch, Christine Sotin, Berné Serge and Vanhaesebroucke Marc:** *New findings of contourite-related structures and their implications on oceanographic and sedimentary conditions on the Demerara Plateau (French Guiana and Surinam)*
24) **Thomas Vandorpe, David Van Rooij, Susana Lebreiro, Belen Alonso, Anxo Mena, Veerle Cnudde and F. Javier Hernandez-Molina:** *CT-images of contourite cores: An onset to processing and data interpretation*
25) **Maarten Van Daele, Willem Vandoorne, Sébastien Bertrand, Niels Tanghe, Inka Meyer, Jasper Moernaut, Roberto Urrutia and Marc De Batist:** *Sediment drifts in Lago Castor (Chilean Patagonia) reflect changes in the strength of the Southern Hemisphere Westerly winds since the Last Glacial Maximum*
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1130-1230 ***Session 4:*** *Advances in diagnostic criteria of contourite systems*

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1200-1215: **Xiaoxia Huang, Wilfried Jokat, Karsten Gohl:** *Bottom currents-controlled sedimentary archives in the southeast Weddell Sea*

1215-1230: **Gabriele Uenzelmann-Neben and Karsten Gohl:** *Early Miocene glaciation in the Amundsen Sea, Southern Pacific: A study of the distribution of sedimentary sequences*

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Contourites and associated sediments controlled by deep-water circulation processes: state-of-the-art and future considerations

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Abstract: *The contourite paradigm was conceived a few decades ago and about 120 major contourite areas are presently known associated to myriad oceanographic processes, which involve dense bottom currents, tides, eddies, deep-sea storms, internal waves and tsunamis. The increasing recognition of these deposits is influencing palaeoclimatology & palaeoceanography, slope-stability/geological hazard assessment, and hydrocarbon exploration. Nevertheless, there is a pressing need for a better understanding of the sedimentological and oceanographic processes governing contourites. Persistent oceanographic processes significantly affect the seafloor, resulting in a continuous spectrum of depositional and erosional features. Although much progress has been made in the large-scale, geophysically based recognition of these deposits, there remains a lack of unambiguous and commonly accepted diagnostic criteria for deciphering the small-scaled contourite facies and for distinguishing them from turbidite ones. Similarly, the study of sandy deposits generated or affected by bottom currents offers great research potential: these deposits might prove invaluable as future reservoir targets. Expectations for the forthcoming analysis of data from the IODP Exp. 339 are high, as this work promises to tackle much of the aforementioned lack of knowledge. In the near future, geologists, oceanographers and biologists will have to work in concert to achieve synergy in contourite research.*

Key words: *Contourite, oceanographic process, sedimentary drift, sedimentary structure, facies model.*

INTRODUCTION

The research on contourites is presently maturing. However, many uncertainties remain, such as lack of indisputable diagnostic criteria for identifying contourites. This field is now advancing similarly to how turbidite research, which is now mature, progressed in the 1960s. Indeed, there is still a glaring disparity in knowledge between the former and the latter: a recent (February 2014) online search for the term contourites yielded 256 results on Scopus and 17,300 on Google, whereas a similar search for turbidites gave 3,841 and 295,000 results, respectively—more than 15 times more in each case.

DATA AND RESULTS

This work arises from a review for the 50th Anniversary Issue of *Marine Geology* (Rebesco et al., 2014). Such exhaustive review is about 42 published pages, including 27 figures and 522 references, and dealt with: the history of contourite research; the implications of contourites for palaeoclimate, slope stability, and hydrocarbon exploration;#~~t~~he occurrence of contourites; the oceanographic processes that affect contourite formation; the depositional and erosional features; the contourite types and facies models; and most recent understandings from IODP Expedition 339.

DISCUSSION

Since the seminal papers on contourites in early sixties, the contourite paradigm has progressed gradually, although much more slowly than has the well-funded area of turbidite research. Momentum following IGCP 432 led to the first International Conference on Deep-water Circulation held in Baiona in 2010, and laying the groundwork for the second edition in Ghent in 2014. It also led to proposal of a new IGCP, which began in 2012: IGCP 619 "Contourites: processes and products".

For many years the research on contourites was the realm of a few specialists. However, it has recently been garnering interest among more and more scientists, even those who are not specialised in contourites, but must deal with sediments affected by bottom currents in their own field of research. Contourites are paramount in three areas: palaeoclimatology & palaeoceanography; slope stability/geological hazard assessment; and hydrocarbon exploration.

The deep waters of the oceans are formed primarily in marginal seas or shallow shelf regions where the water is made cold and dense by cooling and/or ice formation or highly saline upon strong evaporation. The Earth's rotation tends to steer bottom currents to flow parallel to large-scale bathymetry. Small-scale topographic features can disrupt and accelerate the flow. Once the current velocity becomes sufficiently high, the sediment erodes, and as the velocity later decreases, the sediment is deposited. Bottom currents are typically baroclinic: their velocity typically correlates to the strength of their density gradient. The water velocity at the seafloor can also be affected by barotropic currents, tides or intermittent processes such as giant eddies, deep sea storms, vortices, internal waves and tsunamis (Fig. 1).

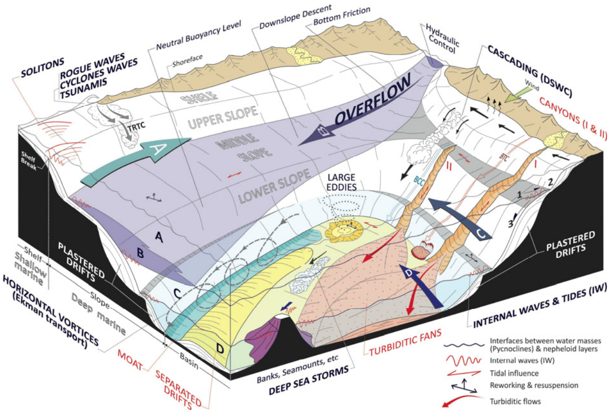

FIGURE 1. 3D sketch depicting the possible oceanographic processes in deep-water environments.

An updated compilation of contourites observed in different settings and associated to either deep, intermediate or shallow water masses (and in ancient sedimentary series that are presently exposed on land) demonstrates that these deposits are ubiquitous within the oceanic basin.

Persistent bottom-current systems and associated oceanographic processes strongly affect the seafloor, ultimately conferring it with pervasive erosional and depositional features. These features can be isolated, but when alongslope processes dominate, are more likely to be part of a *Contourite Depositional System (CDS)*, which is an association of various drifts and related erosional features. Similarly, distinct but connected CDS within the same water mass can be considered to be a *Contourite Depositional Complex (CDC)*. However, contourites also occur interbedded with other deep-water facies types, and do not necessarily form individual sedimentary bodies. The erosional and depositional features produced by bottom currents are found at various scales: they range from small bedforms to large sediment drifts.

The creation of a definitive facies model for contourites poses major challenges. The standard contourite facies model sequence, derived from the Faro Drift, could be considered a good model for fine-grained contourite deposits and pervasive bioturbation would be a diagnostic feature of muddy/silty contourites. However, authors working in contourite settings in which sandy deposits are more common have reported that traction sedimentary structures prevail over burrowing. This controversy about the most significant diagnostic criterion for the recognition of contourite deposits might have limited significance, since different authors have probably worked in different settings. Regardless, the previous research on this issue holds two important lessons: firstly, that there is no unique facies sequence for contourites; and secondly, that traction sedimentary structures are also common within contourites.

Recently, a greater spectrum of contourite facies is being described, especially for cases in which bottom currents strongly contributed to the reworking and redistribution of turbidite fine sands (mixed turbidite/contourite depositional systems). A better understanding of the CDS and related oceanographic processes is needed to provide the optimal conditions required for proposing standard facies sequences for the variety of contourite deposits.

CONCLUSIONS

Contourite processes are not as simple as initially thought. Bottom currents can be driven by myriad oceanographic processes, most of which are not fully understood.

Given the complexity of contourite processes, the contourite nomenclature might need to be reconsidered.

There is too great a variety of deposits affected by bottom currents to be described using a single model. Such deposits must be documented, and new facies models must be established, based on present-day marine data and outcrops.

More work is needed to understand sandy contourites, their differences with bottom-current reworked turbidite sands and their economic potential.

Integrated studies drawing on specialists from geology, oceanography and benthic biology will be essential for providing a holistic perspective.

The hitherto underestimated pervasiveness of bottom-water circulation and associated processes in shaping the seafloor and in controlling the sedimentary stacking pattern on continental margins must be reconsidered.

ACKNOWLEDGEMENTS

This contribution, extracted from a review for the 50th Anniversary Issue of *Marine Geology*, is an outcome of IGCP-619 and INQUA-1204 projects.

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Process, time and architecture: lessons from slope contourites and their failures in the path of the Labrador Current

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Abstract: *The southeastern Canadian continental slope is swept by the powerful Labrador Current. Over the past glacial cycle, changes in ocean circulation, meltwater supply, and glacial ice extent produced strong changes in current strength and pathways which are reflected in sediment drift architecture. Previous studies show that failure of sediment on steep (>3°), canyoned slopes off eastern Canada recurs every ~10-30 ka and are likely related to earthquakes. On gently dipping (1–1.5°) flanks of drifts in Flemish Pass, Atterberg limits show that some silty winnowed sediment is susceptible to liquefaction by cyclic loading. Here, failures occur every ~10-30 ka as on steeper slopes, followed by ~200–400 ka periods of stability and sediment accumulation. Build up of pore pressure from migrating sub-surface gas and fluids then allows earthquake-triggered failure on such low slopes. The style of failure is mostly lateral spreading with partly retrogressive failure upslope. Sediment drifts respond in a complex manner to changes in current flow on at least millennial and longer time scales, with resulting spatial variation in sediment type. Failure preconditioning on low slopes requires winnowed silty sediment capable of liquefaction and less permeable muddier plume sediment that allow build up of gas, followed by triggering by M>7 earthquakes.*

Key words: *drift architecture, current strength, liquefaction, spreading failure, earthquake trigger.*

INTRODUCTION

The Labrador Current is a powerful southward-flowing western boundary current with its main core along the upper slope of the southeastern Canadian margin (Piper, 2005). The current transports relatively cold and fresh water derived from the Arctic Ocean, river discharge from much of Canada, and water from the West Greenland Current (Fig. 1). Blockage of the Arctic Island Channels by glacier ice and changes in the North Atlantic sub-polar gyre resulted in significant changes in Labrador Current strength over the last glacial cycle (Marshall et al., 2014). Two perched slope basins east of Newfoundland, Orphan Basin and Flemish Pass (Fig. 1), record these changes in the Labrador Current; in addition, the basins contain a record of varied sediment failures which were studied because of their geohazard potential in light of recent oil exploration in the region. This work was facilitated by multibeam bathymetry collected by TRAGSA, Spain, as part of the NEREIDA project on vulnerable marine ecosystems.

This study is focused on sediment drifts in Flemish Pass, particularly a prominent detached drift known as Sackville Spur. It was constructed in the Neogene-Quaternary at the northern end of Flemish Pass and its northern slope is continuous with the southern fault-bound margin of Orphan Basin (Tripsanas et al., 2008). Piston cores from the region provide a stratigraphic record of the last glacial cycle since MIS 5e. Heinrich layers rich in detrital carbonate provide important lithostratigraphic markers that return strong reflections in high-resolution seismic reflection profiles. Thus the chronology of core records and of shallow seismic profiles can be easily determined.

CURRENT STRENGTH AND DRIFT ARCHITECTURE

The sortable silt proxy was used to estimate past Labrador Current strength. A 30 ka record in Flemish Pass (Marshall et al., 2014) shows lower current strength during full glacial conditions, increasing at ~ 15 ka, and increasing again in the mid Holocene. Carbonate-free sortable silt in Heinrich layers H1 and H0 indicates greater current strength during and immediately preceding Heinrich events. A lower resolution 130 ka record shows high current strength, similar to the early Holocene, immediately before some Heinrich events and in MIS 5e, but otherwise fluctuating lower speeds from MIS 5d to 2. A set of 180 box cores from the NEREIDA project in Flemish Pass and on Flemish Cap provide a synoptic view of spatial variation in sortable silt at the modern sea floor (Weitzman et al. 2014). The response of drifts to changes in current strength is most pronounced downflow from a constriction in central Flemish Pass. Under full glacial conditions, sedimentation rates of 0.1–0.2m.ka^{-1} are relatively uniform across the drift and adjacent moat; during late glacial and early Holocene sediment accumulated on the drift at >1m.ka^{-1}, with little accumulation in the moat. In the mid to late Holocene sedimentation rates reduced to <0.01m.ka^{-1}.

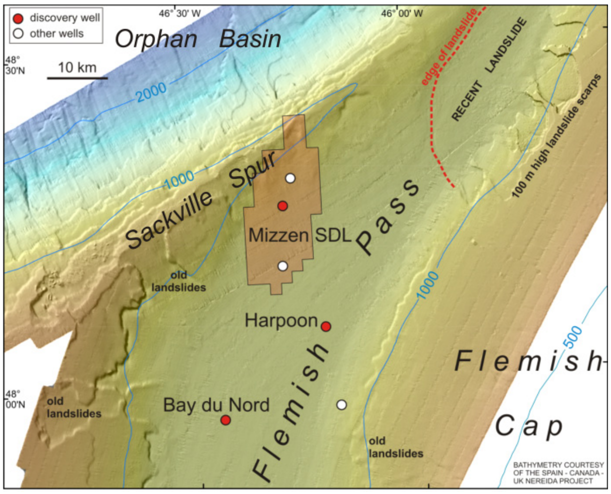

FIGURE 1. Map of northern Flemish Pass showing petroleum wells, sediment drifts and landslides (from Cameron et al., 2014).

SEDIMENT FAILURES ON DRIFTS

Sediment failures on the plastered drift on the steep southern slope of Orphan Basin and the north flank of Sackville Spur have a recurrence interval of 10–20ka (Tripsanas et al., 2008 and unpublished work). Several large failures in drift sediments on the NE flank of Flemish Pass, affecting the upper 100 m of sediment, are dated at 28ka, 21.5ka, 13ka and 7ka (Cameron et al., 2014), a recurrence rate similar to Orphan Basin and to elsewhere on the southeastern Canadian margin where canyons provide local slopes >10° (Piper 2005). Regionally, other local failures of these ages are known, with the widespread occurrence suggesting a seismic trigger. Geotechnical studies from piston cores show that sediments are normally consolidated and silty sediments have Atterberg limits showing susceptibility to liquefaction during cyclic loading.

The NE Flemish Pass failures produced a composite mass-transport deposit (MTD) on the floor of Flemish Pass >80 m thick. Three similar composite MTDs of Quaternary age are present in Flemish Pass, sourced from now buried failures on Sackville Spur, with a recurrence interval of 200–400ka (Piper and Campbell, 2005). These buried failures are of similar size to the surface failures on NE Flemish Pass and all occur on slopes of 1–1.5°. The multibeam bathymetry shows a seabed expression of the youngest buried failure. The corresponding MTD in 3D seismic shows numerous dispersed blocks and the headscarp morphology suggests that liquefaction and lateral spreading may be the mode of failure.

The recent NE Flemish Pass failures are located on a drift that had not experienced significant failure earlier in the Quaternary. They demonstrate that after a long period of stability, earthquakes may be sufficient to trigger a series of failures over tens of thousands of years. By analogy, the buried failures on Sackville Spur may also be composite in origin. Some other process must be responsible for episodic preconditioning of failure. This is most likely the build-up of high pore pressures by thermogenic gas rising up dip and along the fault zone that marks the southern edge of Orphan Basin. Blanketing muds of glacial plume origin, deposited at times of low current speed, provide a low permeability barrier to gas migration.

CONCLUSIONS

1. The Labrador Current experienced highest speeds during interglacials and at some times preceding and during Heinrich events. More generally, oceanographic processes can result in significant changes in current speed on millennial to 0.1Ma time scales.

2. Such variations in current speed result in large variations in the amount of sortable silt in drift sediments, with silty sediment liable to liquefy during cyclic loading by large rare passive-margin earthquakes.

3. On canyoned steep slopes, drifts fail every 10–30ka during earthquakes. On slopes of <1.5°, excess pore pressure builds up in permeable silts due to migrating thermogenic gas that is trapped by blanketing muddy sediments accumulated at times of lower current speed.

ACKNOWLEDGEMENTS

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The role of physical oceanographic processes in contourite sedimentation and how we can work together

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Abstract: *An overview of the dynamics of geostrophic dense currents flowing along the continental slope is given. The effect of Earth's rotation, bottom friction and additional small-scale topography, for example submarine canyons, on the dense water is considered. As a first-order approximation the water moves forward along the depth contours and parallel to the coast. Bottom friction induces a stress which gives rise to the Ekman spiral and a downhill Ekman transport in the benthic boundary layer. The boundary layer dynamics have consequences for the erosion and deposition of sediment and will be described in detail. The transport in the boundary layer also gives rise to a secondary circulation inside the main current, which influences the cross-current transport of suspended sediment. Topographic corrugations such as canyons, ridges and corrugations cross-cutting the path of a dense plume may effectively steer all or part of the dense plume downslope, and an overview of such flows will be given. Typical lateral variations of flow speed will be described and discussed. Depending on the scales of the flow these differences can have consequences for the formation of contourites, which will be discussed. Some examples of how successful multidisciplinary studies involving marine geology, benthic biology and physical oceanography will be presented.*

Key words: *Physical oceanography, contourites, sedimentary processes*

LARGE-SCALE TOPOGRAPHY

The focus of this abstract is on the dynamics of a dense current flowing along a sloping topography, and the consequences of these dynamics on the sedimentation and erosion of bottom contourites. The deep waters of the oceans are formed primarily in marginal seas or shallow shelf regions where the water is made cold and dense by cooling and/or ice formation, or highly saline upon strong evaporation (e.g. Ambar and Howe, 1979; Dickson and Browne, 1994). The relatively dense water thus formed flows into the ocean via narrow or shallow straits. When the water is no longer constricted by the topography, it reshapes into a wider structure that adjusts to the forces of gravity, rotation, and bottom friction.

The Earth's rotation tends to steer bottom currents to the right (in the Northern Hemisphere) to flow parallel to large-scale bathymetry (e.g. along the continental margins). Bottom friction in combination with rotation acts to form a thin bottom boundary layer (the Ekman layer) in which fluid is drained to the left of the main current velocity, i.e. downhill for the largest part of the flow (Fig. 1). At the lateral boundaries, the edges of the dense water mass adjusts in order to make the dense interface horizontal where possible (Wåhlin and Walin, 2001; Price and Baringer, 1994). This is possible e.g. at the upper edge (Fig. 1), or if the flow has carved out a channel so that there is a ridge at the lower side against which it can lean. When the interface is horizontal the velocities are very small, and the Ekman transport reduced so that this is a stable state. This process will tend to increase the deposition upslope of a major bottom current, or in the vicinity of an along-slope directed ridge.

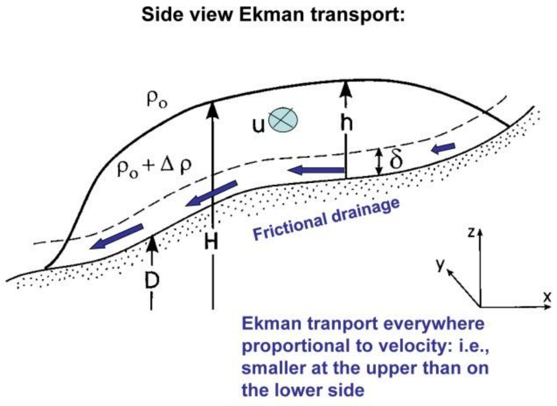

FIGURE 1: Side view of a dense water mass flowing along a sloping topography.

SMALL-SCALE TOPOGRAPHY

Small-scale topographic features such as ridges and canyons can redirect the flow so that it flows antiparallel to the large-scale bathymetry (Figure 2). Examples of this is found in e.g. Darelius and Wåhlin; Allen and deMadron, 2009; Cossu et al, 2010. When this happens the velocity is generally smaller on the right hand side (looking downstream) of the canyon or ridge (in the Northern Hemisphere). Large-scale turbidity currents in submarine channels often show a significant asymmetry in the heights of their levee banks. In the Northern Hemisphere, there are many observations of the right-hand channel levee being noticeably higher than the left-hand levee, a phenomenon that is usually attributed to the effect of Coriolis forces upon turbidity currents (Cossu et al, 2010). It is a good example that shows how the physical oceanographic dynamics inherent in the flow creates horizontally varying flow speeds that are persistent enough to affect the sedimentation during long time scales (i.e. contourites).

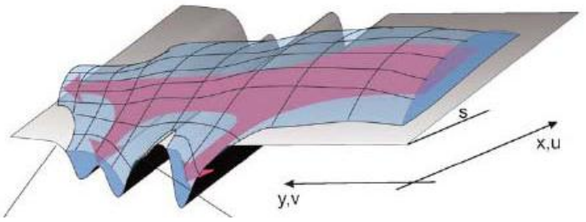

FIGURE 2. Sketch of a current flowing in corrugated topography with portions of it steered down inside the canyons

An example of how we can work together is to select sites for geophysical surveys that are known to harbour persistent physical oceanographic processes, and also the opposite to let the geophysical observations be the guide for where to perform intense physical oceanographic process studies.

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Good neighbours in vigorous currents: contourites and cold-water corals

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Abstract: *Being both triggered by intense bottom currents, contourites and cold-water corals often occur side by side along many continental margins in the world. Whereas the interaction between bottom currents and sediments can form large contourite depositional systems, cold-water corals can build-up impressive seabed structures called coral carbonate mounds. The co-occurrence of contourite drift deposits and coral carbonate mounds frequently aligns such prominent seabed structures in a given region. These can form high-resolution paleo-archives preserving detailed paleo-environmental records, especially with regard to the prevailing bottom current systems. After five respectively two decades of intense research, providing significant knowledge about contourites and cold-water corals, new ideas and concepts may arise from a close collaboration of scientists from these two fields.*

Key words: *Cold-water corals, contourites, bottom currents, continental margins.*

INTRODUCTION

Contourites are linked to the activity of bottom currents by definition, whereas this is less obvious for cold-water corals. The distribution of cold-water corals is controlled by their sensitivity to a number of physico-chemical parameters such as temperature, salinity, and oxygen content. However, in addition to find a suitable habitat fitting their physico-chemical needs, sufficient food supply is another crucial factor controlling the distribution of cold-water corals (Fig. 1).

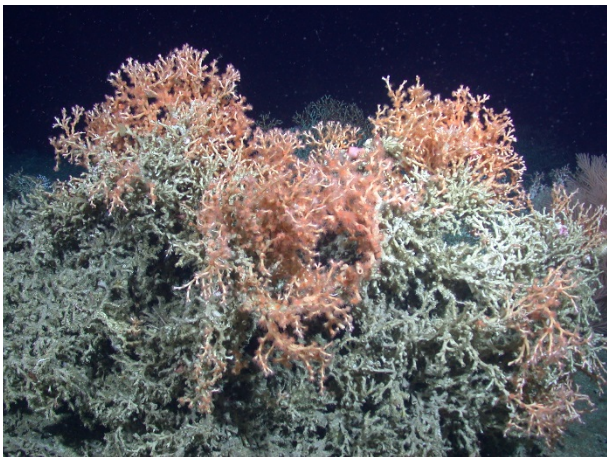

FIGURE 1. Extensive framework of the cold-water coral Lophelia pertusa *on a coral carbonate mound in the Belgica Mound Province, Irish continental margin (© MARUM).*

As sessile suspension feeders cold-water corals rely on a steady or periodic delivery of food particles to their tentacles. Compared to the quasi-vertical pelagic particle flux in a setting without any lateral currents, a quasi-horizontal transport of particles induced by a vigorous bottom current regime (associated with processes such as geostrophic currents, internal tides/waves, downwelling, cascading, etc.) considerably enhances the probability for the corals to catch a food particle. Consequently, all thriving cold-water coral ecosystems are intrinsically linked to a dynamic bottom water regime (see e.g., White et al., 2005) as it is documented, for example, in the association of ripples and dunes with coral carbonate mounds (Fig. 2). In addition, past changes in bottom current strength have been identified to control the occurrence of these ecosystems through time (Dorschel et al., 2005).

FIGURE 2. Rippled seabed covered with cold-water coral fragments within the Belgica Mound Province, Irish continental margin, illustrating the close link between bottom currents and the occurrence of cold-water corals (© MARUM).

DISTRIBUTION

Contourites can basically form in all water depths. In contrast, the physico-chemical requirements of the cold-water corals limit their occurrence largely to shallow and intermediate depths. However, along these depths they are widely distributed. As both are dependent on the presence of a dynamic bottom current regime, the occurrence of cold-water corals is usually intimately linked to the occurrence of contourites (Fig. 2).

The majority of cold-water coral settings explored so far, are concentrated in the North Atlantic, but every year new sites all over the World are being discovered. By now it appears that they occur along almost all continental margins around the entire Atlantic Ocean and at various places in all the other ocean basins.

The progress of our knowledge regarding the distribution of cold-water coral settings resembles somewhat the case of contourites. This is a common picture for relatively young fields of research, where first advances are often made in the well-studied North Atlantic. Thus, especially with respect to the Pacific and Indian Oceans new findings of contourite and cold-water coral sites have to be expected for the years to come.

SHAPING THE SEABED

Contourite Depositional Systems can be quite extensive reaching hundreds of kilometres in length and thicknesses of up to 2km (Rebesco et al. 2014). The positive morphological structures formed by contourites are often aligned with moats additionally indicating bottom current activity.

Especially framework-forming scleractinian cold-water corals, as e.g., the most prominent species *Lophelia pertusa* (Fig. 1), have the capability to form large and three-dimensional seabed structures, so-called coral carbonate mounds. Over a period of ~2.4Ma the giant coral carbonate mounds off Ireland have been grown to >300m above the surrounding seafloor. Although an individual mound structure only reaches perimeter of hundreds to maybe a few kilometres in diameter, the clustering of such mounds to large mound provinces eventually can cover several 10s of square kilometres (e.g., Hebbeln et al. 2014).

HIGH-RESOLUTION PALEO-ARCHIVES

Similar to contourite drift deposits, the coral carbonate mounds act as paleoenvironmental archives that can be characterised by rather high sedimentation rates. For instance, along the Moroccan margin in the Alboran Sea (see also Fig. 3) individual mounds reveal for specific time intervals sedimentation rates of >4m per thousand years (Fink et al. 2013).

The differing capacity of either of the two systems in preserving paleoenvironmental signals (see for example Dorschel et al. 2005) opens the door for significantly improved paleoenvironmental reconstructions. Combining different signal carriers as well as records with different temporal resolutions (sometimes alternating between both archives) will be one among many promising tasks for future cooperation of contourite and cold-water coral researchers.

ACKNOWLEDGEMENTS

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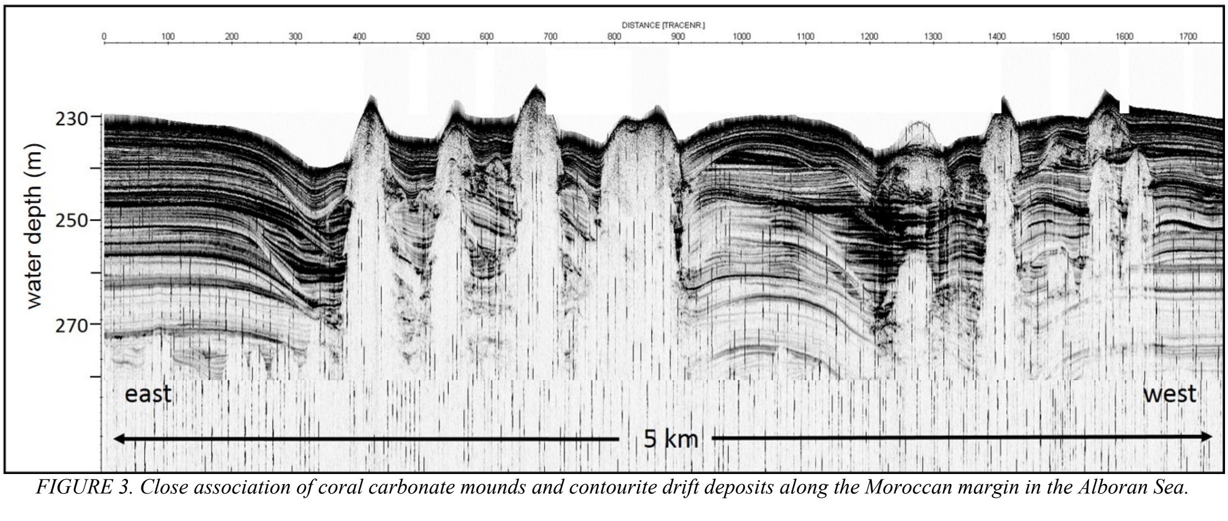

FIGURE 3. Close association of coral carbonate mounds and contourite drift deposits along the Moroccan margin in the Alboran Sea.

Manganese nodules: genesis, distribution and deep-water circulation

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Abstract: *The genesis of nodules and the notion of "nodule field" are analysed to indicate the interactions between four major factors : topography, sedimentation, Life and water. Then, the major, but badly known role of the deep oceanic currents, is approached by examples.*

Key words: *manganese nodules, deep-sea currents, submarine soils, deep-sea sedimentation, nodule field.*

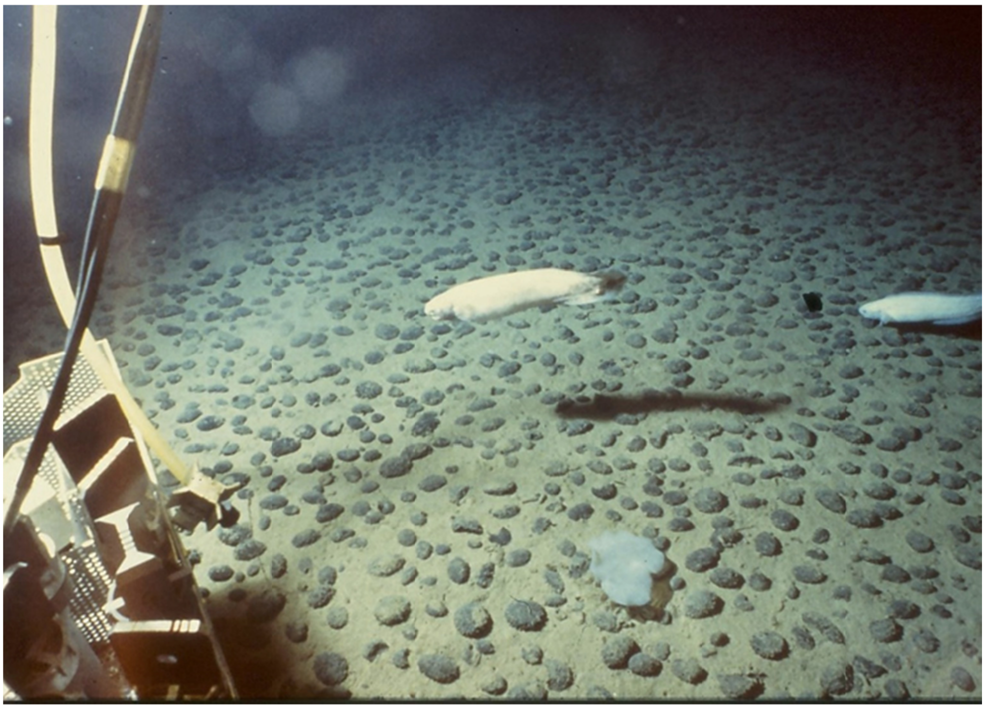

FIGURE 1. Aspect of a nodules outcrop in the Eastern Central Pacific (5135m); on a flat topography, nodules are arranged on soft sediments, associated to life. Currents speed measured in this place was of 5cm/s approximately. The biggest nodules have a diameter of about 10-15cm. (photography : M. Hoffert)

INTRODUCTION

Polymetallic nodules were the objects of intense works during 1970-1990 or so for an industrial exploitation. Then followed a setting in a stand-by mode of these works until recently, a new interest was developed in this potential mining of the future. Recent syntheses allow approaching this new phase of exploration with new concepts (Halbach et al, 1988, Hoffert, 2008 ; ISA, 2009 ; Morgan, 2000).

THE OBJECT NODULE AND ITS GENESIS

The genesis of a nodule requires three conditions: a mobile nucleus arranged in the upper part of soft sediments, a very slow sedimentary deposit rate (1 to 10mm / 1000years) and a lot of time (several million years). The speed of growth of nodules is some millimeters per million years.

Nodules are geological bodies only from sedimentary origins; their formation is a dissolution-precipitation mechanism associated to a submarine pedogenesis. Nodules can be considered as a horizon of a deep-sea soil. The genesis of nodules is independent from active volcanic phenomena.

No life, no nodules! The planktonic productivity at the oceans' surface is the major factor for the primary sedimentation speed at a point of the ocean floor, which determines the nature of the sediment, the nature and the proportion of the ions in solution by dissolution of the tests. The content in organic matter of superficial sediments influence the mechanisms of diagenesis (phenomena of oxydo-reduction and vertical migration of elements), basis of nutriment; it determines the importance of the benthic life, thus of the bioturbation and the nodules' movement.

THE CONCEPT OF "NODULE FIELD"

The vision of "flat abyssal plains" must be replaced by the vision of a very diverse topography, deriving from the basement tectonics, the variations of sedimentation, the erosive actions and the sedimentary transport by the deep currents. Nodules distribution results from the interaction of these factors. Thanks to regional surveys (see Halbach et al, 1988 ; ISA, 2009), the concept of “nodules field" was born.

THE MAJOR, BUT BADLY KNOWN, ROLE OF THE DEEP OCEAN CURRENTS

The action of the deep ocean currents has proven to be present in the environments associated to all scales of nodules.

The combined actions of bioturbation and sporadic intensification of the currents, which provokes the erosion, and the re-sedimentation of sediments, can only explain the maintenance of the nodules on surface. The experimental works of Lonsdale and Southard (1974) consider that a speed about 12cm/s is self-sufficient to provoke erosion in zones with nodules.

The discontinuous growth of the nodules is linked to repetitive variations of their sedimentary environment. They translate variations of water bodies in intervals of time from several ten of thousand years.

Great periods of sedimentary hiatuses, as well as the landscapes modelling (like erosion channels - See Cochonat et al, 1992) must have their origin in currents intensifications.

Since the Eocene, large kinematic modifications of plates strongly modified the traffic of oceanic waters. Latitudinarian becomes meridian and is at the origin of deep cold currents. The “nodule time“ can then start.

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New Advances in the Contourite Paradigm: IODP Expedition 339, Gulf of Cadiz

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Abstract: *IODP Expedition 339 cored over 4.5km of sediment from the Cadiz Contourite Laboratory. This provided a rigorous test for the contourite paradigm. The sediments are remarkably uniform in their mixed siliciclastic-bioclastic composition and textural attributes. They have a general absence of primary sedimentary structures, and an intense bioturbation throughout with a distinctive, small-scale, monotonous ichnofacies and local omission surfaces. Most sections are characterized by bi-gradational sequences from inverse to normal grading, but also include a range of partial sequences of which the base-cut-out sequences are most common. All these features are fully consistent with the established contourite facies model. Important refinements include the nature and significance of sandy contourites, the frequency of base-cut-out partial sequences, and the role of sediment supply.*

Key words: *Contourites, Gulf of Cadiz, IODP 339, facies models, contourite reservoirs.*

INTRODUCTION

IODP Expedition 339 drilled 5 sites in the Gulf of Cadiz and 2 off the west Iberian margin (Fig. 1). One of the principal scientific aims was to investigate the nature and effects of the bottom currents related to Mediterranean Outflow Water (MOW) on contourite deposition and erosion along the Iberian continental margin (Hernández-Molina et al, 2014). The region is informally known as the *'contourite laboratory'* on account of the many detailed studies made over the past four decades, and very clear documentation of bottom currents, contourite drifts, bedforms and erosional features (Stow et al, 2012). The complex architecture of alongslope deposits and erosion along this mid-slope region is known as a contourite depositional system (CDS) (Hernández-Molina et al, 2014).

The sites drilled on IODP Expedition 339 recovered around 4500 m of core through contourite drifts of the Cadiz CDS, at water depths between 570m and 1094m. This provides a rigorous testing ground for the existing contourite facies model (e.g. Stow and Faugères, 2008) and an opportunity to refine its detail as necessary. There is still controversy surrounding the validity of this model, and several authors have invoked rather different sedimentary characteristics for the recognition of ancient contourites exposed on land.

The Gulf of Cadiz straddles the diffuse boundary between the Eurasian and African plates, immediately west of the Straits of Gibraltar. The present-day circulation pattern in the region is dominated by the near-bottom outflow of warm, highly saline MOW and the turbulent inflow of less saline, cool-water mass of the Atlantic Inflow Water at the surface. The MOW forms a strong bottom current flowing towards the W and NW above North Atlantic Deep Water. Interaction of this bottom current with the slope topography has led to construction of the Cadiz CDS over the past 4.5My.

RESULTS

The recovered section ranged in age from Holocene to Pliocene at every site, and penetrated into the uppermost Miocene at two sites. Mean sedimentation rates were generally high for all contourite-dominated Holocene-Pleistocene intervals, compared with typical rates for open ocean slope systems. They ranged from 25-100 cm/ky for the Cadiz sites, with the more rapid rates being more proximal to the Gateway, and from 10-15 cm/ky on the west Portuguese margin plastered drift at site U1391. Mean rates for the Pliocene were very variable, ranging from 5-20 cm/ky, but considerably affected by non-depositional and erosional hiatuses.

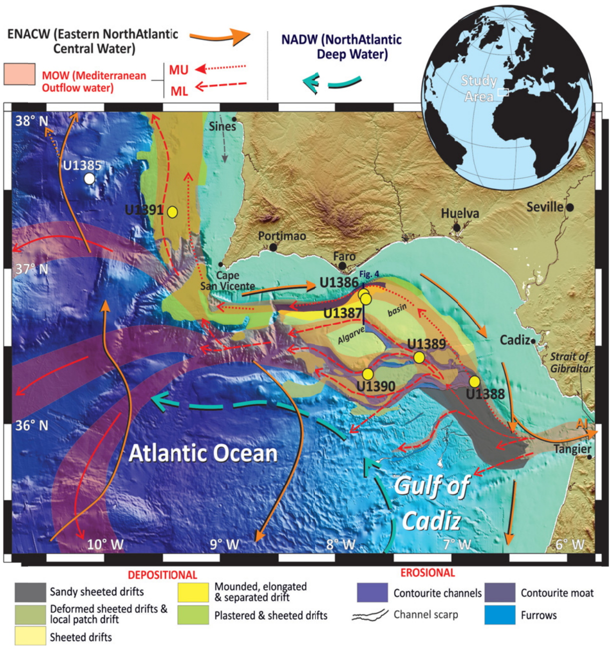

FIGURE 1. Gulf of Cadiz Continental Margin showing IODP Expedition 339 sites and track of Mediterranean Outflow Water.

The principal facies recovered through the contourite drift succession include calcareous muds, silty muds, muddy sands and silty sands. We are confident in their interpretation as contourites for the following reasons: (a) they occur in mounded, sheeted and plastered drifts clearly identified in comprehensive seismic datasets from the region; (b) these drifts are closely aligned with the known passage of MOW bottom currents; (c) the elevated position of all sites away from the passage of downslope processes, for most of the Pleistocene-Holocene; (d) the elevated and completely isolated position of two sites, which precludes the possibility of turbidity current access; and (e) the many previous studies of the present-day seafloor and topmost sediments, which all concur with a contourite aspect of the sediment facies.

For clarity, therefore, we refer to these facies as: muddy contourites, mud-silt contourites, muddy sand contourites, and silty sand contourites. Holocene and later Pleistocene (post 1 Ma) sedimentation was everywhere dominated by contourites, with < 5% clearly turbidite intercalation evident in the sites to which turbidity current access was possible. Prior to 1 Ma during the earlier Pleistocene and Pliocene, turbidites, debrites and slump deposits were more common. Where recovered, the Miocene mainly comprised normal slope hemipelagic sedimentation.

Contourite characteristics

One of the most typical aspects of the Cadiz contourite sedimentation is its *uniformity* throughout: the dominance of greenish grey colour, the general absence of primary sedimentary structures, the sediment homogenization by bioturbational mottling, and the uniformly mixed biogenic-terrigenous composition. There is also consistent cyclicity of facies and grain size in bi-gradational units.

They have a general absence of primary sedimentary structures, except for a somewhat discontinuous and widely-spaced silt lamination within muddy contourites that show the highest rates of sedimentation. There is an intense, continuous bioturbation throughout with a distinctive, small-scale, monotonous ichnofacies and local omission surfaces. Most sections are characterized by bi-gradational sequences from inverse to normal grading, but also include a range of partial sequences of which the base-cut-out sequences are most common.

Taking the total number of measured sequences at each site and the time interval over which they were deposited yields an average cyclicity of 1/6000 y. This ranges from 1/4000 y to 1/8000 y. The actual cycle period may be a little less if we take into account 'hidden' sequences within the mud-rich sections.

The grain size is mostly fine and with poor to moderate sorting for the majority of drift contourites – in the clay, silt and very fine sand range. Coarser bioclastic material is typically in or nearly in situ. The sandy contourite layers range from fine-grained and muddy, with rare well-sorted intervals. Within these sands, there is often scattered coarser-grained and fragmented bioclastic debris. Some of the thicker-bedded sandy contourites in the most proximal site are cleaner and moderately well-sorted fine-medium sands.

Total organic carbon content varies between < 0.3% and 1.5%, with a C/N ratio that implies a general dominance of a marine over terrestrial source, but with some local variation. For most of the Pleistocene-Holocene period, the microfossil assemblage indicates relatively high organic matter supply.

Contourite sands

Spatial distribution of the contourite elements along the Cadiz continental margin are closely linked with the decrease in bottom-current speed down-flow from the exit of the Gibraltar Gateway. The rocky substrate west of Gibraltar gives way to an extensive contourite sand sheet, which extends along a mid-slope terrace for approximately 100 km before diverging into several contourite channels around the prominent seafloor relief created by mud volcanoes and diapiric ridges.

Seismic data and one industry borehole indicate that this sand sheet is at least 800 m thick. Site U1388 penetrated 220 m into this proximal sand sheet before the hole became too unstable to continue. Initial results indicate rapidly-deposited, late Quaternary, sandy contourites are dominant. The areal extent and vertical thickness of clean contourite sands display ideal reservoir characteristics and are therefore especially significant for the oil and gas industry. Deliberate search for this new style of deepwater succession could represent a paradigm shift for oil and gas exploration.

DISCUSSION

Following rigorous testing on over 4.5km of core recovered from the Cadiz continental margin, the existing contourite models (Stow and Faugères, 2008) are found to be in good working order. Some important refinements include the nature and significance of sandy contourites, the frequency of base-cut-out partial sequences in addition to the dominant bi-gradational sequence, and the role of sediment supply as well as bottom current velocity in determining the sequence type and frequency.

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Spatial distribution of deepwater depositional systems and relationship with bottom currents on the northwestern lower slope of the Northwest Sub-Basin, South China Sea

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Abstract: *Using 2D seismic data, a complex of deepwater depositional systems consisting of submarine valleys/canyons, wave-shaped sliding deposits, contourite erosive features and sheeted drifts, are developed within the Quaternary strata on the northwestern lower slopes of the Northwestern Sub-Basin, South China Sea. Alongslope aliened erosive features and non-depositional features are observed on the eastern upper gentle slopes (<1500m-depth), where a V-shaped downslope valley presents an apparent ENE migration. These indicate a major eastward bottom current, possibly within the South China Sea Intermediate Water Circulation. Contourite sheeted drifts are also present on the eastern gentle slopes, with water depth >2500m, referring to a wide unfocused bottom current, which might be related to the South China Sea Deep Water Circulation. Sliding deposits are developed on steeper slopes (>2°), where alongslope current deposition is missing. This suggests a domination of downslope depositional processes on unsteady slopes. The NNW-SSE oriented slope morphology changes from a three-step terraced outline (gentle-steep-gentle) in the east of the investigated area, into a two-step terraced (gentle-steep) outline in the middle, and into a unitary steep slope in the west. Such morphological changes possibly lead to the westwards simplifying assemble patterns of the deepwater depositional systems on this margin.*

Key words: *deepwater system, contourite, turbidite deposits, northwest sub-basin, South China Sea.*

INTRODUCTION

Deepwater depositional systems, including downslope and alongslope current deposits, could record a wealth of information on palaeoceanographic, climate, and tectonic changes (Rebesco et al., 2014). The northwestern lower slope of the Northwest Sub-Basin with a water depth ranging from 1000 to 3500m from the South China Sea (SCS) represents a critical oceanic-continental transition zone in the SCS deepwater area (Fig. 1a). The SCS oceanic circulation is subdivided into 3 main levels: the surface water (0-350m), intermediate water (350-1500m) and deep water (>1500m) circulations. The SCS Intermediate Water sweeps the SCS northern margins, mainly from west to east, while the westward South China Sea Deep Water circulation is known to have an average current velocity of $0.15 m.s^{-1}$ across the Luzon straight and $0.02–0.05 m.s^{-1}$ around the drilling location of ODP1144 (~1900m-depth) (Chen et al., 2014). In this study, we deal mainly with the spatial distribution of deepwater depositional systems, and also focus on the implications of the morphologies based on high-resolution seismic data. The purpose of this study is to elucidate the dominant controlling factors in the formation and evolution of deepwater depositional systems in northern margins of South China Sea.

RESULTS

Varied deepwater depositional systems are present, such as the downslope gravity flow deposits and alongslope contourite deposits, due to the complex paleogeographical relief (Figure 1b). The W-E oriented Xi'sha Trough (>3000m-depth) is located in the southwest study area, as a remarkable morphologic feature (Fig. 1a, b). Series of downslope submarine canyons are observed on slopes lower than 1500m in the northwest. At ~1350m in water depth (slope <1°), a NNW-SSE oriented valley shows an asymmetric V-shaped morphology. Successive incising bases, with obvious ENE migrations, can be identified, showing continuous and high amplitude seismic reflections.

Mass-wasting deposits are restricted between 1500m and 2000m water depth (slope >2°) in the east; their spatial distribution is expanding to from 1400 to 2100m in the west. These deposits show parallel to sub-parallel and moderate to high amplitude seismic reflections, and their configuration displays a sine curve-like geometry. Successive slide scars and failure surfaces are observed between these displaced mass-wasting deposits.

Sheeted drift deposits observed are draping relatively deep (>2500m) and gentle (~1.5°) slopes in the southeastern part of the study area, with an average thickness over 70ms TWT. Their morphologies are mostly flat and smooth, and show fairly continuous, parallel to sub-parallel seismic reflectors of moderate amplitudes. The development of sheeted drifts gradually reduces to the west, in consistent with the disappearance of the lower gentle shapes.

Seamount-related contourite depositional features (moats and elongated-mounded drifts), small-scale alongslope aligned channels (0.5–2km wide and 10-20m deep) and non-depositional features are present on the northeastern slopes, at water depth of 1500m and above (slope <1.2°). Following the contour line of 1500m to the west, they gradually disappear, and slope failures are developed instead.

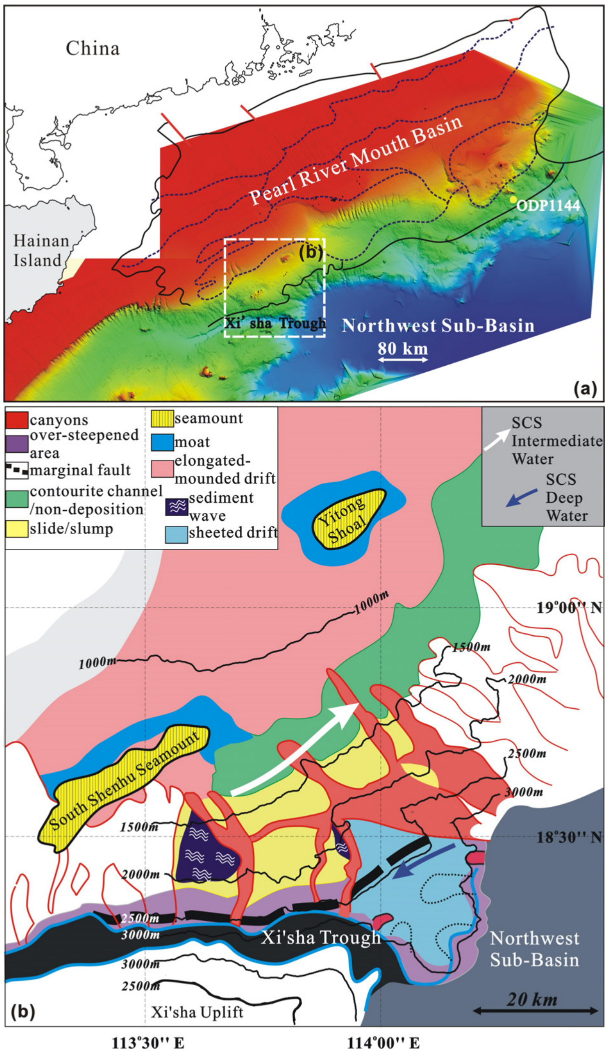

FIGURE 1 (a) Bathymetry of the study area; (b) Block diagram showing the distribution pattern of the deep-water sedimentary systems that developed over the Pliocene-Quaternary in the study area

CONTROLING FACTORS IN FORMATION AND EVOLUTION OF DEEPWATER DEPOSITIONAL SYSTEMS

The slope morphology of the eastern study area is shown as a three-stepped terraced outline, of which the upper part (depth <1500m) and the lower part (depth >2500m) are both gentler slopes (average gradient of less than 1.5°) and the middle part is much steeper (slope >2°). It changes into a two-stepped terraced outline in the middle, and finally into a unitary steep slope in the west. On one side, alongslope channels and sheeted drifts generated by bottom currents are developed on the gentle slopes (in the east), while landslidings dominate the whole steep region. Downslope slumps or slides are the representative products of unstable continental slopes, whereas alongslope depositional records are commonly missing due to the failure of intermediate bottom currents to erode/deposit sediments, and/or the fact that alongslope depositional records are strongly affected by frequent downslope processes. On the other side, the morphological changes, as mentioned above, possibly led to a westward simplification of composite deepwater depositional systems, from a complex of contourite deposits and mass-wasting deposits in the east, to only mass-wasting deposits in the west.

As parts of the SCS Intermediate Water Circulation, the eastward flowing bottom currents generate alongslope erosive or non-depositional features near 1500m-depth. It could push the submarine valley to consistently migrate eastwards, where the hydrodynamics of alongslope currents are locally strong. The SCS Deep Water bottom currents (>2000m-depth) might evolve into non-focused current with decreased velocity when encounter the gentle-flat lower slopes in the west (our study area), generating the slope sheeted drifts. Thus, the different flow directions, hydrodynamics and occurring depths between the SCS Intermediate Water and Deep Water could lead to various depositional processes and products.

CONCLUSIONS

High-resolution 2D seismic data reveal that deepwater depositional systems changed from a complex of contourite erosive/depositional features, slope failures and canyons in the east towards solely mass-wasting and canyon depositions in the west in the study area. The fact indicate that internal architectures and development of deepwater depositional systems are in close association with the steepening of slope morphologies from east to west on one side, and the different flow directions and hydrodynamics of the SCS vertically stratified water masses on the other side.

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The Pianosa Contourite Depositional System (Corsica Trough, North Tyrrhenian Sea): stratigraphic evolution and possible role in slope instability

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Abstract: *The Pianosa Contourite Depositional System (Corsica Trough, North Tyrrhenian Sea) results from the interaction of the Levantine Intermediate Water (LIW) with the Pianosa Ridge. Seismic reflection data and Calypso piston cores show cyclicity in drift morphology and migration, as well as in the lithology, that might be linked to sea-level changes. Major erosional seismic discontinuities in the contourite drifts correspond to coarser sediment and seem to influence the location of slide planes.*

Key words: *contourite drifts, submarine landslides, Levantine Intermediate Water, Tyrrhenian Sea*

INTRODUCTION

The Levantine Intermediate Water (LIW) is formed in the eastern Mediterranean and enters in the Tyrrhenian through the Sicily Channel, being found in between 200 and 600-1000m in the Corsica Trough (Artale and Gasparini, 1990). The Corsica Trough, located between Corsica and the Tuscan shelf, connects the Tyrrhenian and Ligurian Seas through the Strait of Corsica with a maximum depth of 900m. The western part of the basin presents a gentle slope (2 to 3°) and is dominated by the turbidity channel-lobe systems of the Golo basin. Our study area is located in Pianosa Ridge, a tectonic structure with a steeper slope (3.5 to 7.5°) characterized by submarine landslides and contourites that limits the basin to the east. The Corsica Trough becomes shallower and narrower to the north. Therefore, bottom currents accelerate, especially in the eastern slope due to Coriolis effect, forming the depositional and erosional features of the Pianosa Contourite Depositional System. In the southern part of the study area mass transport deposits are larger and more abundant. Submarine landslides in the Pianosa Ridge do not correspond to a unique event, but are recurrent in time (Cattaneo et al., 2014).

DATA AND RESULTS

Multibeam bathymetry, High-Resolution-72 traces (50-250Hz), Chirp (1800-5300Hz) seismic reflection profiles and Calypso piston cores were collected during cruises PRISME2 and PRISME3 in 2013. Gamma density, P-wave velocity and magnetic susceptibility of whole sections were measured with a Geotek Multi-Sensor Core logger (MSCL). X-ray fluorescence (XRF) was measured on split cores using an Avaatech XRF core scanner to obtain the bulk sediment semi-quantitative geochemistry.

The Pianosa Contourite Depositional System extends from the Capraia Sill (43°-00'N) to the southern part of the Pianosa Ridge (42°-18'N) (Roveri, 2002). A small longitudinal mounded drift (2.3km wide) near Scoglio d'Africa forms the southern limit of the system, from the available dataset. Slightly to the north, the slope is strongly modified by submarine landslides. However, recent small contourite drifts have been formed on the slide scar of the "Pianosa Slump" (Fig. 1). West of Pianosa Island the continental slope is narrower and the isobaths retreat towards the east. (Fig. 1). Two parallel mounded drifts develop following the contour of the bathymetry (Fig. 2). Their growth is stopped in the area of high erosion and/or lack of deposition that corresponds to the steepest part of the slope. North of the Pianosa Island, the slope becomes broader and gentler, allowing the development of contourites in two branches: one in the lower slope and another in the mid slope, forming multi-crested drifts. The shallower contourites in the northernmost part of the study area present a complex and repetitive upslope and downslope migration that causes the cannibalization of the older drifts by the new moats.

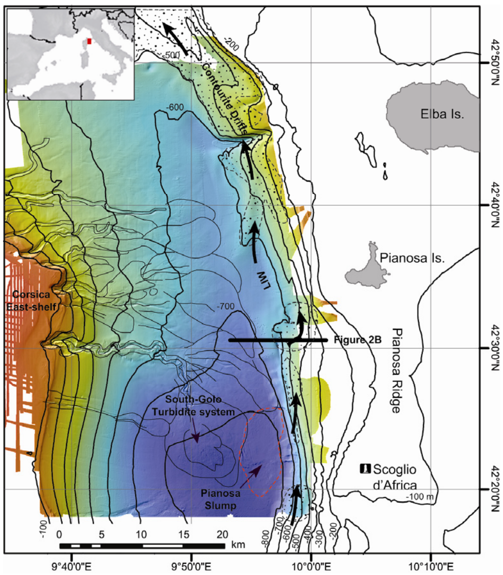

FIGURE 1. Bathymetry of the Corsica Trough (Modified from Cattaneo et al., 2014). Dashed black lines with spotted filling define the location of contourite drifts. Turbidite systems are outlined in grey (from Deptuck et al., 2008). Bottom-current direction (black arrows) outlines the Levantine Intermediate Water (LIW) pathway.

Calypso piston cores show that contourite drifts are composed of silty clay with sandy layers that correspond to high amplitude reflectors and seismic discontinuities (Fig. 2). The sandy intervals are very well identified by peaks in the curve of P-wave velocity and they present very high ratios Sr/Ca, due to the abundance of shell clasts (Fig. 2). The youngest sandy layer found at 12.5m in the central contourite corresponds to an erosional seismic discontinuity that defines the beginning of the last contourite cycle. The seismic reflectors matching these layers have regional extent and seem to influence the location of slide planes of the two largest mass transport deposits at the south.

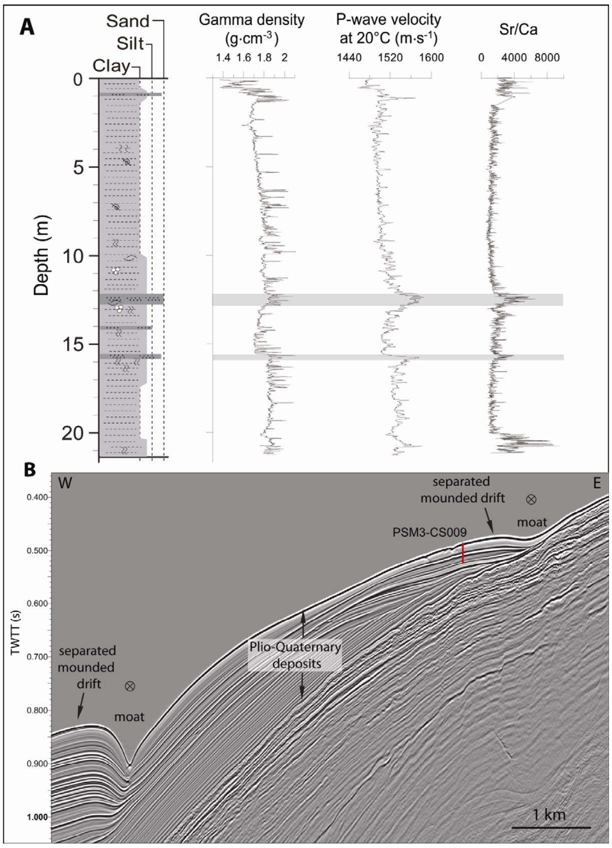

FIGURE 2. A: Lithological log, gamma density, P-wave velocity and Sr/Ca measurements along core PSM3-CS009 collected in the separated mounded drift. Grey bands show the sandy layers. B: High-Resolution seismic profile of the central contourites.

DISCUSSION

Water circulation in the Corsica Trough presents a millennial scale variability, following the pattern of cold periods with faster and well ventilated bottom-currents and warm periods with slower and poorly ventilated flows (Toucanne et al., 2012). Maximum growth of turbidite lobes takes place during low sea level stands (Deptuck et al., 2008), as well as mass wasting processes (Cattaneo et al., 2014). Roveri (2002) suggested that contourite drifts mostly grow during periods of enhanced bottom-currents. The Pianosa contourites present erosional surfaces composed of bioclastic sand at the bottom of muddy drifts possibly formed during early stages sea-level lowstands. This might imply that there is a period of fast currents but no deposition before the emplacement of the contourite drifts. These cyclic changes in contourite facies may correspond to different mechanical behaviours. We suggest that some countourite levels might favour conditions of slope instability, possibly triggered by earthquakes and/or fluid escape. Contourite drifts might have been present all along the Pianosa Ridge, but now they might be absent due to mass wasting processes.

CONCLUSIONS

Contourites along the Pianosa Ridge follow a clear cyclicity in their morphology, internal geometry, migration and grain size distribution that might be linked to sea-level changes. Mass wasting processes are also recurrent and seem to occur during sea-level lowstands. Further geotechnical analyses on the contourite sediment will contribute to clarify the relationship between contourites and slope instability.

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Different styles in configuration of the contouritic drifts in the northern sector of the Argentine Continental Margin: implications in slope stability and geohazard

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Abstract: *The northern sector of the Argentine Continental Margin includes areas with significant differences in the morphosedimentary configuration of the contouritic drifts. In the northernmost part (MP area) they are represented by relatively continuous deposits not deeply affected by gravity downslope processes, whereas in the southernmost part (BB area) they are discontinuous and highly dissected by mass-transport and turbiditic deposits. These differences can be addressed to local conditioning factors manifested in a different morphology of submarine canyons, tectonic influence and sediment dynamics, which have relevant implicances in slope stability and geohazard.*

Key words: *Argentine Continental Margin, contouritic drifts, sediment dynamics, slope instabilities, geohazard.*

INTRODUCTION

The Argentine Continental Margin (ACM) contains one of the largest contouritic depositional systems (CDS) worldwide (Hernández Molina *et al.*, 2009). In the passive sector of the margin (36 to 50°S) the CDS extends along ~1600km at water depths between 400 and 4000m, shaping the continental slope and rise that together reach a maximum width of ~500km (Fig. 1). Other contouritic systems develop off the continental rise in the Argentine basin at depths >5000m. All these systems are genetically linked to the activity of the different branches of the Antarctic-sourced water-masses that form the regional oceanographic system of the South Western Atlantic Ocean (Antarctic Bottom Water, Circumpolar Deep Water, Antarctic Intermediate Water and Malvinas Current), in whose interfaces high dynamic with strong currents produce erosive and depositional processes that modelate alongslope terraces characterizing the margin morphology.

The extension of the CDS and the diversity of geotectonic settings where it develops are evidenced in distinct morphosedimentary configurations. In the present contribution two key areas in the northern sector of the CDS are described, one of them deeply affected by slope instabilities as a result of interaction among diverse conditioning factors. This research highlights the implicances of contouritic deposits as important tools for assessing the geohazard in the ACM.

REGIONAL CHARACTERISTICS OF THE CDS

The ACM depicts two major configurations. In the southern region (central and south Patagonian Margin) the margin cross-section has a convex shape; the CDS is there represented by wide contouritic terraces mainly formed by mounded and sheeted drifts of good lateral continuity, shaped in five stepped subhorizontal mixed (erosive and depositional) features, separated by inclined erosive surfaces (Hernández Molina *et al.*, 2009). Large submarine canyons with strong evidences of contouritic affectation develop in the northernmost part of this southern region.

The northern region (north Patagonian margin and Rio de la Plata cratonic margin) shows a concave-shaped cross-section, composed of extended contouritic terraces in the middle and upper slope formed by mounded drifts; an erosive inclined surface develops seaward of the middle slope, whereas the lower slope is mainly composed of plastered drifts that grade offshore to turbiditic complexes and mass wasting deposits that dominate in the continental rise (Hernández Molina *et al.*, 2009: Violante *et al.*, 2010; Krastel *et al.*, 2011; Preu *et al.*, 2012; 2013). Submarine canyons with varied morphologies and sizes are present in this region.

MORPHOSEDIMENTARY FEATURES IN THE NORTHERN SECTOR OF THE CDS

Ongoing research activities in the northern sector of the Rio de la Plata cratonic margin (37-42°S), led to find significant differences between two key areas: Mar del Plata -MP- and Bahia Blanca -BB- (Fig. 1). MP area is characterized by relatively continuous and well developed contouritic drifts with few evidences of affectation by gravitational downslope processes, except close to the large submarine canyons (e.g. Mar del Plata canyon) and also individual landslides and slumps. Instead, BB area depicts discontinuous, highly dissected contouritic bodies cut by numerous small canyons and features associated to sedimentary instabilities like large landslides, mass transport, debris flow and turbidite deposits, as well as normal and thrust faults affecting the drifts. The Bahía Blanca canyon seems to be the most active transverse-to-the-margin feature in this area.

DISCUSSION AND CONCLUSIONS

Differences between MP and BB areas represented by distinct configurations of the contouritic drifts and the varied influence of gravity downslope processes, allows defining the sectors of the margin affected by major slope instabilities. Since the adjacent coastal areas are densely populated with large industrial, port and tourism facilities, the nearby presence of a potentially unstable sea-floor is important for assessing the geological hazard in the entire region.

The conditioning factors differentially affecting MP and BB areas must be addressed to local, rather than regional, conditioning factors, having into consideration that they belong to the same relatively stable morphosedimentary and tectonic setting corresponding to the “Rio de la Plata cratonic margin” (Hernández Molina *et al*., 2011). Local conditioning factors that favour the increasing of downslope processes in the BB area are, considered in a possible order of importance: 1) a dense set of small submarine canyons that interfere in the alongslope sediment dynamic, increasing the concentration of instability points subjected to gravity downslope processes; 2) the inclusion of this area in a region of possible higher tectonic activity related to the presence of a major fracture system of the margin´s deep structure (Ventana Transfer Zone, Franke *et al*., 2010); although other major fracture system (Salado Transfer Zone) is close to the MP area, morphosedimentary evidences seem to show more activity in the BB area; 3) strong influence of fluvial activity during lowstands through a paleo-Colorado river fluvial system (Violante *et al*., 2014), that could signify more sediment supply to the shelf-slope transition, increased sediment accumulation subjected to gravity instabilities and rapid translation to the deep ocean through the dense set of submarine canyons.

Based on these conditions and the way that contouritic deposits are affected by gravity processes, the BB region is considered as a potential source for slope instabilities with implicances in geohazard.

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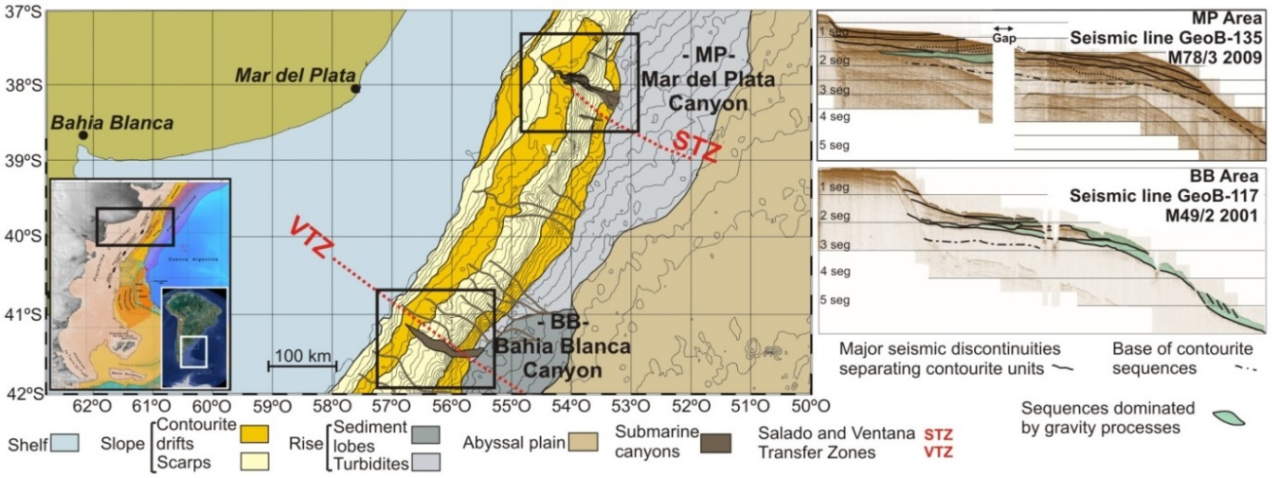

FIGURE 1: Regional map and examples of seismic lines characterizing MP and BB areas. Note the dissected relief and the significant influence of gravity downslope processes in BB area in relation to MP area. Location map includes the CDS defined by Hernández Molina et al. (2009).

Along- and down-slope process interactions in proximal channel-levee systems: Implications for hydrocarbon exploration

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Abstract: *There is an increasing catalogue of turbidites hosting atypical characteristics across proximal channel-levee systems. While some of these may be attributed to system instabilities, these proximal deposits host characteristics more associated with contourites than turbidites, identifying a potential for a new 'mixed-levee zone' to become incorporated into turbidity models. Integrating pre-existing mixed-drift theories with a large literature review and newly acquired 3D seismic data, we have began to identify key characteristics promoting the interplay of along- and down-slope processes along proximal turbidity system, suggesting a 'mixed-levee' system should be used in proximal settings. Deposit confinement has been recognised due to the morphological constraints of turbidites and contourite drifts, though synchronous (simultaneous) and interpolated (in between) process-interactions offers the most significant potential for deposit alteration. Interpolated interactions are fairly long-lived, with the potential to rework sediments across submarine fans, though will offer only subtle differences in reservoir geometries and qualities and have little effect proximally. Synchronous interactions are periodic, following the frequency of turbidity events, bottom-currents have the potential to strip fine-grained overspill in proximal zones, leaving reduced flow quantities, but better sorting. The extent of this flow-stripping in mixed-levee systems has the potential to significantly enhance flow quality, and has been proven to provide economic quantities of 'clean' channel-fill deposits.*

Key words: *mixed-drift, reworked deposits, reservoir quality, 'cleaned' turbidite, channel-levee*

INTRODUCTION

The recent quest for hydrocarbons has seen exploration efforts target more distal settings on continental margins. While this has lead to a significant increase in our understanding of turbidity deposits, contourite and mixed-drift deposits have only recently seen resurgence in research.

Following the discovery of the 100 tcf gas field in the Mamba complex, Mozambique, there has been a recent resurgence in the demand for characterising mixed-system plays. While Faugères et al (1999) and Mulder et al. (2008) offer insights into process-interaction, it is becoming more apparent that these interactions are more common and significant than previously thought. Despite this, bottom currents are often overlooked in hydrocarbon exploration.

Mixed-drift plays have been speculated across the North Sea and Gulf of Mexico, (Shanmugam. 2012), though the absence of diagnostic criteria means these claims still remain speculative. With the aid of 3D seismics, new defining characteristics have been recognised across several frontier exploration programmes across the South Atlantic Margin and offshore east Africa. Based on atypical deposit morphologies and seismic stacking patterns, it is now possible to begin to characterise the nature of interaction between

METHODOLOGY

Integrating a large literature summary with newly acquired 3D seismic surveys, we have begun to characterise possible zones of interaction between turbidity and contourite processes in the late Cretaceous. Recognising anomalies due to system-based inefficiencies, it is possible to differentiate geometric and sedimentological anomalies due to process interaction, from those internal variances within the down- and along-slope redistributary system.

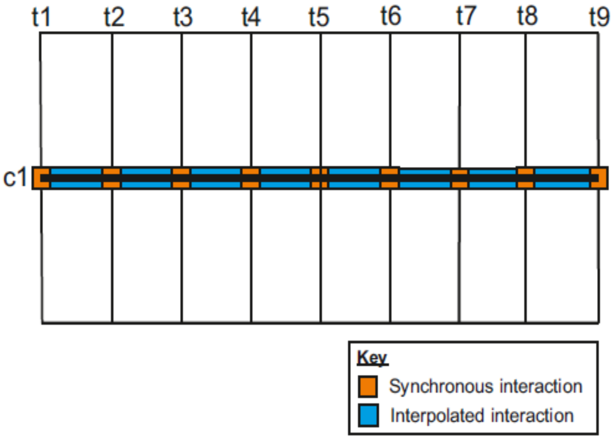

FIGURE 1. Schematic diagram showing the interaction of a contour current (c1) with turbidity events (t1 – t9). The dominance of synchronous styles of interaction occurs as a function of turbidity event frequency.

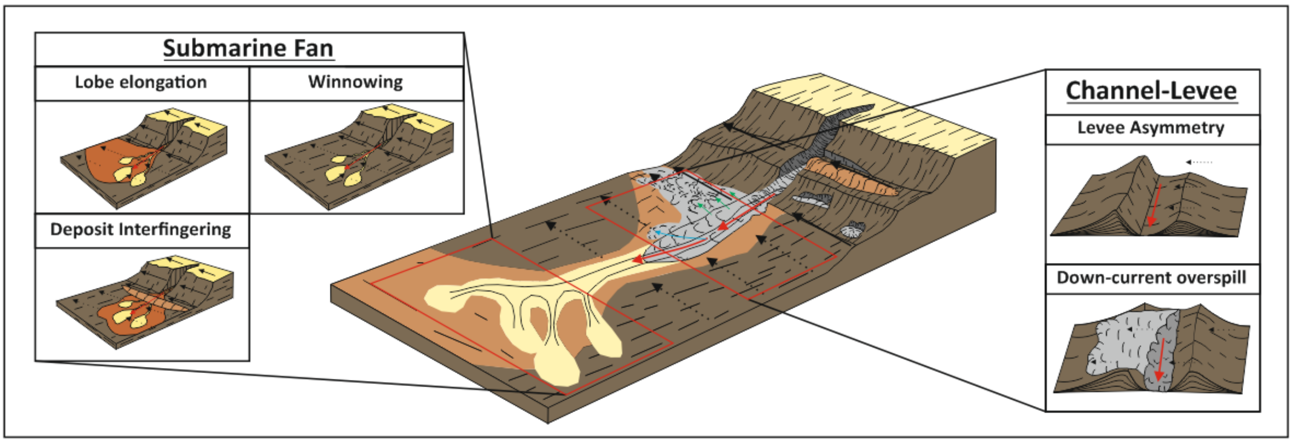

FIGURE 2. Conceptual diagram showing the various zones of process interaction across a turbidity system and examples of how geometries and sediments are affected. Red arrows = turbidity currents; black = along-slope currents; blue arrow = turbidity overspill; green arrow = along-slope induced overspill.

DISCUSSION

Building on the foundations laid by Mulder et al. (2008), we now propose a three stage model for turbidity systems: mixed-levee system; channel-levee system; and distal fan. The nature of interaction changes significant within these zones, though three typical styles of interaction have been recognised:

- **Morphological interactions**
- **Process interactions**
  - Synchronous
  - Interpolated

Morphological interactions focus on the positioning of the overall system. Typically, drifts form down-current from turbidity systems, with often large drifts forming perpendicular to the slope. Submarine channel orientation may also be loosely confined into troughs between slope-perpendicular drifts.

Process interactions aims to understand the resulting effects due to the synchronous (same time) and interpolated (between event) interactions.

Synchronous events are typically short-lived, due to the episodic nature of turbidites. They have the potential to trigger preferential deposition on one levee and remove fine-grained overspill, 'clean' channel fill deposits in proximal zones. In distal channel-levee systems, these are commonly not recognised.

Interpolated events are much more long-lived, occurring between two major turbidity events. While these may not affect the initial deposition of units, these may winnow or erode fine-grained sediments away from deposits, enhancing the net-to-gross sand ratio.

The dominance of synchronous events occurs based on the frequency and magnitude of the turbidity event. As a near-permanent entity, bottom currents will continuously rework the deposits. While these may introduce external sediments into the system, the quality is ultimately controlled by the turbidity system.

CONCLUSIONS

The frequency and magnitude of the turbidity system ultimately dictates the reservoir quality of a mixed-drift system. While morphological interactions may loosely control the geometries of deposits, process interaction offers the most substantial implications for deposit enhancement.

Synchronous events offer the most potential for reservoir enhancement, with the removal of fine-grained overspill in channel-levee systems, which will 'clean' channel-fill sediments and the subsequent flow. While interpolated interactions may subtly affect reservoir geometries, the quality of reworking is still ultimately dictated by the material in the turbidity systems.

These interactions are mainly recognised in proximal settings and change distally into typical channel-levee systems. From this, we propose a 'mixed-levee system' zone should be applied to proximal turbidites, where they host both turbidite and contourite characteristics.

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Down, across and along: sediment deposition and erosion on the glaciated southeast Greenland margin

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Abstract: *The Southeast Greenland continental shelf, slope and rise are subjected to along- and across-slope erosional and sedimentary processes. Turbidity currents flow through valley systems downslope and create large channel-levée sequences, orientated perpendicular to the slope. Meanwhile strong ocean currents sweep along the slope and rise and over the shelf, bringing in new sediments from other region, interacting with downslope sediment transport processes or eroding sediment. The different processes prevail at different depths and their imprint has changed over time. Climatic changes (glacial vs. interglacial times), but most likely also tectonic processes have a large effect on where and when which processes dominate.*

Key words: *Greenland, Irminger Sea, glaciated continental margin, bottom current, turbidity current.*

INTRODUCTION

The southeast Greenland continental margin represents an area where many different types of erosional and depositional processes interact. Sediment is transported from onshore to the deep basin in many different ways along many different paths, but it is also swiped into the Irminger basin by a lot of different ocean currents and icebergs (see Fig. 1). This area is characterised as a ´glaciated continental margin´ (Nielsen et al., 2005). Ice masses have directly (i.e. severe erosion and large-scale deposition) and indirectly (i.e. iceberg rafted detritus and meltwater plumes) played an important role in delivering sediment to the shelf and slope.

The continental margin is not morphologically uniform. The SE Greenland shelf dips landwards. It is up to 500km wide in the northern part, but it becomes remarkably narrower (45-55km) in the south. In the northern part there are two large shelf crossing troughs. Further to the south more, but smaller and narrower troughs are found. The slope morphology is strongly affected by powerful, southward flowing geostrophic bottom currents in combination with glacial-induced down-slope mass transport (Clausen, 1998; Rasmussen et al., 2003).

DATA & RESULTS

Seismic data collected since the 1970´s on the southeast Greenland shelf, slope and rise was brought together and re-evaluated. Along the entire SE Greenland slope there is a morphological step at ca. -1750m water depth which corresponds to a moat zone, with a large drift complex just south of it.

Clausen (1998) and Rasmussen et al. (2003) identified three main seismic sequences along the SE Greenland margin between 62 and 64°N. They are separated by unconformities of late Miocene, Early Pliocene and Mid Pliocene ages. The seismic facies of the two youngest sequences suggest a mixed deposition from both bottom currents and turbidity currents.

However, Clausen (1998) and Rasmussen et al. (2003) only focussed on a small area of the southern part of SE Greenland margin, where large channel-levée/drift sequences, almost perpendicular to the slope, are present. In the north, such structures are completely absent and further south they are less clear. This indicates that there is no one-size fits all story for this glaciated margin.

DISCUSSION & CONCLUSION

The morphological difference between the northern and southern part of the SE Greenland margin indicates a different evolution and domination of different sedimentary processes in time and space. A succession of multiple glacial-interglacial cycles has been central in determining which sedimentary process (downslope vs. alongslope) could dominate when and where.

The Greenland Ice Sheet itself has had an influence on the formation and location of the shelf troughs, which were most likely formed by ice streams and on the supply of sediment to the SE Greenland margin.

However, the ages of the unconformities separating the different seismic unit correspond well with periods of uplift in the area (Japsen et al., 2014). This age synchrony accentuates that we need to consider the interplay of several (e.g. climatic, oceanographic and tectonic) process drivers. The spreading evolution of the Reykjanes spreading ridge was crucial in changes in shape and depth of the Irminger Sea (Ehlers et al. 2013), impacting sediment accommodation space

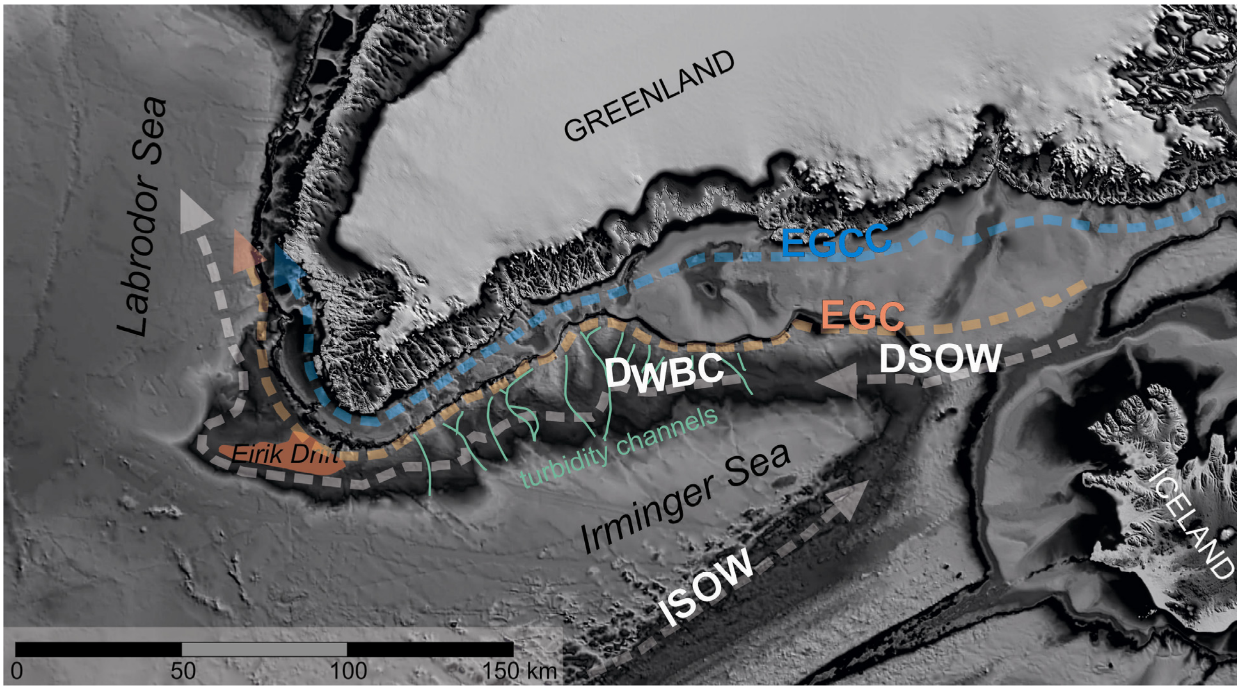

FIGURE 1: Extract of the International Bathymetric Chart of the Arctic Ocean (IBCAO) (Jakobsson et al., 2012) showing the southern tip of Greenland. The boundary currents sweeping along the slopes of the Irminger Sea are indicated with dashed lines: DWBC = Deep Western Boundary Current; EGC = East Greenland Current; EGCC = East Greenland Coastal Current; ISOW= Iceland Scotland Overflow Water; DSOW = Denmark Strait Overflow Water. Green lines indicate some of the turbidity channels that are present on the continental slope providing across slope erosion/sedimentation processes.

(more essential for the northern shelf) and ocean current formation and location. Differences in accommodation space were crucial in the northern (less space) and southern (more space) development of the SE Greenland shelf.

Linking the different seismic facies and drift sequences from the SE Greenland margin with the Eirik drift (Müller-Michaelis et al., 2013) emphasizes the importance of ocean current dynamics in the process of the sediment distribution and drift formation. Here we see a clear link between tectonic movements, the opening/closing of oceanic gateways and ocean current activity.

ACKNOWLEDGEMENTS

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Slope instability along a countorite-dominated margin in the Mediterranean Sea

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Abstract: *The South-Western Adriatic Margin (SWAM) has been imaged through multibeam bathymetry, sidescan sonar mosaics and high resolution chirp profiles. Geophysical investigations aims to recognize multiple slide scars and extensive mass transport complexes (MTCs) that are the results of widespread and recurrent sediment failure of contouritic drifts along the SWAM. Distinctive failures styles are mainly controlled by the source region and by the stratigraphic template of the margin. The interaction between contuor and cascading currents flowing across the SWAM plays an important role both in controlling the pre-failure depositional environment and in reshaping the morphology of the resultant MTCs.*

Key words: *Mass transport complex, Drift, Cascading current, Multibeam, Magnetic susceptibility,*

INTRODUCTION

The shelf and the slope of the South-Western Adriatic margin (SWAM) in the Mediterranean sea are swept by two main bottom-flowing water masses of thermohaline origin: the Levantine Intermediate Water (LIW), and the North Adriatic Dense Water (NAdDW) (Cushman-Roisin et al., 2001). The LIW is a steady-state, contour-parallel current that forms through evaporation in the Eastern Mediterranean and enters the Adriatic sea along a counter-clockwise path in a depth range of 200-600m. The seasonally modulated NAdDW (North Adriatic Dense Water), forms through winter cooling in the north Adriatic shelf and cascades obliquely across the SWAM slope (Cushman-Roisin et al., 2001).

Along the continental slope, the cascading NAdDW energetically interacts with the LIW, leading to locally-enhanced dynamic condition at the sea-floor (Verdicchio and Trincardi, 2006).

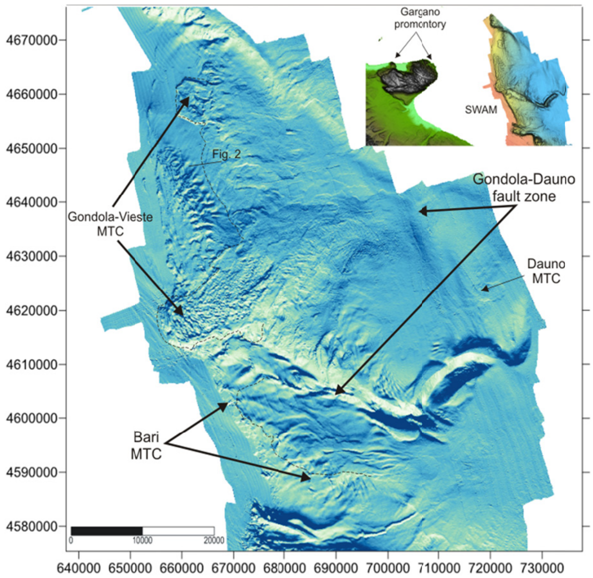

FIGURE 1. Shaded Relief image of the SWAM from DTM.

In the last 10 years, a series of geophysical surveys lead by ISMAR along the SWAM have imaged geomorfic features such as drifts and moats, sediment waves, barchans, furrows, and scours genetically linked to the action of the intermingled bottom currents (Verdicchio and Trincardi, 2006).

In addition, multibeam and high-resolution seismic surveys have revealed that the stratigraphic architecture of the SWAM is characterized by the presence of multiple and overlaying mass transport complexes (MTCs) encompassing most of the continental slope and the basin plain, between 400m and 1100m of depth (Minisini et al., 2006).

In this paper, the extensive available data set is used to address a geomorphological study of recent, mass-transport complexes (MTCs) linked to contourite failures. The analysis and interpretation of the variety of SWAM geomorphic features allows us to infer the source regions of the MTCs, their transport mechanisms and emplacement processes and thus offer the possibility to test the impact of different controlling factors on landslides ignition and evolution.

DATA AND RESULTS.

High resolution multibeam bathymetry data (Reson 8160) acquired by ISMAR-Bologna between 2003 and 2008, have been used to generate an highly-detailed Digital Terrain Model (DTM) with 20m of grid (Fig. 1). The acquired swath bathymetry data, coupled with Chirp-seismic data allowed us to image the elementary architectural elements of the SWAM margin. In particular, we focussed on the geometries of the contouritic features of the margin, in order to reconstruct the shape and the dimension of the MTCs linked to drift failures. The TOBI sidescan data were processed at the "National Oceanographic Center, Southampton". In addition, magnetic susceptibility signatures of selected sedimentary cores have been investigated and correlated in order to estimate the minimum age of the main failure events.

Around 60% of the mapped SWAM slope is dominated by MTCs that affects the downslope flank of the shelf-edge/upperslope contourite drifts. MTCs spans form the shelf-edge to the deep basin plain, and range from simple deposit affecting a single sediment drift, to composite geometries affecting also unit older than contouritic deposit.

In the northern sector of the SWAM is characterized by two composite MTC that cover an area of around 1700km^2 (The Vieste and Gondola MTC, Fig. 1). South of the Gondola-Dauno fault zone, a prominent tectonic lineament that dissect the slope of the SWAM, an around 880km^2 MTC affects the shelf-break and the continental slope (Bari MTC, Fig. 1). At 1100m of depth, in the basin plain, the Dauno MTC affect a deep-water drift. The Vieste and Gondola MTC display contiguous evacuation regions, covering a lenght of around 95km in a NS direction. In the northern sector of the SWAM, the headwall roots in the upper-slope and have a relief less than 50m. Moving southward, it indents also the shelf-edge forming an around 10km wide amphitheatre-like scar with a maximum height of 250m. The Vieste MTC is generally thin skinned, with thickness of the failed body that does not exceed 35m, whereas the Gondola MTC, especially in the sectors where the MTC is close to the structural highs, reaches thickness up to beyond the seismic penetration of the Chirp (~80m).

Where exposed, the Vieste-Gondola MTC is characterized by a broad area of high back-scatter and with reduced acoustic penetration and diffraction hyperbolae that corresponds with rotated blocks of coherent sediment shown in the bathymetry as 30m high elements. In the other sectors, both MTCs appear buried below a 25m thick layered sedimentary cover, that, however, gives a glimpse of the underlying MTC morphology. Where is free to spread, the Gondola MTC is characterized by a seismic facies made up of weakly reflective, chaotic seismic facies, emplaced parallel to the underlying stratigraphy. On the contrary, where it is confined by the SWAM pre-existing topography, it develops erosional ramps and pressure ridges.

The Bari MTC spans through the southern sector of the SWAM and is composed of vertical and lateral stacked MTDs originated by multiple failures of upper-slope conturitic drifts. Its deposits reach the deep basin plain, at 1100m of depth, with run out that exceed 60km. Also the Bari MTC is buried by a 25m thick sedimentary cover, and is made up of fully chaotic seismic facies, with a thickness that do not exceed 35m.

Duano MTC is a slope-detached MTC that affects a basinal, deep-water drift, giving rise to 12km^2, thin-skinned deposit. Seismic correlations show that the emplacement of the MTCs of the SWAM slope is, at the resolution of the Chirp profiles, contemporaneous. Magnetic susceptibility curves analysis of selected cores has permitted to estimate the age of emplacement of the MTCs at around 40ka, during the MIS3. In addition, in most sectors, the Vieste and Gondola MTC occurred on the same basal decollement layer, whereas in other ones there are remarkable differences in the depth of the weak layer.

DISCUSSIONS

We argue that the dimensions, the planform and the morphological variations of the different MTCs of the SWAM are strongly controlled by the pre-existing topography of the margin. In particular, we consider the topographic confinement resulting from the structural framework of tha SWAM as one of the major controlling factors on landslides direction, style of transport along the slope, and emplacement dynamics.

The other main controlling factor is represented by the contour currents dynamic that act across the SWAM. The oceanographic regime seems to have played a control on the areal extension and depth of the weak layers used by the landslides. Contour currents are important both in setting pre-conditions for failure and in determining volume and areal extension of slope failure. In addition, contour currents also modify the morphological expression of the product of the failures, giving rise to buried and exposed sectors across the same MTC, depending on the depositional or erosional attitude of bottom currents.

CONCLUSIONS

The SWAM oceanographic regime controls the stratigraphic template of the margin by controlling the areal extent of sediment drifts and by controlling the depth of the weak layers of the landslides.

The landslide of the SWAM form deposits that range form single-stacked body to multiple stacked, composite MTCs. The Vieste and the Gondola MTCs are the product of a large margin failure that rooted in the middle-slope and successively propagated upslope toward the outer-shelf around 40ka. The study documents the effect of significant confinement provided by the pre-existing topography onto the MTCs rooting, evolution and emplacement.

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Micropalaeontological Discrimination of Contourite and Turbidite Depositional Systems

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Abstract: *Unambiguous recognition of ancient contourites remains problematic on sedimentological grounds alone. Identification of clear, unambiguous and simple tools that could be applied to depositional systems on multiple scales from outcrop to drill stem cuttings would have major application in both academic and industrial research. Benthic foraminiferal micropalaeontology appears to offer such a tool. Comparison of similar materials from a turbidite system (El Buho canyon and fan, Tortonian, Tabernas Basin, Spain; EB) and a contourite system (Gulf of Cadiz Contourite, southwest of Iberia; GC) provides three key points of difference: 1) most medium and coarse sand deposits in EB are barren of tests, whereas barren samples GC are rare; 2) diversity is higher in muds than in silts in EB, but the opposite is true for GC; 3) EB taxa show a tendency towards opportunism, whereas GC taxa contain abundant filter-feeding specialists. Considerably more data is needed before these differences can be concluded to be general and diagnostic, but the potential for micropalaeontology to provide strong support for traditional sedimentological approaches is clear.*

Key words: *Micropalaentology, ancient contourite, palaeo-ecology.*

INTRODUCTION

The record of ancient contourites is very limited, primarily because no simple, unambiguous basis for their identification has been established. This is problematic for the study of the geological record of contourites, but also for analysis of ancient oceanic sedimentation and for industrial studies of ancient sand deposits on the slope, the origin of which remains ambiguous. New tools for distinguishing contourite and turbidite depositional systems therefore remain key to unlocking the unique potential of contourite depositional systems.

One major environmental difference between channelized systems originating from turbiditic and contouritic processes is the variance of bottom velocity. Whereas in contourite systems bottom velocity at single sites varies over millennial timescales e.g. (Toucanne et al., 2007), in a turbidite system the passage of a single gravity flow event results in energy changes over the timescale of hours to days (Anschutz et al., 2002). Consequently, the bottom ecology in contourite systems will be in equilibrium with the bottom energy throughout deposition (Schönfeld, 2002), whereas in a turbidite disequilibrium ecologies will arise subsequent to sand emplacements events (Rogerson et al., 2006). This raises the possibility of discriminating the resulting deposits using benthic microfossils such as foraminifera.

RESULTS

Comparison of two depositional systems of similar water depth (500-1500m) and latitude (~35°N) allows an initial investigation into the key points of difference between the benthic foraminiferal record of downslope-oriented channelized turbidite and contourite sequences. The channelized turbidite used here is the El Buho Canyon and Fan system (EBC; (Rogerson et al., 2006) of the Tortonian Tabernas Basin (SE Spain) and the contourite is the unusual downslope-oriented Gil Eanes Channel and Drift (GEC; (Rogerson et al., 2011) of late Quaternary-Holocene age in the Gulf of Cadiz (SE Spain).

Assemblages from both settings reveal more than one type of assemblage within deposits of the same age, depending on energy (i.e., grain size). On low-energy slopes, infaunal taxa dominate with high abundance of the epifaunal genus *Cibicidoides* (Table 1), indicating that background conditions in both settings are similar. Greater differences are found in sandy materials within the channels. Proximal sites in the GEC host a low density, low diversity assemblage dominated by elevated epibenthos such as *Cibicides lobatulus* (Schönfeld, 2002). In contrast, in the EBC all samples in the proximal canyon were found to be barren of all tests: it must be emphasised that mud-rich as well as non-muddy samples were inspected.

Sites within the channel axis from the GEC contain significantly more tests (>500 tests.g^{-1}) than similar deposits in the EBC (<150 tests.g^{-1}) and a different assemblage, dominated by either elevated epifauna such as *C. lobatulus* or taxa typical of much shallower water, such as the epiphyte *Planorbulina mediterranensis*.

Comparing muddy drift / fan settings, both settings display assemblages dominated by deposit feeding infauna, but the EBC assemblages contain more of the facultative anaerobe *Globobulima* spp.

Finally, the number of tests per gram are generally higher in the GEC.

Environment		Barren Samples %	Test density in tests.g^{-1}	Dominant Taxon
Proximal Channel	EBC	**100**	**0**	N/A
	GEC	14	117	***C. lobatulus***
Channel Axis	EBC	5	138	*Cibicidoides* spp.
	GEC	0	590	***P. mediterranensis***
Distal Channel	EBC	14	350	*C. laevigata*
	GEC	0	348	*C. laevigata*
Fan / Muddy Drift	EBC	5	500	***Globobulimina* spp**.
	GEC	0	488	*U. mediterranea*
Slope	EBC	0	450	*Cibicidoides* spp.
	GEC	0	10947	*C. dutemplei*

TABLE 1. Basic micropalaentological characteristics of similar environments in GEC and EBC. Highlighted text indicated potential diagnostic criteria.

DISCUSSION

The two systems show significant micropalaeontological differences, particularly in the higher energy environments. Below, we summarise the most important diagnostic criteria.

1) Barren or very low density assemblages in muddy, proximal turbidite settings

Whereas in the GEC, only one sample was found to be barren of benthic foraminifera not a single test was found in the proximal channel at EBC. Other samples in high-energy settings from the EBC show very low densities of ~10 tests per gram. This likely reflects exclusion of benthic fauna from the proximal channel due to disturbance, combined with export of tests during sand emplacement. Similar samples from the GEC are rarely barren, but contain an assemblage dominated by taxa adapted to living under strong bottom currents.

2) Abundant transported taxa in contourite channel sand.

Shallow-water taxa such as *P. mediterranensis* or *Elphidium* spp. occur in both systems, but only become common or even dominant taxa in GEC. Transported assemblages in GEC also vary down- channel, with heavier taxa (e.g. *E. crispum*) in [proximal settings and lighter taxa (e.g. *E. macellum*) in more distal settings. Experimental investigation into postmortem transportation of representative taxa confirms this pattern of spatial fractionation is reproducible and reflects the turbulent kinetic energy of the flow (Kelham et al., in prep).

The abundance of transported taxa on the GEC reflects sorting and concentration of these tests, which are supplied from the shelf alongside clastic sediment. The EBC does now show this concentration affect.

3) High organic matter deposition in proximal turbidite settings

The impact of transported refractory organic matter in turbidity-current dominated settings is well known (Fontanier et al., 2005), and in these settings high organic content can exclude all benthic taxa other tan facultative anaerobes. This is rare in GEC, which rarely become more eutrophic than indicated by *Uvigerina* spp. dominated assemblages. Recognition of these “anoxic pockets” in the distal channel and fan settings of turbidites is thus a useful diagnostic criterion.

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Benthic storms in the north-western Mediterranean continental rise caused by deep dense water formation

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Abstract: *The north-western Mediterranean Sea is a well-known region where dense water formation occurs on a yearly basis due to winter heat losses and evaporation caused by cold and dry northerly winds. Dense waters are formed offshore by open-sea convection, but also on coastal regions along the Gulf of Lions shelf, from where they overflow the shelf edge and cascade downslope until reaching their equilibrium depth. During severe winters, both convection and cascading can reach the basin (>2000m depth), increasing bottom currents and inducing sediment resuspension. To investigate in detail this process, a focused analysis of time series observations collected in the north-western Mediterranean continental rise during winter 2012 has been conducted. Several peaks of suspended sediment concentration coincident with enhanced current speeds were observed during the spreading phase of newly formed dense water. Maximum concentrations reached ~9mg/l while associated current increases ranged between 20 to 40cm.s^{-1}. Such sediment resuspension events can be considered "benthic storms" and play a major role in the redistribution of sediment particles along this region, presumably contributing to the development of a large field of muddy sediment waves found in the continental rise south from Cap de Creus and La Fonera submarine canyons.*

Key words: *dense water formation, resuspension, benthic storm, sediment waves, north-western Mediterranean.*

INTRODUCTION

Recent studies have evidenced that deep-water formation processes in the north-western Mediterranean can increase deep-sea bottom currents and induce active sediment resuspension on the basin seafloor (Martín et al., 2010; Puig et al., 2012; Stabholz et al., 2013). Such energetic events have been observd in deep-sea regions elsewhere, and based on the Hollister and McCave, (1984) definition, they can be categorized as "benthic storms". However, the exact mechanisms involved in the sediment resuspension and transport are not well elucidated, since these previous studies mainly rely on data collected with moored sediment traps.

Additionally, this region is characterized by a large field of muddy sediment waves that develops south from Cap de Creus and La Fonera submarine canyons (Fig. 1), which has been genetically related to the sediment transported by major (deep) dense shelf-water cascading events (Jallet and Giresse, 2005). This contribution aims to investigate in detail the sediment resuspension events during the "benthic storms" associated to major dense water formation episodes, and asses how the suspended sediments are redistributed along the north-western Mediterranean continental rise.

DATA

As part of the FOFA and PERSEUS projects, an instrumented mooring line was deployed at ~2450m depth (41° 38.9'N / 4° 11.4'E) from 15 October 2011 to 27 July 2012, over a field of sediment waves south of La Fonera canyon mouth (Fig. 1). The array included three levels of measurements (surface, mid-waters and near-bottom) including on each one a current meter and a sequential sediment trap. The near-bottom current meter was moored just 10 meters above the seafloor and included a turbidimeter and a high precision CTD probe. For the purpose of this contribution, only the data from this current meter, which collected data at 10 minutes sampling interval, will be presented. The turbidimeter measured in Formazine turbidity units (FTU) that were converted to suspended sediment concentrations (SSC) using the general equation from Guillén et al. (2000): SSC = 0.79FTU.

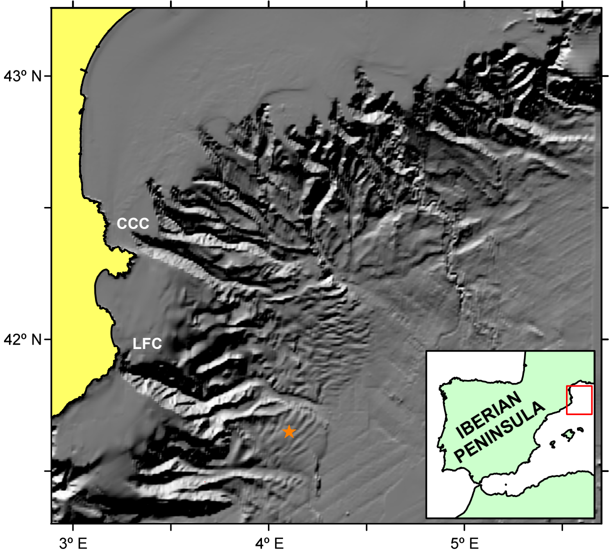

FIGURE 1. Shaded relieve map of the north-western Mediterranean continental margin showing the location of the instrumented mooring (star) and the field of sediment waves that develop on the continental rise. CCC: Cap de Creus Canyon; LFC: La Fonera Canyon.

RESULTS and DISCUSSION

During the first four months of the record, near-bottom potential temperature was quite constant (~12.9ºC), velocities were below 13cm.s^{-1} and SSC displayed constant background values ~0.1mg.l^{-1} with the exception of few isolated peaks <0.3mg.l^{-1} (Fig. 2). On 12 February 2012, current speed increased to values >30 cm/s and SSC peaked to ~1 mg/l for few hours. At the same day, temperature started to decrease gradually until a sharp drop of >0.4ºC, coincident with a second SSC peak ~1.5mg.l^{-1}, occurred four days later, on 16 February. The intrusion of such a cold water mass at the mooring site indicates the arrival to the basin of the signal from a major dense water cascading event that occurred during winter 2012. The fact that the near-bottom currents increased slightly before reflects the occurrence of a concurrent deep open-sea convention event that preceded the cascading process (see Durrieu de Madron et al., 2013 for further details).

After this first cascading outburst, near-bottom temperature, current speed and SSC progressively tended to recover previous values until a second drop in temperature (>0.3ºC) occurred on 25 February 2012. On this occasion, currents exceeded 40cm.s^{-1} and several SSC peaks ~9mg.l^{-1} were recorded (Fig. 2). These high concentrations contrast with previous observations in the same region that recorded SSC increases <6mg.l^{-1} during similar resuspension events linked to deep water formation processes, when cascading was less intense (Puig et al., 2012). Low temperature values persisted for more than a month and high current speeds lasted for almost four months, showing a fluctuating pattern of few days or weeks, presumably related to the passage of near-bottom eddies. During this period, SSC displayed several increases (>1mg.l^{-1}), not always coincident with maximum velocities, which denote the formation and maintenance of a bottom nepheloid layer that was being advected and redistributed along the rise and basin.

ACKNOWLEDGEMENTS

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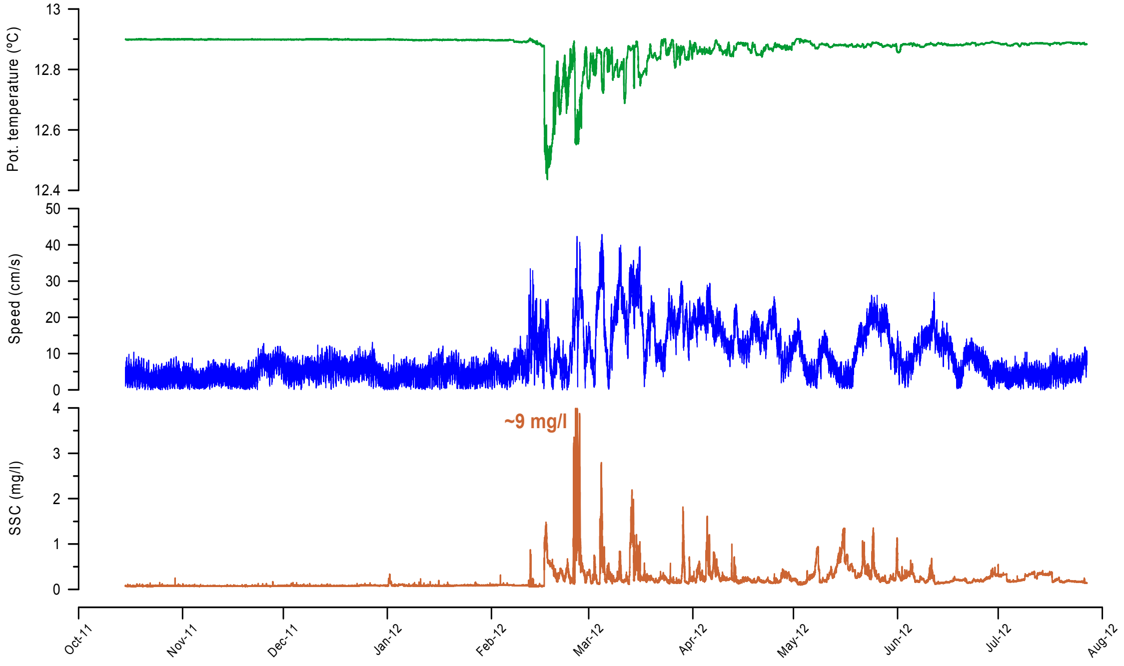

FIGURE 2. Time series of potential temperature, current speed and suspended sediment concentration (SSC) during the studied deployment.

Mediterranean Outflow Water changes in the Gulf of Cadiz during the Mid-Pleistocene Transition – The role of insolation

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Abstract: *This multi-proxy study of IODP Site U1387 (Faro Drift) aims to reconstruct the history of the surface water and the Mediterranean Outflow Water (MOW) during the interval from 630 to 1100ka, i.e. the Mid-Pleistocene Transition. Surface and MOW experienced orbital- and millennial-scale variations. MOW related proxies show a tight coupling to insolation with poor ventilation during insolation maxima and contourite layers being formed by a faster flowing MOW during insolation minima.*

Key words: *IODP Exp. 339, Site U1387, Mediterranean Outflow Water, Contourites, insolation*

INTRODUCTION

During the mid-Pleistocene transition (500-1250ka) the dominant pacing of glacial/ interglacial cycles changed from the 41ky obliquity to the 100ky eccentricity cycle. Superimposed on the orbital-scale changes are millennial-scale climate instabilities that in the mid-latitude Atlantic are related to insolation (e.g., Weirauch et al., 2008). In the Mediterranean Sea sapropel layers were formed during insolation maxima and the associated circulation changes in the basin also affected the chemical properties of the water exiting through the Strait of Gibraltar and forming the MOW (Fig. 2). MOW's paleoceanographic history in the Gulf of Cadiz was unknown prior to 100ka but this is changing now with the Plio-/Pleistocene contourite drift sequences retrieved during IODP Expedition 339 (Fig. 1). IODP Sites U1386 and U1387 were drilled into the Faro-Albufeira Drift, formed by the upper MOW core, and their mud-rich Pleistocene sediments contain numerous contourite layers related to MOW activity (Stow et al., 2013). The shipboard bio- and magnetostratigraphies of Site U1387 (36.8°N; 7.7°W; 559mbsl) point to an average sediment rate of 25cm.ky^{-1} during the Pleistocene (Stow et al., 2013).

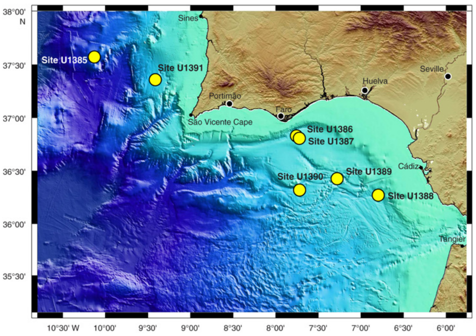

FIGURE 1. IODP Expedition 339 drilled seven Sites off the southwestern Iberian margin with records extending back into the Miocene (Stow et al., 2013).

MATERIAL AND METHODS

Paleoclimatic changes during Marine Isotope Stage (MIS) 16 to 32 (630-1100ka) at Site U1387 are being reconstructed using a multi-proxy approach with most records currently having a sample spacing of 24-25cm equal to having a temporal resolution of about 1 kyr (330yr for the XRF data). Bioturbation is of low intensity throughout the sequence (Stow et al., 2013) and not hampering the paleoclimatic interpretations. The stable isotope data of the planktonic foraminifer *G. bulloides* reflects surface water variations. The benthic (*Cibicidoides pachyderma*; *Planulina ariminensis*) stable isotope records reveal hydrographic conditions in the MOW. For splicing the data of these two species together the $\delta^{13}C$ data of *Planulina ariminensis* needs to be corrected by –0.3‰. No correction is currently applied to the $\delta^{18}O$ data. Changes in bottom current strength are inferred from the weight percent (wt%) of the sand fraction, the mean grain size of the bulk fraction <63µm and the XRF scanning-derived Zr/Al ratio (Bahr et al., submitted). The mean grain size and Zr/Al records mirror each other and reveal gradual grain-size increases that often precede the change in the wt% sand signal. In this region with potential sediment advection, as indicated by the C/N data, the Ti/Ca and Fe/Ca ratios cannot be interpreted as reflecting purely the contributions of terrestrial (Ti, Fe) versus marine (Ca) sediment components, even though the records mirror the carbonate content. XRF-derived element ratio records were essential in correcting the shipboard splice because during the course of the study it became obvious that some splice transitions needed to be adjusted – most by inserting sediment sections.

RESULTS AND DISCUSSION

Besides the glacial/ interglacial cycles both surface water and MOW records show millennial-scale stadial/

interstadial oscillations, in particular during the glacial inceptions (Fig. 2). Planktonic and benthic δ^{18}O records are correlated on the orbital and millennial-scale level highlighting the constant exchange (en-/detrainment) between the (sub)surface waters and the MOW. Ventilation in the upper MOW core varied significantly. Low benthic δ^{13}C values during deglacial and peak interglacial periods, coinciding with insolation maxima, reveal a poorly ventilated upper MOW core (Fig. 2) and point to a coupling between MOW ventilation and sapropel formation in the Mediterranean Sea. Better ventilation was recorded during glacial and stadial intervals, often in association with the formation of contourites. Current velocity related proxy records indicate contouritic layers occurring during interglacial and glacial periods (Fig. 2). During the warmer MIS contourite layers were not formed during the peak interglacial period, but during the stadial(s) marking the transition from the interglacial to the glacial stage. Contourites are often more pronounced during the warm than the cold (glacial) MIS but during both, contourite formation is occurring during northern hemisphere summer insolation minima (Fig. 2) revealing a direct link between upper MOW core velocity changes and cooler climate conditions.

CONCLUSIONS

The new U1387 records show that climate conditions were as variable during the early to mid Pleistocene as during the late Pleistocene. Changes in the upper MOW core are tightly coupled to summer insolation with poor ventilation occurring during insolation maxima and higher current velocity marking insolation minima. This insolation forcing reveals a close coupling between MOW and Mediterranean Sea climate conditions.

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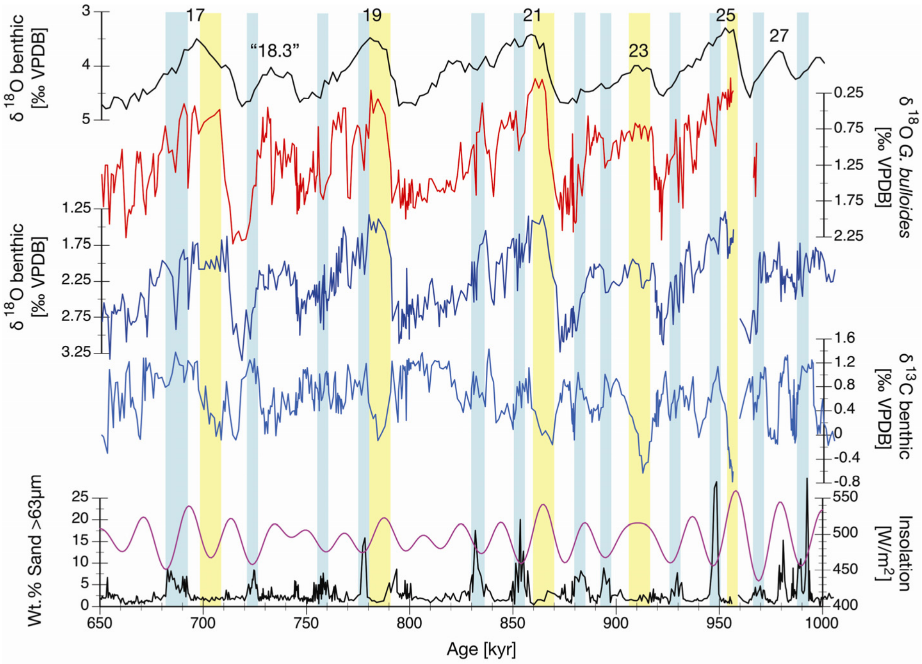

FIGURE 2. The Mid-Pleistocene Transition as recorded at IODP Site U1387. Panels show from top to bottom: benthic isotope stack LR04 of Lisiecki and Raymo (2005); planktonic foraminifer δ^{18}O record for U1387, benthic foraminifer δ^{18}O and δ^{13}C records and at the bottom the weight-% of the sand fraction >63µm and the insolation for June 21st at 65°N. Yellow bars mark periods of poor ventilation in the upper MOW core, blue bars some of the contouritic layers. Numbers in the top panel denote Marine Isotope Stages.

High-energy contourite settings related to North Atlantic Deep Water flow

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Abstract: *North Atlantic deep convection in the Greenland Sea region and Labrador - Irminger Sea basins leads to strong bottom current activity associated with Greenland-Scotland Ridge (GSR) overflow and deep western boundary current circulation. Seismic records and other evidence (e.g. side scan sonar) document strong bottom current action on the seabed in relation to the Nordic Seas overflow pathway from the Faroe-Shetland gateway via the Southern Greenland margin towards Davis Strait. Seabed evidence from the Greater Antilles Outer Ridge north of Puerto Rico demonstrates strong boundary current activity still persisting far south at western North Atlantic lower latitudes. Geomorphological response to this high-energy bottom boundary current regime is expressed in a variety of dynamic bedforms ranging from mega-scale contourites via well-defined sediment waves, sand ribbons and erosional furrows to small-scale ripple marks. Boundary current activity may interact with other seabed shaping processes as, for instance, downslope mass flow and turbidity currents. Combining known relationships between various bedform types and bottom water dynamics with results from actual current measurements and sediment core studies demonstrate important variations in this flow pattern having had a significant impact on contourite development through time.*

Key words: *Contourite, North Atlantic, Greenland-Scotland Ridge Overflow, North Atlantic Deep Water, bottom current activity.*

INTRODUCTION

Ocean deep convection has a major impact on the environmental conditions and ventilation of the deep ocean basins. In the northern North Atlantic deep convection occurs in the Nordic Seas and Labrador-Irminger Sea basin, from where North Atlantic Deep Water (NADW, Fig. 1) strongly concentrated in the high-energy Deep Western Boundary Undercurrent (DWBU) flows south along the North American continental slope (Dickson and Brown, 1994). Deep convection and associated bottom water flow have, however, been found to display significant variations, both at inter-decadal and at geological time scale (Sy et al., 1997; Kuijpers et al., 2003), with several studies showing a negative correlation between deep convection activity in the Nordic Seas north of the Greenland-Scotland Ridge (GSR) and processes in the Labrador Sea region. Significant deep-water transport from the Nordic Seas via the main GSR gateways, i.e. the Faroe-Shetland Channel system and Denmark Strait, into the North Atlantic Basin has been found responsible for the formation of most of the North Atlantic sediment drifts (Wold, 1994). Many studies have documented climatic control of these overflow processes having been significantly reduced or virtually ceased during glacial climate conditions (Kuijpers et al., 1998).

DATA AND RESULTS

Both seismic and acoustic data as well as sediment core records and seafloor photographs have been used to document seabed morphological and depositional response to cold water, high-energy bottom currents associated with GSR overflow and Labrador Sea Water formation on a transect from the GSR region towards the northern Caribbean. Within this framework detailed attention is given to the Faroe-Shetland gateway, both the southeast and southwest Greenland margin, and to the Greater Antilles Outer Ridge, north of the Caribbean. The data correspondingly show evidence of intense bottom current action along the entire transect under recent, i.e. interglacial, climate conditions. Intermittent, maximum near-bottom current speed inferred from current-induced bedforms exceeds 0.5 $m.s^{-1}$, and may locally reach 1.0 $m.s^{-1}$ or even more (Kuijpers et al., 2002; Kuijpers et al., 2003). The latter maxima particularly apply to the Faroe region and SE Greenland margin. Sediment core evidence from these areas correspondingly indicates a significant reduction in flow speed under full glacial climate, but an interesting difference in overflow activity when focusing on the Younger Dryas. In contrast to the contourite deposits from the Faroe region, contourite development on the SE Greenland margin displays many large-scale features revealing interaction with downslope processes that appear to have been particularly active in relation to glaciations. In contrast, the contourite setting from the SW Greenland margin (Nielsen et al., 2011) shows a more simple alternation of depositional stages characterized by either downslope sediment transport processes (e.g. glacial debris flows, Nielsen and Kuijpers, 2013) or along-slope current transport. Significant long-distance sediment transport associated within the DWBU and associated high bottom current speed is further confirmed by seabed photographs and composition of sediments collected from the Greater Antilles Outer Ridge in the deep, southwestern North Atlantic basin (Kuijpers and Duin, 1986).

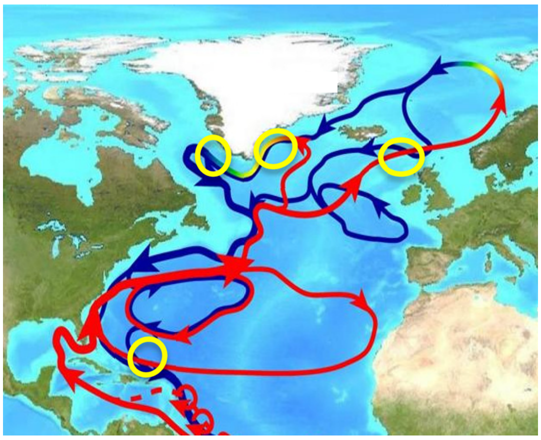

FIGURE 1. Study areas (yellow) with North Atlantic thermohaline circulation pattern. Red and blue arrow lines indicate warm surface and cold bottom water currents, respectively (from NOAA).

DISCUSSION AND CONCLUSION

Significant differences in glacial-interglacial deep water formation and transport patterns have been found, which implies a marked periodicity in the development of North Atlantic contourite systems within the NADW realm. Continental sediment input to the continental slope, rise and adjacent basin is dominated by glacially controlled processes which involve mass wasting, debris flows, turbidity currents and other modes of downslope sediment transport. Re-activation of deep-water formation and associated deep water current activity in course of subsequent deglaciation leads to remobilisation of the previously deposited sediments and thus contributes to the further, intermittent, development of the existing contourite systems. This is, amongst others, also evident from the sedimentary record from the Greater Antilles Outer Ridge, which shows (late) glacial, higher-latitude pollen and turbiditic mineral assemblages initially derived from the North American continent through turbidity flows much further north. If the along-slope processes would be simultaneous with significant downslope processes, instead of a relatively simple, stratified contourite pattern (e.g. Faroe Islands, SW Greenland), a morphologically more complex system may develop. In fact, this is what is observed on the SE Greenland margin (Rasmussen et al. 2003). Several studies indeed do indicate continuation of deep water convection (‘Glacial North Atlantic Deep Water’) south of the GSR during glaciation, which apparently also applies to the Younger Dryas (Kuijpers et al. 2003). We therefore conclude that contourite development in the western part of the Irminger basin, and possibly to some extent also bottom-current controlled deposition on Eirik Drift south of Greenland, may have been more continuous and persistent than in other areas farther away from the Irminger Sea Basin. In these other areas, a distinct shift occurred between along-slope and down-slope transport and depositional regimes. Maximum near-bottom current speed inferred from dynamic bedforms in respective areas in combination with information from long-term current meter arrays confirm variations in GSR overflow intensity and NADW bottom current speed, also under present climate conditions.

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Short-term sediment dynamics on a contourite body (off NW Iberia), Part I: Rapid changes of bottom-flow intensity during the past 50ka deduced from a sediment-core transect

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Abstract: *The sediment dynamics in a confined contourite system off NW Spain are reconstructed using high-res bathymetric mapping, seismic profiling, and sediment core transect. This depocenter and its 150m deep moat surround an 800m high obstacle. Since mid-Eocene, a pre-drift unit and two current-controlled contouritic units have formed. Fine-grained (10µm) basinwide current-influenced deposition was episodically interrupted by short-lasting high-energy conditions during MIS-3. High glacial and later Holocene periods show markedly calm conditions. The deglacial/early Holocene interval shows, in contrast, a pronounced increase in bottom-flow energy (70µm) with a waxing-and-waning dynamic from 17 to 5 cal ka BP. Process-based simulation demonstrates that not a water-mass core or boundary distributed those sands. Instead, pulse-like hydrographic fronts travelling inside the mixing zone of two water masses led to sand mobilization. Compared to paleoceanographic reconstructions, the downward-upward migrating MOW/LSW mixing zone is suggested as driving mechanism. A conceptional model shows how seafloor obstacles redirect and perturbate bottom flows with the special effect of oceanographic-front pulses occurring in the mixing zone. Front-driven secondary eddies on the contourite body itself provide an efficient mechanism for widespread sediment re-distribution.*

Key words: *Ocean bottom currents, current-obstacle interaction, Eastern Atlantic, Late Quaternary.*

INTRODUCTION

The formation of bottom-current induced (i.e. contouritic) depocenters is still a matter of debate with regard to the detailed hydrographic control on the sedimentation processes. This study uses a multi-disciplinary approach to investigate the hydro- and sediment dynamics in a comparably small-sized contourite system by using high-resolution bathymetric data, 2D reflection seismic profiling, sediment-core analyses along a transect, and numerical modelling of ocean-current processes.

DATA AND RESULTS

A classically shaped 150m high contourite body off NW Spain surrounds a pronounced 800m high structural obstacle at the toe of the continental slope, separated from each other by a 1.5km wide moat (Fig. 1). Seismic profiles indicate that the basal sedimentary unit overlying the acoustic basement represents normal hemipelagic basin fill, without evidence for current control (Fig. 2). In contrast, the following two sedimentary units show a mounded climbing-upward geometry in association with a successively filled palaeo-moat.

The sediment cores across this contourite body illustrate that MIS-3 was characterized by a rhythmic swap between calm and high-energy conditions, and MIS-2 and the later Holocene were oceanographically quiet

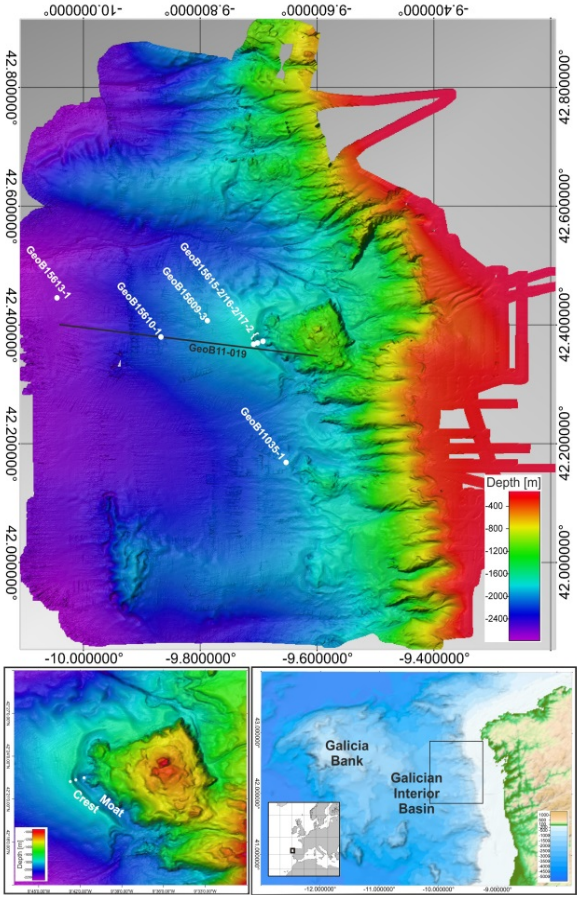

FIGURE 1: Bathymetric map of the study area.

intervals. Most notably is the deglacial to early Holocene time interval, nevertheless; with an episode of remarkable bottom-current intensification rapidly waxing-and-waning dynamics were sensitively recorded across the core transect (Fig. 3).

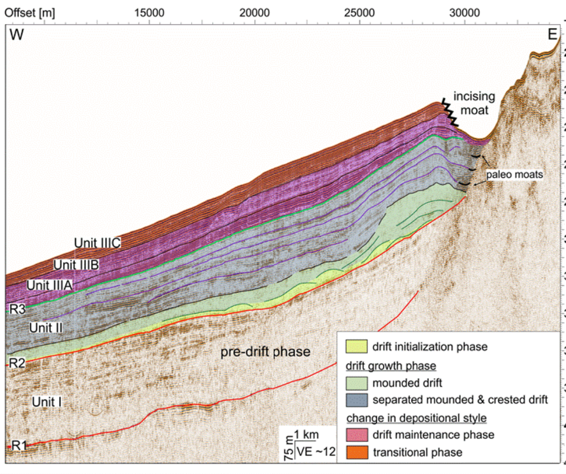

FIGURE 2: Seismic profile across the contourite body.

A 3-D process-based sediment-transport model is applied based on different scenarios in which the two major water masses (MOW and LSW) potentially responsible for sediment dynamics on the contourite body are regulated, mimicking the modern and paleo-oceanographic conditions. Simulation results exclude a water-mass core as force driving an evolution of the system. It clearly indicates, instead, that pulse-like appearing fronts within the approximately 300m thick water-mass mixing zone have the potential to remobilize and distribute fine sands. These fronts cause local bottom currents inside the moat as well as km-scaled eddies on the gentle seaward-directed contourite flank. Such migrating fronts are well known as common elements in the modern hydrographic system, but appear on the steep and bare-of-sediments middle slope off Galicia at present (Fig. 4). Thus, the resulting sandy contouritic sediment record is not mainly controlled by a net increase in front energy within this mixing zone but by the temporary climate-related deepening of this zone of about 300m.

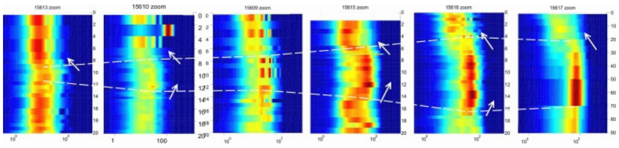

FIGURE 3: Grain-size distribution during the period 20-0 cal ka BP illustrating the offshore gradients as well as duration of the coarsening during the deglacial/early Holocene interval.

The comparison with existing palaeoceanographic data suggests that fine-grained deposition on the contourite body was driven by the Labrador Sea Water (LSW) over major parts of the past 50ka. A short-lasting increase in bottom velocity during Dansgard-Oeschger intervals (Völker et al., 2006) can be observed throughout the basin. The most remarkable interval of sediment transport intensification occurred during the last deglacial to early Holocene times. With the general, climate-driven decrease in salinity leading to a weakening of the lower Mediterranean Outflow Water (MOW) core in the outflow region (the Gulf of Cadiz), the upper MOW core has presumably strengthened and due to an increase in its salinity, temporarily (17-5ka) deepened by the identified 300m in the study area (Schönfeld and Zahn, 2000).

CONCLUSIONS

This study refines the concept how medium-sized seafloor obstacles redirect and perturbate bottom currents on local scale. Sharply defined water-mass boundaries are not necessarily the hydrographic elements to provide high-energy conditions but, instead, a rather transitional zone between two water masses might provide a powerful bottom-flow and, thus, sediment transport regime. The well-sorted sands seem to originate from the moat itself, instead of being delivered from a remote source and transported over long distances. The migrating eddy system on the contourite body itself provides an efficient mechanism to distribute these sediments in suspension equally over the area.

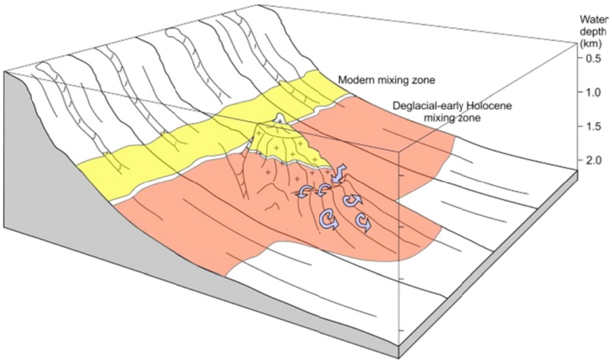

FIGURE 4: Conceptional scheme comparing the modern (yellow) and deglacial/early Holocene (orange) LSW/MOW mixing zones. Whilst the modern mixing zone interacts with the middle slope and the top of the obstacle (possibly producing morphological/erosional terraces), the 300m lower palaeo-mixing zone with its hydrographic fronts and associated eddies had strong impact on the contouritic system sedimentation.

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Short-term sediment dynamics on a contourite body (off NW Iberia), Part II: The impact of hydrographic fronts as deduced from numerical modelling

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Abstract: *A 3-Dimensional process-based morphodynamic model is applied to simulate deep-sea current – topography interaction and sediment dynamics on a contourite body located between 1,700 and 2,200m modern water depth at the NW Iberian continental slope. Different oceanographic scenarios were designed to investigate the impact of mixing between the Mediterranean Outflow Water (MOW) and its underlying water mass (Labrador Sea Water) on the morphogenesis of the contourite body. The simulated short-term sediment dynamics and bed-level elevation changes induced by density-anomaly induced oceanographic fronts provide a reasonable explanation on the grain-size distribution pattern derived from a sediment-core transect across this body. Based on this good agreement, we hypothesized that local-scale strong gravity-driven oceanographic fronts, generated by density disturbances in the mixing zone between two water masses, might play a significant role in the long-term morphogenesis of a contourite system.*

Key words: *process-based modelling, mixing, density front, moat erosion, eddy.*

INTRODUCTION

Contourite drifts are medium- to large-scale sedimentary units generated by contour-parallel sediment transport and deposition (Heezen et al., 1966). Rapidly growing knowledge during the past two decades has strengthened our knowledge on possible driving mechanisms for morphogenesis of these sedimentary systems. However, comprehensive studies combining seismic and sediment-core data sets across an entire contourite body with a process-based simulating approach are still extremely sparse. This triggered our motivation for the study presented here.

METHOD AND RESULTS

Short-term sediment dynamics and current-topography interaction on a contourite body located between 1,700 and 2,200m water depth off the NW Iberian continental slope (Fig. 1) are simulated by a 3-Dimensional hybrid morphodynamic model (Zhang et al., 2014). The model applied to the research area consists of 5 major modules which calculate the processes of interest at different temporal and spatial scales (Hanebuth et al., subm.). Two types of fine sediments (i.e. cohesive, non-cohesive) are distinguished in the calculation according to the fraction of clay component by a threshold value of 10%. Simulations are carried out in a nested grid system. A rectilinear regional grid (Fig. 1, left panel) with a spatial resolution of 4 × 4km is used to provide open boundary conditions (tidal constituents and flow flux) for a local grid (Fig. 1, bottom right panel) covering the contourite drift with a maximum spatial resolution of ~150 × 150m. After a removal of a surface sediment layer (15cm) on the contourite body which is recognized from the sediment cores as late Holocene hemipelagic deposit, a map of the underlying sediments' grain-size is used as model input to calculate sediment transport. Two scenarios are designed in the local model to investigate the impacts of mixing between the Mediterranean Outflow Water (MOW) and its underlying water mass (Labrador Sea Water) on the morphogenesis of the sedimentary system.

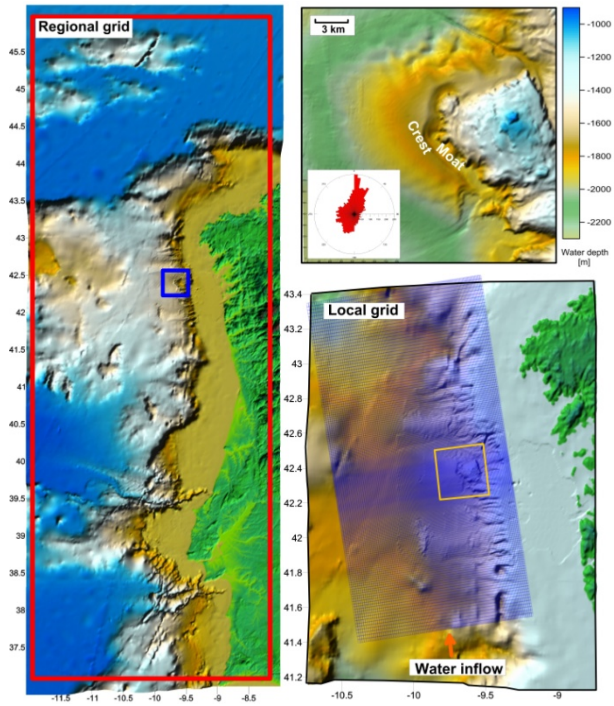

FIGURE 1. Location of the contourite body and computational grids used in the numerical model. A current rose (upper right panel) derived from the MORENA mooring program (1993-1994) indicates a predominant northward flow component at 2,000m in the study area.

The first scenario is based on the modern oceanographic setting in which the mixing zone is located far above the contourite body. Simulation results indicate that the seabed surface flow is relatively calm and stable, with only minor changes during the pass of a regional surface storm. Current speeds are persistently below 20cm.s^{-1} on top of the contourite body which is too weak to induce detectable sediment re-suspension. This simulation result matches the oceanographic MORENA mooring data (Fiuza et al., 1998) covering the period 1993-1994 as well as the uni-modal grain-size composition of the Late Holocene-to-modern surface sediments on the contourite system.

The second scenario assumes a 300-m deeper relocation of MOW which places the most dynamic parts of the contourite system (i.e. moat and crest) into the range of the mixing zone. As the mixing between two water masses leads to highly dynamic and unstable conditions, any disturbance on the physical properties (salinity, temperature) may result in a strong response of flow pattern which might affect the sediment dynamics.

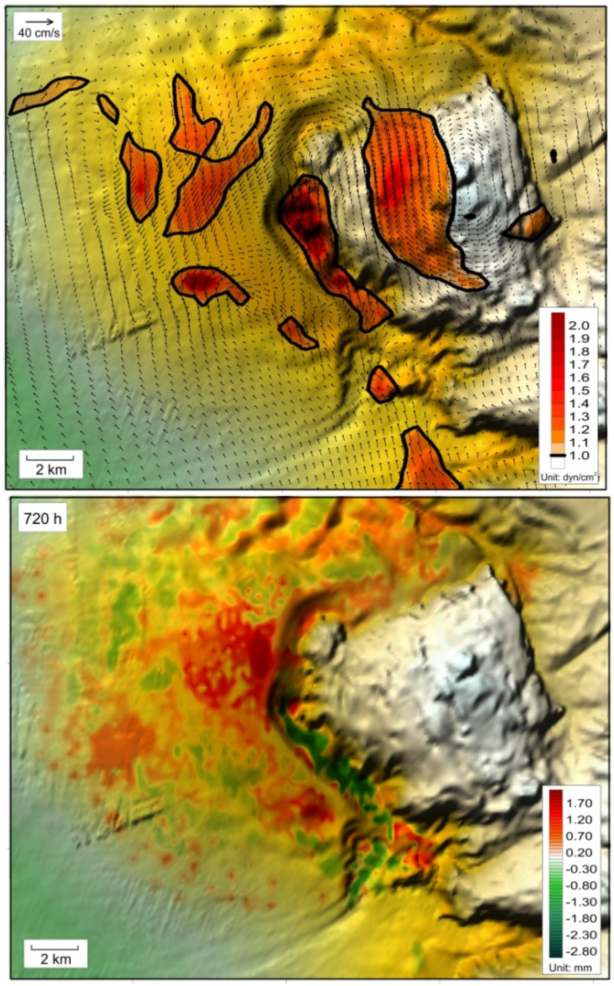

FIGURE 2. Top: Simulated horizontal bottom-current velocity field (plotted every three grid cells in both x and y directions) and corresponding bed shear stress during a northward march of the density front. The critical shear stress (1dyn.cm^{-2}) for re-suspension of surface sediment is marked by black line. Bottom: Simulated bed-level change (positive value for deposition and negative for erosion) induced by such an event.

Our simulation results indicate that, rather than a continuous mode imposed by quasi-stable water-column stratification, episodic strong fronts induced by density anomalies in the mixing zone are the major driving force for sediment remobilization inside the moat. Density anomalies in the mixing zone can be generated by internal-wave trains and benthic storms which result in denser-water intrusion into the moat through the channel in its southern entrance. Due to a topographic constraint by the moat, this density front flow is further strengthened and remains active for a considerably long period (e.g. several days) inside the moat to erode and transport sediment towards the north, until those are being lifted up along the moat's outer flank. Strong mixing and interaction between the density front and the surrounding water at the contourite crest cause high turbulence energy dissipation and result in a weakened flow, which is no longer able to entrain the full load of suspended sediment originated from the moat. Parts of the suspended sediment settle down on the crest as a result. The interaction between the density front and the background water is a dynamic process as the front continuously migrates northward. Further redistribution of sediments on the contourite body itself is driven by medium-scale eddies with extent from 1 to 5km which are produced by the passing front.

CONCLUSION

The simulated sediment dynamics and bed-level elevation changes induced by density-anomaly induced fronts provide a reasonable explanation on the grain-size distribution pattern derived from a sediment core transect. Based on this good agreement, we hypothesized that local-scale strong gravity-driven oceanographic fronts, generated by density disturbances in the mixing zone between two water masses, play a significant role in the morphogenesis of a sedimentary contourite system. The vertical migration of a mixing zone, controlled by long-term climate changes, induces an alternation of the system between two modes, one of calm and one of high-energy oceanographic conditions, which are well reflected in the sediment cores.

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High-resolution structure of the upper Western Boundary Undercurrent core shaping the Eirik Drift

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***Abstract**: For the first time the method of seismic oceanography was applied to identify fine structure of a water mass in greater depths (> 1500m) close to the seafloor. The pathway of the upper high-velocity Western Boundary Undercurrent (WBUC) branch was tracked over the Eirik Drift, 200km south of Greenland at seafloor depths between ~2200 and 3000m. It appears as an upward convex structure attached to the slope with a transparent, i.e. well mixed, core surrounded by higher amplitude reflections. These reflect gradients and fine structure. Fine structure is a result of enhanced mixing processes, presumably due to entrainment of surrounding water of less momentum by the intensified deep current core. We show that this new information about structure and pathways of the WBUC could not have been gained by conventional oceanographic measurements alone.*

***Key words:** Western Boundary Undercurrent (WBUC), seismic oceanography, Eirik Drift, Thermohaline Circulation, Labrador Sea.*

INTRODUCTION/BACKGROUND

The North Atlantic Western Boundary Undercurrent (WBUC; also referred to as Deep Western Boundary Current (DWBC)) is a deep (~1900-3000m), equator ward contour current along the western continental slope. It represents the main component of the deep branch of the North Atlantic Thermohaline Circulation (THC) (e.g., Dickson and Brown, 1994; Stanford et al., 2011). The WBUC (location, intensity) is believed to be an important indicator for climate changes, and since the Eirik Drift is located closely downstream of the WBUC formation region it appears as a well-suited location to detect changes in the complex WBUC system.

We analyzed high-resolution seismic reflection data along with discrete CTD stations aiming for the first seismic oceanography study of deep-water circulation in water depths > 1500m. This study will show that tracking the high-velocity core of the WBUC at the Eirik Drift and imaging its pathway, morphology and structure in a high lateral resolution by using seismic data represents an important supplement for the conventional, discrete oceanographic measurements.

DATA AND RESULTS

During RV Maria S. Merian cruise MSM12/2 in 2009, ~2000km of high-resolution multichannel seismic reflection data were collected at the Eirik Drift. Eight CTD casts were conducted during MSM12/2 cruise and we used a CTD cross-section at the entrance of the Labrador Sea of the following cruise MSM12/3 (CTDs 8-12; by courtesy of Rhein (2011)), which lies east of our study area (Fig. 1).

The temperature-depth profiles of the CTDs in the pathway of the upper WBUC core (MSM12/2 #4, #5, #7; Fig. 1) show a similar pattern: A homogenous bottom layer (T ~2°C) of different thickness is observed. Above the gradient a section of fine structure is observed, which extends up to ~2000m, where pronounced intrusions mark the top of the section of enhanced T variability. The T profiles then continue upward to 1500m depth with an almost linear increase. The sections of strong T gradients and fine structure of the CTD casts are reflected in the synthetic seismograms as sections of enhanced reflectivity.

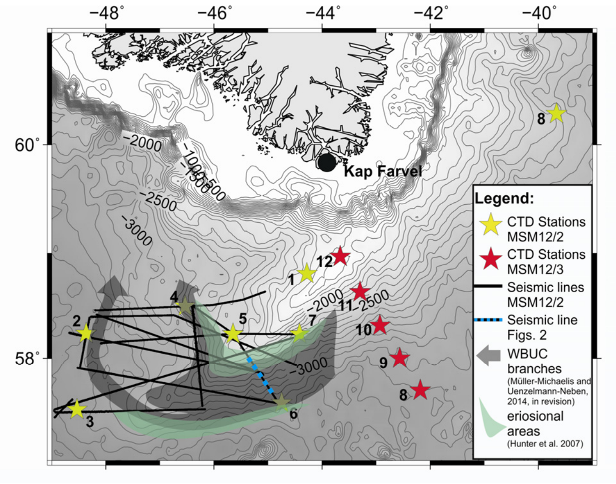

FIGURE 1. Satellite bathymetric map including the locations of the seismic lines and CTD stations. The seismic section shown in FIGURE 2 is indicated by the blue dotted line.

In our seismic data we observe an upward convex band of higher reflectivity attached to the slope of the Eirik Drift. The higher reflectivity band domes up from the seafloor and the reflections diverge at the center of the structure (Fig. 2). The area enclosed by this reflections and the seafloor appears rather transparent (Fig. 2). The transparent interior of the structure correlates with the non-reflective mixed layer of the synthetic seismograms of the CTD stations (Fig. 2). The high reflections of the synthetic seismograms resulting from thermohaline fine structure correlate with the high reflection band in the seismic profile (Fig. 2). Thus, we assume that this structure is the upper core of the WBUC with its mixed interior surrounded by higher reflections representing fine structure due to mixing processes as suggested by the CTD data.

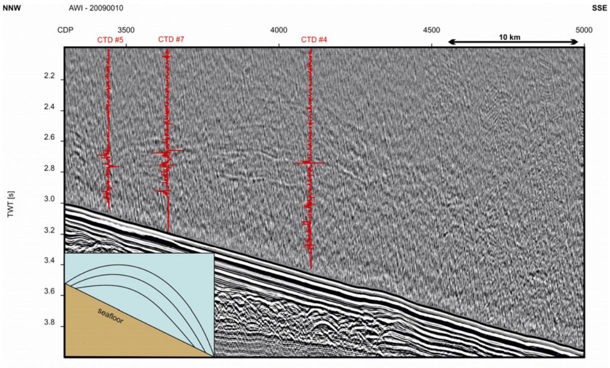

FIGURE 2. Seismic line AWI-20090010. The synthetic seismograms calculated out of CTD MSM12/2 #4, #5, and #7 are inserted according to their water depths of each CTD cast. Please note that these are not the true but projected locations of the MSM 12/2 CTD casts. The box in the lower left corner depicts a schematic sketch of the structure observed in the seismic data at the SE flank of the Eirik Drift.

DISCUSSION

The WBUC core described above is attached to the slopes of the main Eirik Drift at seafloor depths between 3.0 and 3.8s TWT at the SE flank of the Eirik Drift (Fig. 2) and at seafloor depths between 3.1 and 4.15s TWT at the NW flank. The observed downslope shift of the WBUC core from the SE to the NW flank of ~200m may result from an increased sediment load carried by the WBUC core at the NW flank due to enhanced erosion at the SE flank. Also the bathymetric structure may be responsible for this shift. The thickness of the WBUC core is about ~800m at the SE flank and ~600m at the NW flank and its domed structure is found flattened at the NW flank. Also the lateral extent of the structure changes from ~35km at the SE flank of the Eirik Drift to 70-90km at the NW flank. The observed structural changes at the downstream and upstream flanks of the drift go along with a strong change in the slope of the flanks. The SE flank of the Eirik Drift shows an almost homogenous dip of ~1.3° from 2000 to 3500m depth. The NE flank, however, has a steep upper part (slope ~1.3-1.5°) and continues almost horizontally to the west (slope < 0.3°). We can therefore conclude that the change in topography over the drift influences the shape of the WBUC core. It appears concentrated and domed at the homogenous, steep slope at the SE flank and broadens, flattens and maybe also deepens at the NW flank due to the influence of an almost horizontal part of the slope.

The observed pathway of the upper WBUC core over the drift is in good agreement with that suggested by Müller-Michaelis and Uenzelmann-Neben (2014) for the time period < 800000 years based on a subsurface seismic study. The structure of a concentrated WBUC core attached to the slope of the flank as observed in the seismic data cannot be observed in the MSM12/3 CTD section at the entrance of the Labrador Sea (Fig. 1). We can state that discrete CTD stations alone are not sufficient to resolve the structure of the upper WBUC core.

CONCLUSIONS

We were able to identify and track the upper core of the WBUC via the combination of CTD and seismic reflection data. It appears as a concentrated transparent seismic feature with a high reflectivity surrounding attached to the slope of the Eirik Drift at seafloor depths between 2200 and 3000m. Its lateral and vertical extent changes with the dip of the seafloor slope from a concentrated domed core (35km broad and 800m thick) at the steep, homogenous SE drift flank to the flattened, broader core (70-90km broad and 600m thick) at the NW drift flank, where the slope changed significantly and provides an almost horizontal part (< 3° steep). The pathway of the upper WBUC core suggested by Müller-Michaelis and Uenzelmann-Neben (2014) for the period < 800000 years was confirmed by our observations. For the first time the seismic oceanography method was successfully applied to depths > 1500m, but seems restricted in depths > 3000m. This study revealed that seismic oceanography provides an important supplement to conventional oceanographic measurements, as the small-scale structures of the deep-water masses cannot always be resolved properly by discrete CTD measurements due to their large distance.

ACKNOWLEDGEMENTS

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Contourite Terraces in the Middle-Slope of the Northern Scotia Sea and Southern Atlantic Ocean: Palaeoceanographic Implications

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Abstract: *The morphology of the continental margin off Tierra del Fuego is highly influenced by the presence of middle-slope contourite terraces. This area is dominated by the relatively strong flow associated to the northern Antarctic Circumpolar Current, with the North Scotia Ridge acting as an important morphological barrier. The flow includes portions of Upper Circumpolar Deep Water and recently formed Antarctic Intermediate Water that later flows northward reaching the Northern Hemisphere. The depth of the boundary between these water masses coincides with the regional occurrence of the terraces. Similar terraces have also been identified along the Argentine and Uruguayan margins, representing a major morphologic element in the South Atlantic Ocean with important oceanographic and palaeoceanographic implications.*

Key words: *Contourite Terraces, Antarctic Intermediate Water, Scotia Sea, Malvinas/Falkland Through, Morpho-stratigraphic analysis.*

INTRODUCTION

Conceptually, a terrace is "an isolated relatively flat horizontal or gently seaward inclined surface which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side". The contourite terraces have been genetically related to water mass interfaces (Preu et al., 2013). Although terraces have been globally identified (e.g. Harris et al., 2014) few studies have focussed in the contourite terraces and their oceanographic implications (e.g. Hernández-Molina et al., 2009; Preu et al., 2013). Several terraces are identified in the present work in the Scotia Sea-Atlantic Ocean transition through morpho-stratigraphic analysis based on single- and multi-channel seismic (SCS and MCS) surveys (Fig. 1A). The observation and implied genesis of these terraces suggest previously unknown oceanographic and palaeoceanographic processes of global relevance.

GEOLOGICAL SETTING

The study area is located offshore of Tierra del Fuego continental margin (Fig. 1A), including the northwestern Scotia Sea and the Malvinas/Falkland Depression. The E-W trending North Scotia Ridge (NSR) represents the eastward prolongation of the orogenic system emerged in Tierra del Fuego. The northern flank of the NSR is influenced by the active subduction of the South America plate beneath the Scotia plate (Fig. 1A), while the southern flank is mostly characterized by strike-slip structures (e.g. Lodolo et al., 2006).

OCEANOGRAPHIC CONTEXT

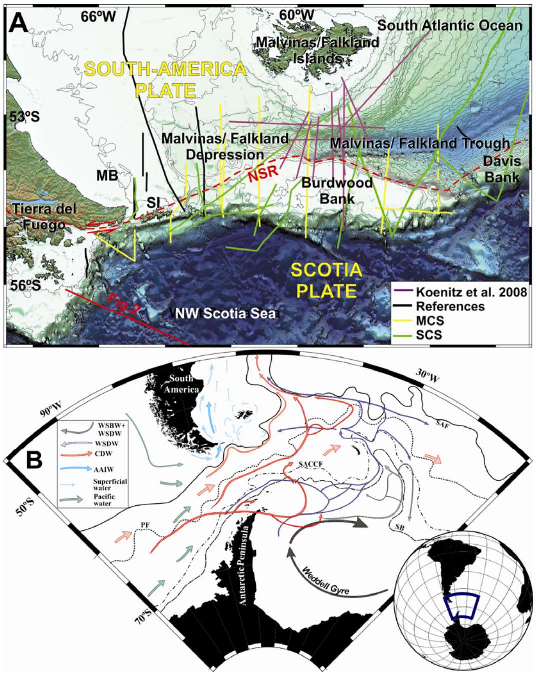

FIGURE 1. (A) Scotia Sea-Atlantic Ocean transition showing the location of seismic lines used in this study. MB, Malvinas Basin; NSR, North Scotia Ridge; SI, Los Estados Island. (B) Simplified sketch of the water masses circulation in the study area. Water masses defined in text. Fronts of the ACC: SAF, Sub-Antarctic Front; Pf, Polar Front; SACCF; Southern ACC Front; SB, Southern Boundary of the ACC.

The deepest water mass in the northwest Scotia Sea is the Southeast Pacific Deep Water (SPDW), which flows to the north of the Southern Antarctic Circumpolar Current Front (SACCF). Above the

SPDW, the Circumpolar Deep Water (CDW) flows eastward as the deepest fraction of the Antarctic Circumpolar Current (ACC). CDW is divided into an Upper (UCDW) and Lower (LCDW) fractions, separated by the Southeast Pacific Deep Slope Water (SPDSW, Well et al., 2003). Above the CDW the Antarctic Intermediate Water (AAIW) and the Antarctic Surface Water (AASW) are found. AAIW and UCDW contribute to the Malvinas/Falkland Current. Water depths along the crest of NSR range from 200 to 2000m. As result, the ridge forms a huge barrier to ACC northward flow deeper components (Fig. 1B; Naveira-Garabato et al., 2003).

RESULTS

A well-developed terrace is identified in the middle continental slopes of both northwest Scotia Sea and around the Malvinas/Falkland Depression. In the northwest Scotia Sea the terrace is located between 900 and 1100m water depth (wd) being around 10km wide (Fig. 2). A similar terrace is evident in the northern slope of the Malvinas/Falkland Depression at between 400 and 600m wd, where it widens to 6km. Laterally, eastward this terrace is well-developed in the southern slope of the Malvinas/Falkland Islands were it exceeds 10km wide based on the data from Koenitz et al. (2008).

DISCUSSION AND CONCLUSIONS

11.6% of the global continental slopes are shaped by terraces (Harris et al., 2014). Only those genetically related to bottom currents can be considered as contourite terraces (e.g. Preu et al., 2013). In the Scotia Sea-Atlantic Ocean transition, the water depth of the regional interfaces between water masses matches with the occurrence of terraces along the middle-slope (Fig. 2). The largest contourite terrace is located in correspondence with the lower boundary of the AAIW mass, which has being considered in this study area between 200 and 1100m wd (Naveira-Garabato et al., 2003). AAIW is formed by surface water mixing and northward subduction at the Antarctic Convergence Zone/Antarctic Polar Front (Naveira-Garabato et al., 2003). This water mass flows to the north within the Malvinas/Falkland Current, above the UCDW and farther north above North Atlantic Deep Water (NADW), and contributes to the formation of other equivalent terrace identified in the Southern Hemisphere: the Perito Moreno (~1000m) and the Ewing (~1500m) terraces defined in both the Argentinian and Uruguayan margins (Hernández-Molina et al., 2009; Preu et al., 2013). Therefore, the genesis of theses terraces can be associated with the northward circulation of the AAIW and the dynamics of its lower boundary. Also the depths of these terraces are indicative of a slight northward deepening of the AAIW layer. The seismic analysis allows us to identify the occurrence of these terraces since the emplacement of the Horizon-c (Fig. 2). According to other regional studies, the age of this reflection corresponds to middle Miocene (Maldonado et al., 2006), the same period in which the lower boundary of AAIW started to generate the Perito Moreno and the Ewing terraces (Hernández-Molina et al., 2009; Preu et al., 2013). Consequently, we can establish the middle Miocene as the age of the AAIW/UCDW emplacement and the onset of the northward AAIW widespread flow.

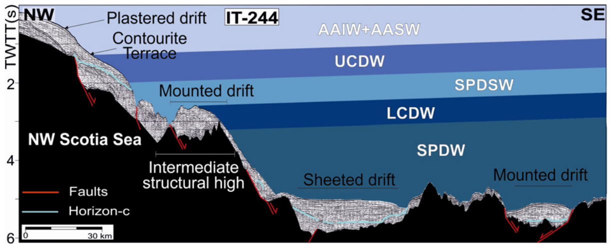

FIGURE 2. Multichannel seismic line (Lodolo et al., 2006; Location in Fig. 1) with seismo-stratigraphic interpretation and tentative outline of the water masses distribution in the northwestern Scotia Sea.

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Comparison of large contourite drifts in the western North Atlantic

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Abstract: *Large contourite depositional systems (CDS) are a common morphological feature of the North American margin of the western North Atlantic Ocean. High quality seismic reflection data and drilling results allow correlation and comparison of these features over several thousands of kilometres. Greatest apparent drift growth was during the Late Miocene and Pliocene. The locations of CDS coincide with pre-existing structural features such as ancient faults and bedrock promontories. Most CDS show evidence of gas hydrate accumulation. Submarine slope failures are associated with CDS; on detached drifts, thick accumulations of mass transport deposits and stepped escarpment morphology indicate repeated instability over time. The synchronicity of maximum drift growth over such a vast region implies that ocean-wide changes in circulation, continental-scale changes in tectonics and climate, and eustacy dominate over local changes in sediment supply in controlling CDS development.*

Key words: *North Atlantic, Pliocene, contourite, mass transport deposit, gas hydrates*

INTRODUCTION

Some of the earliest recognized contourite depositional systems (CDS) are from the western North Atlantic (WNA), specifically the US Atlantic margin (e.g. Heezen et al., 1966). Subsequent work focused on the analysis of seismic reflection data, supplemented by ocean drilling data, to determine timing of significant drift development and major erosional periods (Mountain and Tucholke, 1985; Arthur et al., 1989 among others). Since the initial discovery and study of these features in the 1960s-1980s, vast amounts of high quality seismic reflection, scientific and exploration drilling, and seabed data have been collected. This study focuses on deposits along an approximately 6000 km long segment of the NE United States and Canadian margin, exposes broad similarities between WNA contourite drifts, and examines some of the questions raised by these observations.

DATA AND RESULTS

This study uses a range of geophysical and geological data including: 1) multi- and single-channel seismic reflection data collected by the petroleum industry, academia, and government; 2) lithological and biostratigraphic information from scientific boreholes and exploration wells; and 3) high resolution bathymetry data. In addition, this study incorporates and synthesizes previously published results from CDS in the study area.

The Cenozoic seismic stratigraphy for most of the WNA margin is remarkably consistent. The stratigraphy can be broadly divided into 4 units (Table I). Large contourite deposits are principally confined to Unit 3 (Upper Miocene to Pliocene). The quality of age control for Unit 3 varies across the margin, however there are several indications that apparent drift development was greatest during the latest Miocene and Pliocene, and that changes in the dominant current system occurred in the Early Pliocene; for example the Chesapeake Drift (Locker and Laine, 1992), the Nova Scotia margin (Campbell, 2011), the Newfoundland Basin (unpublished results), Sackville Spur (Kennard et al., 1990), Hamilton Spur (unpublished results) and Davis Strait (Nielsen et al., 2011) (Figure 1).

Seismic Unit	Age	Character
Unit 4	Quaternary	Gravity flow, hemipelagic and plume fall-out deposition predominance.
Unit 3	Upper Miocene-Pliocene	CDS predominance.
Unit 2	Oligocene-Middle Miocene	Primary depositional modes overprinted by polygonal faults, local CDS development.
Unit 1	Upper Cretaceous-Eocene	Variable reflection geometry, higher seismic amplitude, local CDS development.

TABLE I. General division of Cenozoic seismic stratigraphic units of the western North Atlantic margin.

Large CDS in the study area comprise separated, detached, and plastered drifts. Major pre-existing structural elements exert first order control on the distribution of these deposits (Figure 1). In general, drifts are located where significant changes in the trend of the margin occur. In some cases, these changes correlate to ancient fault and fracture zones, for example at Hamilton Spur, Funk Island Spur, and Sackville Spur. In other locations, large CDS are anchored to pre-existing submarine bedrock promontories, for example the CDS around Flemish Cap, Newfoundland Ridge, the Nova Scotia margin, and the Chesapeake Drift (Figure 1). Another feature shared amongst most CDS in the study area are bottom simulating reflections (BSRs) indicative of the presence of gas hydrates in the sub-surface (e.g. Mosher 2011). Coincident with gas hydrate indicators are gas and fluid chimneys and seabed mounds. Most CDS in the study area exhibit evidence of seabed instability during their development. For example, in the case of detached drifts, layered mass transport deposits, in places >200 m thick, are interbedded with contourite deposits on the gently-dipping down-current sides, while stepped failure terraces characterize the steeply-dipping up-current sides (Figure 1).

DISCUSSION

The results from this study show several broad similarities in CDS over a vast extent of the WNA margin which include the location of initiation, propensity for large slope failure during development, and the presence of gas hydrates. The observed timing of apparent increased drift growth during the latest Miocene and Pliocene in the WNA agrees with drifts in the northern and eastern North Atlantic, especially the Gardar and Eirik drifts (Wright and Miller 1996). The timing of drift growth implies that the tectonic events across the Greenland-Scotland Ridge that influenced CDS development patterns in the eastern North Atlantic had far-reaching effects “downstream” in the system. Additionally, the synchronous timing indicates that more global events such as Northern Hemisphere glaciations and the onset of glacioeustacy were important in driving local changes in sediment supply and circulation.

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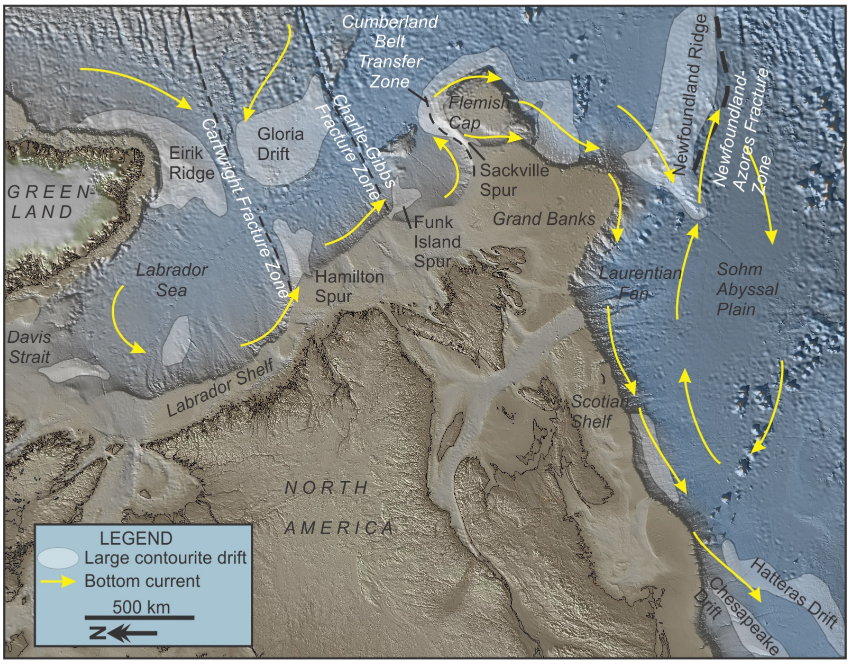

FIGURE 1. Map showing the distribution of CDS in the western North Atlantic and locations discussed in the text.

The Impact of the Agulhas Current System on Sedimentary Systems at the Southeast African Margin - Shallow, Mid- and Deep-Water Contourite Formation

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Abstract: *Sedimentary systems from Madagascar through Davie Ridge, Zambezi and Limpopo Margin, Natal Valley to the Cape of Good Hope were investigated with multichannel seismic and echosounder surveys to prepare the SAFARI drilling proposal 702 to IODP (Hall, Zahn et al.), which is going to be scheduled within the coming years. On the search of suitable drilling locations to study the Agulhas Current paleoceanography in the Neogene, intense interaction with the sedimentary systems was observed in water depths ranging from the shelf edge in front of the Limpopo and Zambezi River, in mid-water off Madagascar and on Davie Ridge, to deeper water in the Natal Valley and at the Cape of Good Hope.*

Key words: *Contourite, Southeast Africa, Agulhas Current, Seismic Survey*

The thermohaline circulation in the Eastern Indian Ocean is dominated by the Mozambique and Madagascar Currents, which join as the Agulhas Current south of Madagascar to carry enormous amounts of heat from the Indian to the Atlantic Ocean. The most sensitive part of the interocean exchange is located at the southern tip of Africa and on the Southeastern African continental margin. As the current patterns are assumed to be heavily influenced by changes in the global climate, variations in current intensity and enhancement of the retroflection back into the Indian Ocean are closely related to glacial and interglacial conditions, which drive N-S shifts of the frontal system with the Circumantarctic circulation. Drilling results may therefore reveal critical information about the evolution of both the paleoclimate and the paleociruclation back to Miocene times.

A multichannel seismic survey off Mozambique, Madagascar and South Africa was carried out to identify potential drilling locations to study the Neogene evolution of the Agulhas current system during the last 10 million years. As an outcome of several regional surveys between 35°S and 15°S, we found the margin to be dominated by current-controlled sediment builtups, rather than being influenced by terrigenuous sediment input only (Fig. 1). Wide parts of the continental margins were shaped by contour currents ranging in water depth from ~100 m down to more than 3000 m water depth. Also shelf regions reveal pronounced coast-parallel sediment transport, serving as redistribution mechanism and as significant margin sediment source.

Drilling along the pathway of the Agulhas Current from Madagascar to South Africa is challenging due to the erosive capacity of this major ocean current and associated countercurrents, and depositional processes need to be understood to ensure the completeness of sedimentary archives and sufficiently stationary depocenters through the time interval of investigation.

A combination of plate tectonic constraints, determining average slope angles and the breakup geometry of the margins, and the orientation of the currents with respect to the average contour direction in turn control a locally variable setting with huge contouritic depocenters forming at indentations of the margins, e.g. in front of the River Zambezi and River Limpopo, while areas in close proximity are characterized by strong erosion. Off Madagascar, mid-water deposition is fed by local channels and overspills, being redistributed by alongshore currents in >1000 m water depth. The same water depth is affected on Davie Ridge near DSDP Site 242. Shallow water contourites form from 100 through 1500 m off Zambezi and Limpopo (Fig. 2), with maximum deposition in a few hundred meters water depth.

Further south, near the Natal Valley and off the Cape of Good Hope, the margin slope is particularly steep and orientation of contours and currents match quite well, leading to non-deposition or erosion at the upper and middle slope. The Agulhas Current, having picked up material on its path, loses particles at its base forming thicker fallout units beneath.

At the southern tip of Africa, winnowing and erosion dominate on the whole margin, with local variations due to complex topography. At the proposed sites, winnowing or reduced sedimentation can be clearly identified.

A suite of drill sites has been proposed to trace the Agulhas Current and its related deposits. While off Madagascar and at Limpopo and Zambezi, terrigenous input feeds the current, and material is partially just redistributed by shelf recirculation cells from lee eddies, southern sites lack sediment supply, sedimentation at the southern sites may be controlled by variations in transport capacity.

Overall, although main objectives of the drilling proposal focus on paleoclimate and paleoceanography back to the mid Miocene, significant evidence can be expected from the SAFARI drilling about contourite systems at the East African margin and its spatial and temporal variability

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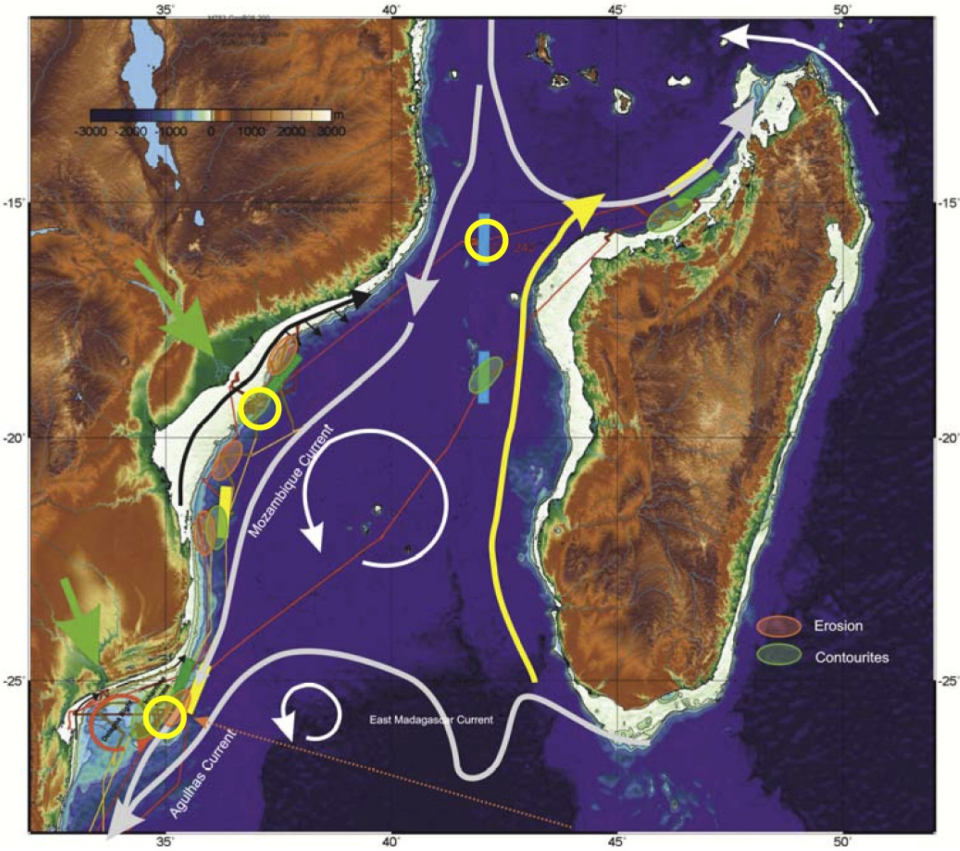

FIGURE 1. Current-controlled sedimentation on the SE African continental margin between 10°S and 30°S. A distinct pattern of erosional (red ellipse) and contouritic (green ellipse) domains is observed. Formation of deep water (blue bars), mid water (yellow bars) and shallow water (green bars) contourites is documented in seismic pre-site survey data for the IODP drilling proposal SAFARI. Green arrow denote significant terrigenuous sediment flux from Limpopo and Zambezi River, which contribute to the contourite formation. Drilling is proposed at the yellow circles, which represent sediments being distinctly influenced by the ambient current regime through most of the Neogene.

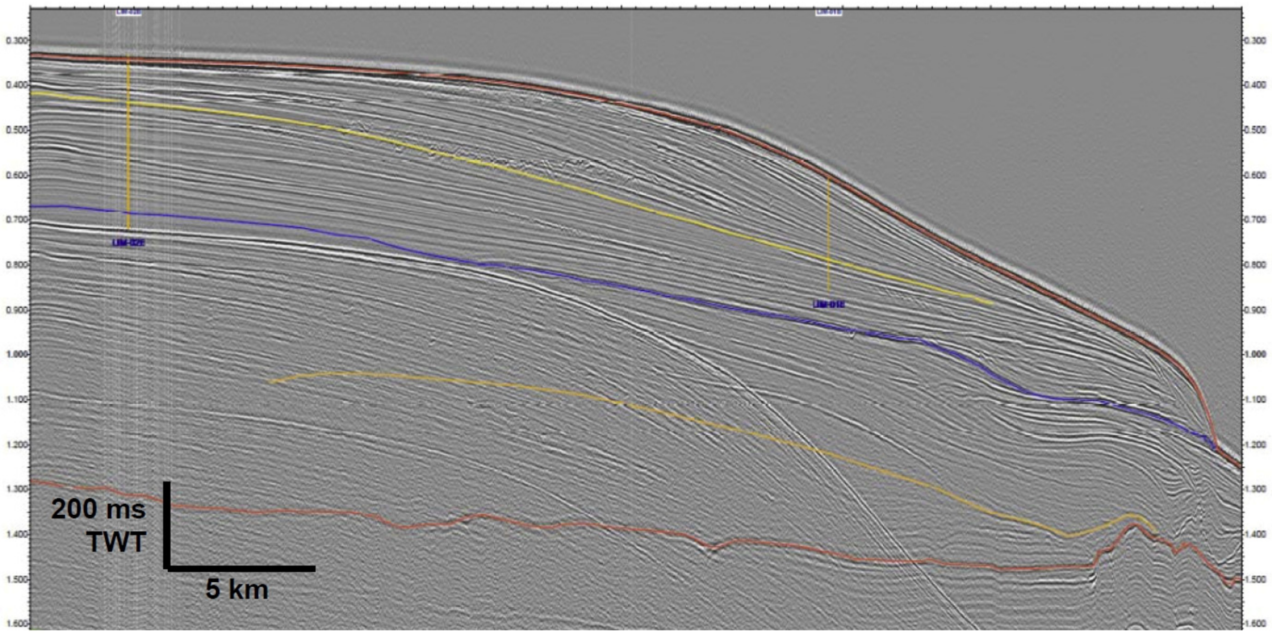

FIGURE 2. Seismic line across proposed Sites LIM-01B and LIM-02B (orange lines) on the Inharrime Terrace off Limpopo River. Interpretation according to Preu et al. (2011) identifies plastered drift units back to the middle Miocene (blue horizon).

Millennial-scale influence of southern intermediate component water into the North-east Atlantic during the last 40kyr

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Abstract: *The advection of Antarctic Intermediate Water (AAIW) is important for the distribution of heat, salt, nutrients and carbon to the North Atlantic. However little is known about the links between intermediate water circulation and abrupt climate events such as Heinrich events. Here, we have investigated εNd of seawater and cold-water corals located to the Alboran Sea and to the SE of the Gulf of Cadiz to constrain the present day seawater εNd and to reconstruct the past water mass mixing during the last 37kyr. The coral εNd values range from -8 to -10.4, most likely indicating changes of the dominant water mass provenance. Glacial cold-water corals (from 19 to 37kyr) are characterized by more radiogenic εNd values (> -9.5) compared to the ones from the Holocene demonstrating a decreasing contribution of MOW and/or AAIW in the SE Gulf of Cadiz during climate warming. Strikingly, Heinrich events H2 and H3 reveal even more radiogenic εNd values (~-8). In addition, deep-sea corals from the Alboran Sea indicate that εNd of the MOW do not change significantly trough time. These results points to significant advance of southern component water at 500m depth in the eastern temperate Atlantic.*

Key words: *AAIW, Nd isotopes, deep-sea corals, north Atlantic cold events.*

INTRODUCTION

Throughout the last glacial-interglacial cycle, major reorganizations of water masses in the North Atlantic occurred. Nutrient-proxies (δ^{13}C and Cd/Ca) provide evidence that deep-water production in North Atlantic was shallower and thus the deep basin was occupied by southern water (Antarctic Intermediate Water = AAIW and Antarctic Bottom Water = AABW; Duplessy et al., 1988). However little is known about the hydrological parameters of the intermediate water masses.

Antarctic Intermediate Water (AAIW) is an important water masse of the general ocean circulation because its production and advection influence interhemispheric heat exchange as well as the distribution of salinity, nutrients and carbon. Recently it has been shown a decrease in the AAIW fraction in the North Atlantic during cold events (Heinrich events and Younger Dryas; Kuo-Fang et al., 2014). Nevertheless, deglacial variability of Atlantic AAIW is still unclear, other studies arguing for a greater fraction (e.g. Pahnke et al., 2008). Furthermore Mediterranean Outflow Water (MOW), being an important source of saline and warm intermediate water, has been modulated regarding its strength and mean depth (Voelker et al., 2006; Toucanne et al., 2007).

In order to constrain the hydrology of these water masses in the NE Atlantic, we have investigated εNd that constitute a reliable proxy to trace water mass provenance in oceans. The residence time of the dissolved Nd in the ocean (about 800yrs, Tachickawa et al., 1999) is shorter than the global turnover time of the ocean (about 1000yrs). Consequently, intermediate and deep-water masses acquire εNd signature from downwelling surface water though lithogenic input.

Here, we have investigated εNd of seawater and cold-water corals (L. *pertusa*, M. *oculata* and D. *dianthus*) located to the Alboran Sea and the SE of the Gulf of Cadiz (between 550 and 850m) to constrain the present day seawater εNd and to reconstruct past water mass mixing during the last 37kyr.

HYDROLOGICAL SETTINGS

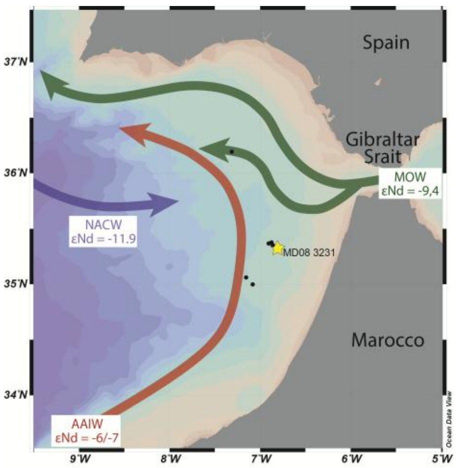

FIGURE 1. Simplified distribution of intermediate water masses in the Gulf of Cadiz. εNd values are also reported. The yellow star indicate the location of the studied core and black dots indicate other sampling sites used in this study.

The Gulf of Cadiz near the Strait of Gibraltar is located in a region influenced by the 3 major temperate

Atlantic mid-depth water masses (Fig. 1) : (1) MOW flows out the Mediterranean Sea along the Southern Iberian slope into two main cores — the upper and lower Mediterranean Sea Water (MSW) at depths of 500 to 800m and 800 to 1200m respectively; (2) North Atlantic Central Water (NACW) formed in the western Atlantic basin, flows from west to east in the Gulf of Cadiz at 100-600m depth; (3) AAIW has been identified in the Gulf of Cadiz in several studies (e.g. Louarn & Morin, 2011). It is formed at the polar front in the south-west Pacific and is characterized by low oxygen and high silicate values.

Those water masses are today characterized by contrasted Nd εNd : NACW εNd = -11.9; MOW εNd= -9.4; AAIW εNd= -6 to -7 (Fig. 1).

MATERIAL AND METHODS

εNd values have been analyzed on seawater and fossil deep-sea corals from a sediment core MD08-3231 (35°18.90'N, 06°48.19'W; Fig. 1) recovered at 550m water depth on the Gamma Mound from the Pen Duick Escarpment (PDE) during the MD 169 MiCROSYSTEMS Cruise.

Corals have been dated using U-Th method. Nd has been separated following the procedure described in details by Copard et al. (2010). A Nd-oxide technique for thermal ionization mass spectrometry (TIMS) was used to determine the Nd isotopic composition.

RESULTS AND DISCUSSION

Seawater εNd value of -11.6 indicates that the NACW is today the predominant water mass at the position of the studied site (core MD08-3231).

The coral εNd values range from -8 to -10.4 during the last 37kyr, most likely indicating changes of the dominant water mass provenance. Glacial cold-water corals (from 19 to 37kyr) are characterized by more radiogenic εNd values (> -9.5) compared to the ones from the Holocene. At this time, the weaker southward export of Atlantic water results in more radiogenic and less diluted AAIW.

Strikingly, Heinrich events H2 and H3 reveal even more radiogenic εNd values (~ -8). In addition, deep-sea corals from the Alboran Sea indicate that εNd of the MOW do not change significantly trough time. These results imply a higher contribution of AAIW linked to an increase in AAIW formation and a collapse of the AMOC.

The incursion of southern source water into the Gulf of Cadiz at 19kyr ago is also described in a core of the western basin (Pahnke et al., 2008). This event is not associated with an increase in AAIW production. However, it is coeval with the southwards flow of the Fennoscandian ice sheet derived meltwater as seen in a core of the Fleuve Manche and several cores of the Bay of Biscay (Toucanne et al., 2010) that could have weakened the GNAIW convection.

CONCLUSION

We report for the first time past seawater εNd record obtained from cold-water corals of the intermediate water of the Gulf of Cadiz. Glacial time is characterized by more radiogenic εNd values than the Holocene implying the presence of a higher contribution of AAIW in the Gulf of Cadiz. Our results indicate an advance of southern component water (AAIW) at shallow depth into the NE Atlantic during the cold events H2 and H3 and at 19kyr.

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Development of Mediterranean cold-water coral ecosystems since the late glacial

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Abstract: *Based on all available ages obtained on the dominant framework-building scleractinian cold-water coral species Lophelia pertusa and Madrepora oculata collected in the entire Mediterranean Sea (compiled from literature review and own studies), we discuss the basin-wide occurrences of these species emphasising their spatial and temporal development during the late glacial and Holocene. We show that these species became abundant since the deglacial (<14ka) and their Late Pleistocene and Holocene proliferation or demise significantly differed between the eastern and western Mediterranean Sea sub-basins, depending on regional (sub-basin-related) environmental conditions, like the availability of food or bottom water oxygenation. In combination with the corals' preference to settle in intermediate depths, a strong relationship between Mediterranean cold-water coral development and intermediate water mass circulation is suggested, though resulting regionally in different parameters influencing the corals' prosperity.*

Key words: *Cold-water corals, Mediterranean Sea, Holocene, Levantine Intermediate Water*

INTRODUCTION

Cold-water corals are common in the temperate Mediterranean Sea, where they currently thrive in intermediate water depth. Numerous cold-water coral carbonate structures on the seafloor indicate their prosperity in the past. Former studies dealing with the past development of cold-water corals in this marginal sea discussed their occurrences in a rather generalised manner for the entire basin (e.g. McCulloch et al., 2010) or trace their appearance trough time on a locally restricted setting (e.g. Malinverno et al., 2010, Fink et al., 2012, 2013).

As the Mediterranean sub-basins were affected by basically different events since the last glacial (e.g. anoxic formation of sapropel S1 in the east; variability of the inflow of Atlantic surface waters in the west), which resulted in different paleo-environmental conditions, this study outlines for the first time the prosperity of cold-water coral ecosystems on a regional sub-basin scale.

DATA AND RESULTS

Eighty-one cold-water coral ages obtained on the reef-forming scleractinian coral species *Lophelia pertusa* and *Madrepora oculata* collected in the entire Mediterranean Sea were compiled from literature (references see caption of Fig. 1), and complemented by nineteen new radiocarbon ages of coral specimens sampled in the Alboran Sea and in the Strait of Sicily (Fig. 1). Becoming abundant in the deglacial (after ~14ka), cold-water corals seem to have thrived throughout the entire Holocene. However, by grouping the coral dates according to their sampling area (Alboran Sea, Strait of Sicily, Eastern and Western Mediterranean Sea) distinct age cluster and regional differences appear.

DISCUSSION

Whereas in the western Mediterranean Sea the initial deglacial cold-water coral growth was forced by increased primary production and well ventilated intermediate water masses prevailing during the formation of the so-called organic rich layer 1 (ORL1, ~14.5 to 8.2ka), favourable conditions for cold-water corals in the eastern basin were established only during the Younger Dryas (YD, 12.9 to 11.7ka). However, in the Alboran Sea, as the westernmost part of the Mediterranean Sea, the YD is characterised by an absence of cold-water corals probably induced by enhanced inflow of Atlantic waters during this cold event, which led to environmental instabilities.

During the deposition of sapropel S1 in the deep eastern Mediterranean Sea, dysoxic conditions prevailing in intermediate water depths caused a temporal coral demise in the eastern basin (~11.5 to 5.9ka). Moreover, the impaired formation of both, Levantine Intermediate Water (LIW) in the east (during S1 deposition) and Winter Intermediate Water in the west (after ORL1 deposition), had a negative impact on the prosperity of western Mediterranean coral ecosystems during the Mid Holocene (8.2- ~6ka).

Along with the onset of LIW formation (~ 6ka) cold-water corals re-colonised the entire Mediterranean Sea and thrived there throughout the Late Holocene until today.

CONCLUSIONS

This detailed comparative study between the western and eastern Mediterranean sub-basins indicates that the development of cold-water corals during the late glacial and Holocene relies on a rather complex pattern, precluding any generalised basin-wide approach to describe their occurrence trough time. Their proliferation or demise rather depends on different regional (sub-basin-related) environmental conditions, mainly driven by the intensity of the intermediate water circulation, which is linked to climatic conditions.

ACKNOWLEDGEMENTS

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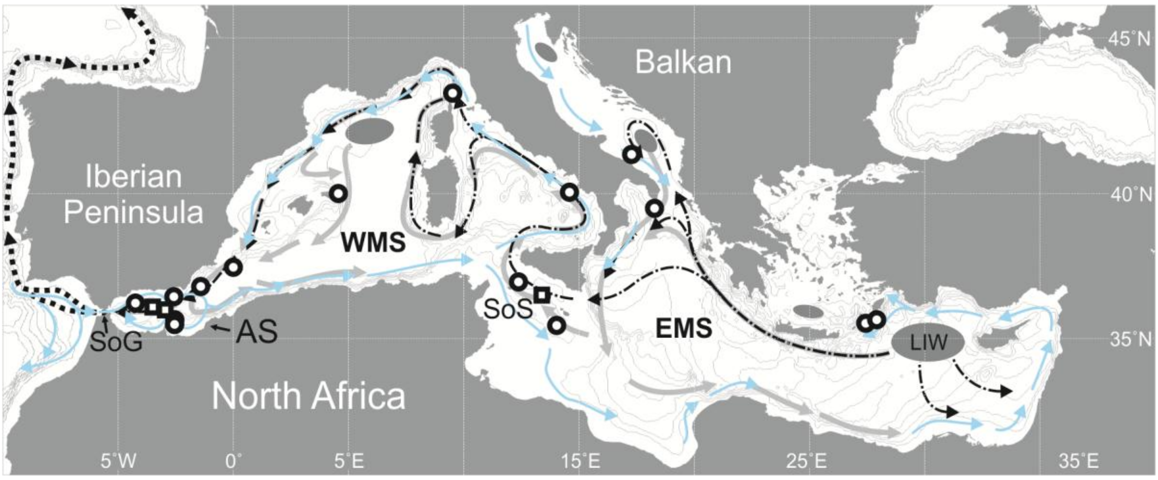

FIGURE 1: *Overview map of the Mediterranean Sea. Displayed is the general ocean circulation pattern in the Mediterranean Sea (modified after Millot and Taupier-Letage, 2005). Blue arrows: Surface water circulation. Dashed-dotted black arrows: Intermediate water circulation. Thick grey arrows: Deep water circulation. Dotted black arrows: Mediterranean Outflow Water (MOW). Highlighted in grey are the areas of modern dense (deep- and intermediate) water formation. Displayed are the sampling sites of this study (squares) and reference locations (circles; data from Schröder-Ritzrau et al., 2005; Malinverno et al., 2010; McCulloch et al., 2010; Angeletti and Taviani, 2011; Frank et al., 2011; Taviani et al., 2011; Fink et al., 2012; 2013. Abbreviations: AS-Alboran Sea, EMS-Eastern Mediterranean Sea, WMS-Western Mediterranean Sea, SoS-Strait of Sicily, SoG Strait of Gibraltar.*

Buried cold-water coral mound provinces and contourite drifts along the Eastern Atlantic margin: controls, interactions and connectivity

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Abstract: *this paper reports on the discovery of a large province of buried cold-water coral mounds within a sediment drift setting along the Moroccan Atlantic Margin. They possibly represent an even largest set of buried cold-water coral mounds with respect to the Magellan Mound province in the Porcupine Seabight. However, the generally smaller Moroccan mounds have a more random spacing and are rooting on at least 4 different stratigraphic levels. Through correlation with adjacent sediment and contourite drifts, controls and interactions are proposed, as well as an attempt to correlate both provinces through the occurrence of other contourite drifts along the Eastern Atlantic Margin.*

Key words: *Cold-water coral mound, contourite drift, Porcupine Seabight, Gulf of Cádiz.*

INTRODUCTION

The association between cold-water coral (CWC) mounds and contourite drift deposits has been fully demonstrated in the Belgica mound province, located in the Porcupine Seabight, off Ireland (Fig. 1; Van Rooij et al., 2003). It was also in that location that IODP expedition 307 was able to drill through the base of a mound, enabling to date mound initiation at 2.65Ma (Thierens et al., 2013). However, the Belgica mounds are just one of the many expressions of mound growth in this basin, and beyond. More enigmatic is the buried Magellan mound province, located in the northern part of the Porcupine Basin, featuring over 1000 relatively closely spaced buried mounds, which are all rooted on a common reflector (Huvenne et al., 2007). This indicates a common and sudden start-up event, but the true driving forces behind the initial settling, growth and demise of this province are still unknown. The influence of bottom currents cannot be ruled out, since clear obstacle marks are present surrounding the mounds. In 2013, some 3000km south of the Magellan mound province, a new province of buried CWC mounds was discovered along the Moroccan Atlantic Margin (Fig. 1), which may shed new light on the "life" cycle of CWC mounds. In this paper, we report about the preliminary results of this discovery, and propose a first view on the controls, interactions and connectivity between these 2 provinces, assisted by a series of studies of contourite drifts along the Eastern Atlantic Margin.

MATERIAL AND METHODS

The data used for this study primarily resulted from three research cruises. The R/V Belgica "COMIC" cruise (25/05/13-07/06/13) was carried out as a site investigation cruise for the R/V Marion Dufresne MD194 Gateway cruise (10/06/13-20/06/13) along the Moroccan Atlantic. The first cruise acquired high-resolution single channel sparker seismic reflection profiles, together with selected CTD and LADCP stations. The latter cruise acquired both gravity and Calypso cores on selected sites.

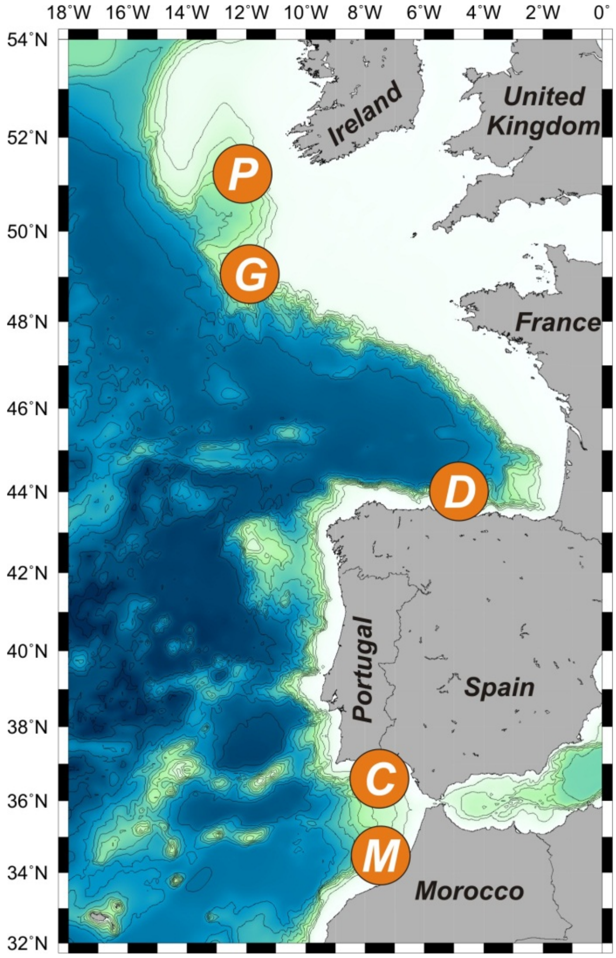

FIGURE 1.Discussed CWC mound provinces (Porcupine; Morocco margin) and contourite drifts (Goban Spur; Le Danois; Cádiz) along the Eastern Atlantic margin. All sites are linked with each other by depth, water mass and/or palaeoceanographic evolution.

Finally, the MSM36 "MoccoMeBo" expedition on board R/V Maria S. Merian (18/02/14-17/03/14) revisited identical sites (among others), visualizing them in very high-resolution using the shipboard PARASOUND subbottom profiler.

DISCUSSION AND CONCLUSIONS

The newly discovered buried CWC mounds can be associated to a vast province of several clusters of seabed mounds (Fig. 2), reported by Hebbeln et al. (2008). They occur in water depths between 500 and 1000 m, buried under up to 50 m of sediment. With respect to the Magellan mounds, they are smaller, but more importantly, they do not root on one single stratigraphic level. At least 4 different initiation levels were identified. The off-mound reflectors indicate a slight influence of bottom currents, since the mounds are located in a large sediment drift that is related to the Pen Duick CDS, for which a seismic stratigraphy has been proposed by Vandorpe et al. (2014).

Moreover, the link between the two buried mound provinces may be found in connecting the evolution of the associated contourite drift systems, respectively in Porcupine Seabight and the Gulf of Cádiz. Intermediate sites on Goban Spur and near Le Danois Bank have enabled to correlate stratigraphic events over such large distances, mainly driven by changes in the Mediterranean Outflow Water (MOW). However, Vandorpe et al. (2014), clearly pointed out the influence of the Antarctic Intermediate Water (AAIW) on the Moroccan Margin, but that a correlation with the Cádiz CDS is feasible, suggesting a linkage between MOW and AAIW dynamics in the southern Gulf of Cádiz.

ACKNOWLEDGEMENTS

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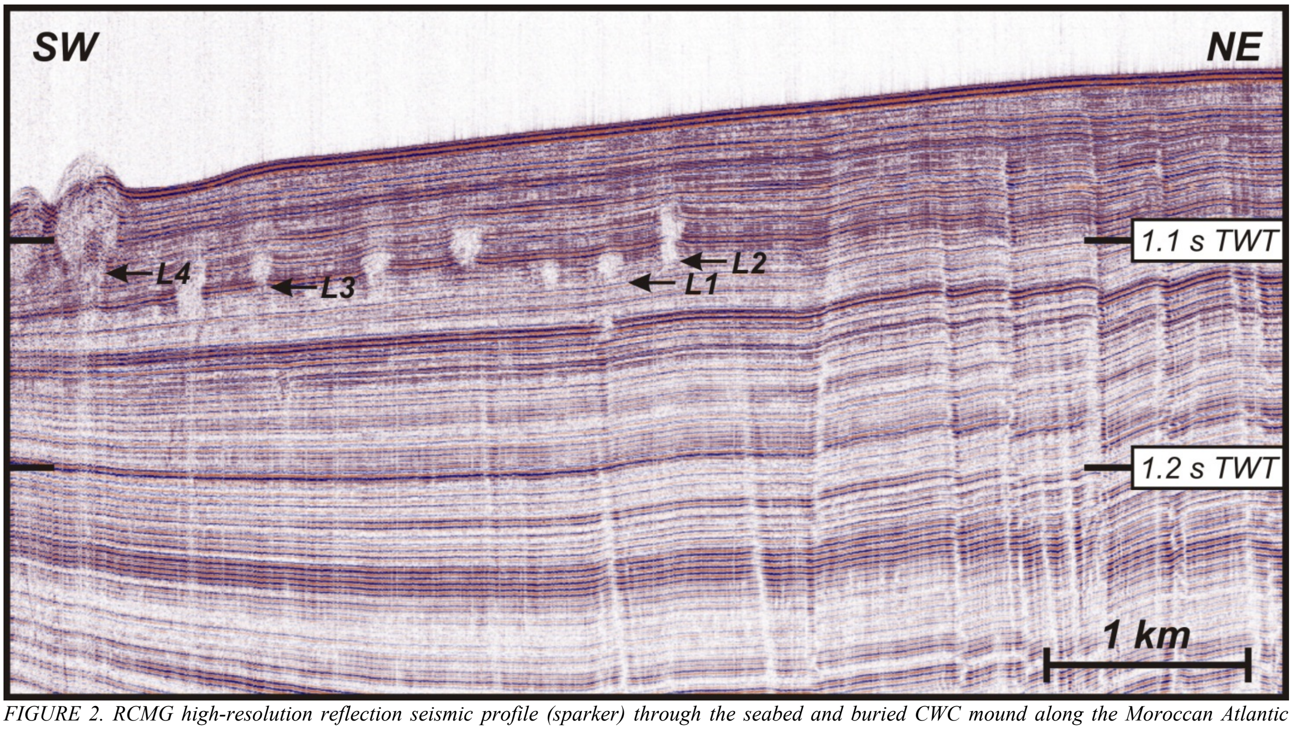

FIGURE 2. RCMG high-resolution reflection seismic profile (sparker) through the seabed and buried CWC mound along the Moroccan Atlantic Margin. Note the 4 different levels on which all mounds root, as well as their association with a recently active fault system. The surface of the seabed mounds are notably influenced by bottom current flow around an obstacle.

The Darwin Mounds, N Rockall Trough: how the dynamics of a sandy contourite influenced cold-water coral growth

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Abstract: *The Darwin cold-water coral mounds in the northern Rockall Trough have often been considered potential analogues for the initial stages of giant cold-water coral mounds. However, the origin and formation mechanism of the 5m high mounds, which sit in a thin sandy contourite, have never been clear. A new set of piston cores that sampled two Darwin Mounds from top to base now provides unprecedented insight in the mound initiation and development history, in relation to the regional palaeoceanography and contourite development. Radiocarbon and U-series dating, together with CT-scanning and grainsize analysis established that the first corals started to grow in the early Holocene. Vigorous coral growth was maintained until ca. 8.8ka, after which an increased current regime caused partly reduced growth. From 3-5ka coral growth seems to have been very limited, although live coral can still be found on the mounds today. The pattern is similar to coral records found at the top of large mounds in the region, and tentatively can be linked to variations in regional circulation patterns.*

Key words: *cold-water corals, sandy contourite, cold-water coral mound, Rockall Trough.*

INTRODUCTION

The Darwin Mounds are small cold-water coral mounds, up to 75m across and 5m high, discovered in 1998 in the N Rockall Trough, at ~1000 m water depth. They sit in a thin (10-12cm) sandy contourite, located on the upstream flank of a large sediment drift, which formed as a result of the slow-down of, and consequent sediment deposition by, the lower Shelf Edge Current as it sweeps around the head of Rockall Trough due to the presence of the Wyville-Thomson Ridge.

The origin and formation mechanism of the mounds have been debated for more than a decade. Masson et al (2003) suggested they may be coral-topped sand volcanoes, linking their initiation to fluid (pore water) escape, also observed further downstream in the shape of a field of pockmarks. However, both Wheeler et al. (2008), based on a thorough analysis of mound morphology and bedform patterns, and Huvenne et al. (2009), who studied the sediment characteristics both on- and off-mound, concluded that sediment baffling most probably caused the build-up of the mounds.

So far, none of the mounds had been sampled from top to base, leaving a lack of conclusive evidence, especially about their initial stages. In 2011, during expedition JC060 on board the *RRS James Cook*, two piston cores were obtained from two Darwin Mounds, coring right through the mound base. An Ultra Short Base-Line beacon on the coring equipment, together with high-resolution, AUV-based sidescan sonar maps, ensured precise positioning of the cores.

The detailed study of the cores, presented here, had the following objectives: (1) to identify and date the process of mound initiation; (2) to understand the coral growth and mound development in relation to the formation of the surrounding sandy contourite; and (3) to place the mound development in the context of the regional palaeoceanography.

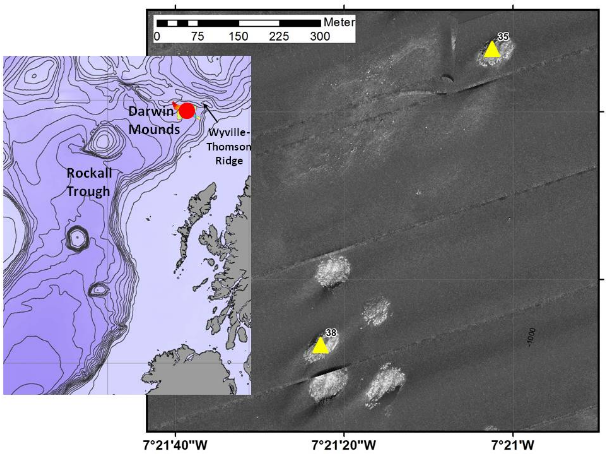

FIGURE 1. Sidescan sonar detail of the two Darwin Mounds cored during JC060. Left: location map of the Darwin Mound area

DATA AND RESULTS

The top 4m of both cores, containing the mound sequence, were imaged using X-ray Computerised Tomography (CT-scanning) at the μ-Vis facility of the University of Southampton. Image analysis was carried out in VG Studio Max and ImageJ, and allowed visualisation of coral content in 3D. Volume % coral was measured, and coral bio-erosion state and species composition were noted. Once imaged, the cores were split in frozen state, and grainsize was analysed at 25cm intervals using a Malvern2000 laser particlesizer. Four coral fragments were radiocarbon dated by Beta-Analytic Inc. (USA); 10 fragments were dated using U/Th in the LSCE laboratories in Gif sur Yvette.

The moundbase was found at 343cm resp. 285cm depth in the two cores, depths that correspond well with the total height of the mounds as identified from high-resolution AUV bathymetry. The base was characterised by a sharp grainsize change, from silty clay or clayey silt to fine sand. The first coral fragments were found to coincide with this sharp contact in core JC060-035, and occurred 12cm higher in core JC060-038. They were dated at 10.0-10.4 ka, indicating that coral growth, and mound formation, started in the early Holocene. Coral volume % was highest in the first phase following mound initiation (4-14%). Grainsize decreased slightly, compared to the very base of the mounds, probably as a result of current slow-down by the coral framework, supporting the model of mound build-up through baffling. This first phase lasted until ca. 8.8ka, and resulted in 70-90cm of mound build-up, equivalent to a mound growth rate of 58-70cm/ka.

From 8.8ka onwards, grainsize increased slightly, coral volume % decreased (<4%) and mound growth rate reduced to ~40cm/ka. When mound growth rates are extended to the core tops, growth appears to have stopped at ca. 3ka resp. 5ka. However, ROV video surveys and high-resolution sidescan sonar records have shown that live coral colonies are still present on the Darwin Mounds, suggesting that coral growth did not stop at 3-5ka, but instead was strongly reduced.

Bio-erosion rates are variable in both cores, and do not appear correlated to grainsize or coral volume %. The majority of the coral is *Lophelia pertusa*, although in both cores the proportion of *Madrepora oculata* increases towards the top.

DISCUSSION

The analysis of the JC060 cores has shown that the Darwin Mounds are not merely coral-topped sand volcanoes, but that they contain coral fragments/ framework throughout, confirming their formation through sediment baffling. Coral growth started in the early Holocene, shortly after the Younger Dryas cold reversal, when the warming climate resulted in increased bottom current speeds, eroding and winnowing the underlying glaciogenic fine-grained sediments. Coral settlement most probably started on winnowed boulders and dropstones. At the same time an increase in surface productivity in the region will have caused increased food input for the corals.

The initial period of intense coral growth and fast mound build-up finished around 8.8ka, when mound growth rates nearly halved. This reduction corresponds to a grainsize increase, a decrease in coral volume % and an increase in *Madrepora oculata*. Although the inverse relation between coral volume and grainsize may be caused by the fact that a denser coral framework slows currents down more, resulting in deposition of finer-grained sediments, the dominance of *M. oculata* may point to a change in environmental conditions. The smaller polyps of *M. oculata* are less susceptible to the adverse effects of increased or coarser sediment loads, suggesting that an increase in local current regime may have reduced coral growth and mound accumulation.

A similar pattern of coral growth, with (re-)initiation in the early Holocene, intense growth until ca. 8.5ka and reduced growth until ca. 4ka has been observed in other locations in the Rockall Trough and Porcupine Seabight (Frank et al., 2009). Part of this pattern could potentially be linked to changes in dominance of the Sub-Polar Gyre versus the Sub-Tropical Gyre in the area, which affected the hydrodynamical regime and primary productivity in the region.

CONCLUSIONS

For the first time, small cold-water coral mounds set within a sandy contourite have been cored from top to base. CT-scanning, grain-size analysis and dating have given insight in mound initiation and development. Cold-water coral growth in the Darwin Mounds started in the early Holocene, with a first pulse of intense growth. After ca. 8.8ka, growth rates halved, probably as the result of a coarser sediment input and an intenser current regime. By 3-5ka, coral growth became sporadic and patchy, a pattern also observed elsewhere in the region. The results illustrate once again the close interplay between current regime, sediment dynamics and coral growth/mound development.

ACKNOWLEDGEMENTS

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The modern carbonate contourite drift of the Little Bahama Bank: a geophysical, sedimentological and biostratigraphic study

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Abstract: *We focus on a major sedimentary body situated of the northwestern slope of the Little Bahama Bank (LBB), the second largest carbonate bank of the Bahamian archipelago. Our objectives are (1) to determine sediment export processes from the shallow-water bank to the northern slope of LBB, which is exposed to prevailing winds (windward side) and (2) to evaluate sediment deposition related to variations in the regional Antilles Current. This work focused on two marine cores located on the western side of the northern slope of LBB in combination with high-resolution bathymetric and very-high resolution seismic data (Chirp) collected during the CARAMBAR cruise (2010). Off-bank processes are the major sedimentary processes during sea-level highstands, resulting in high accumulation rates of foraminifera-rich carbonate ooze deposits. Interglacial clay-rich deposits may be related to a slowdown of currents, allowing clay-size particles to settle within the contourite system, and an increase of clay production and export from continental areas. Glacial deposits are less massive and show a bioturbated coarsening-up unit succeeded by a bioturbated fining-up unit. The presence of coral mound and non-deposition areas and/or erosion is an additional evidence of bottom current circulation shaping the northward-elongated hemi-conical contourite body*

Key words: *contourites, sediment export, Antilles Current, sea level, carbonate slopes*

INTRODUCTION

Contourite deposits are generally associated with dense currents related to thermohaline circulation (Heezen et al., 1966) and are widely documented in the scientific literature. However, few studies have also highlighted the importance of intermediate contour bottom-currents along carbonate slopes. In the vicinity of the Bahamas five modern carbonate contourite drifts are developed: the Pourtales Drift, the Santaren Drift, the Cay Sal Drift, the Great Bahama Bank (GBB) Drift, and the Little Bahama Bank (LBB) Drift (Mullins et al., 1980; Anselmetti et al, 2000; Bergman, 2005).

The Bahama Banks are a modern carbonate system with very limited terrigenous clastic input except for particles carried by wind and oceanic currents. The Bahama platforms are situated on a passive margin, and the sedimentation is mainly controlled by changes in relative sea level and biogenic production with no major influence from regional tectonics. In this study, we focus on the major sedimentary body situated on the northwestern part of Little Bahama Bank (LBB) slope. Our objectives are to study the sediment export processes from the bank to the northern LBB slope (windward side) and to assess sediment distribution related to the regional surface current, the Antilles Current, that partly controls sedimentation at the sea floor near the core locations (Fig. 1).

DATA AND METHODS

This study focused on: (1) two marine cores CARKS-20 and CARKS-21 located at the western side of the northern slope of LBB; (2) high-resolution bathymetric; and (3) very-high resolution seismic data (Chirp). All data were collected during the CARAMBAR cruise in 2010 (Mulder et al., 2012).

The stratigraphy is based on planktonic foraminifera and coccoliths assemblages, radiometric dating, $\delta^{18}O$ on planktonic foraminifera and strontium signal from XRF. Sedimentary analyses include photospectrometer-colorimetry, grain-size measurements, thin sections, XRF and Scanning Electron Microscopy (SEM) analyses.

RESULTS

Bathymetric and seismic data show the external and internal architecture of the LBB drift. The LBB drift present a hemi-conical shape with scattered coral mounds. A circular scarp visible on the sea floor testifies of past submarine landslide not entirely filled.

Analysis of the spatial sediment distribution shows an asymmetric configuration around coral mounds. This suggests that the distribution of fine grain sizes is modified by bottom currents that are locally confined against escarpments. These processes produce non-deposition areas and/or erosion.

In both marine cores, the $\delta^{18}O$ curve correlates well with the strontium signal. Stratigraphic results indicate continuous deposition from the present-day down to marine isotope stage 11 (MIS 11; ~ 424kyr) and highlight perturbation in the sedimentation from MIS 12 to MIS 15-25.

The carbonate sediment in both marine cores is a mixture of planktonic foraminifers, calcareous nannofossils, aragonite needles, some pteropods and benthic foraminifers. Both marine cores contain white to light grey fine-grained beds (mudstones) interrupted by coarser-grained beds (wackestone). Coarse-grained sediments show a bioturbated coarsening-up unit succeeded by a bioturbated finning-up unit, which is interpreted as a current related deposit.

XRF results indicate three peaks of terrigenous elements such as Si, Fe, Ti, K and Zr. The two most recent ones are well dated and correspond to short time intervals in interglacial periods MIS 7 and MIS 11.

DISCUSSION AND CONCLUSIONS

Off-bank processes are the major sedimentary processes during sea-level highstands, resulting in high accumulation rate deposits of foraminifera-bearing carbonate periplatform ooze. Clay-rich deposits may be related to a slowdown of currents, allowing clay-sized particle to settle on the contourite system topography, combined with an increase of clay production and/or export from continental areas such as North America (Hüggenberg and Füchtbauer, 1988), Cuba and Hispaniola (Eberli et al., 1997), or Africa (Eaton, 1986).

Glacial periods and sea-level lowstands correspond to exposure of the bank and relate to low production and sediment export and reduced sediment deposition on the Bahamian slope. Current-related deposits dominate during sea-level lowstands on the northern Bahamas slope over the last 424kyr. The merging of the Antilles current with the Florida current shapes the northward-elongated hemi-conical contourite body.

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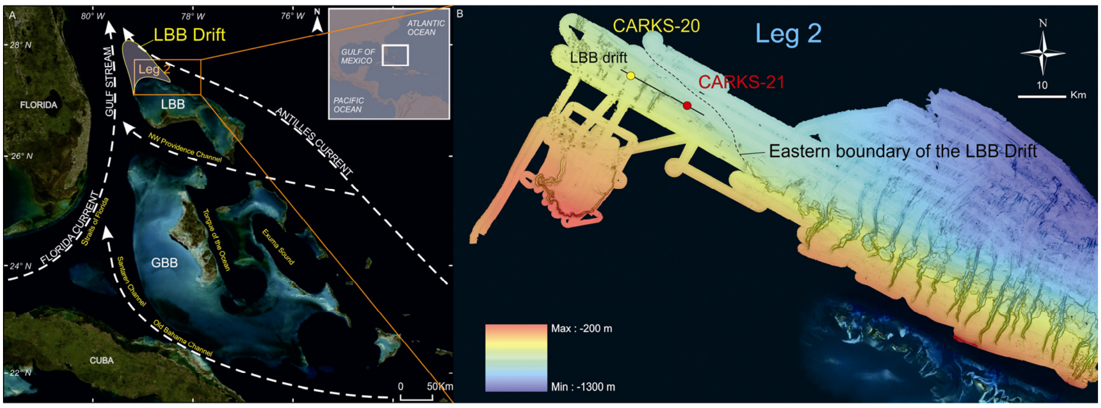

FIGURE 1. A: Location of the study area (CARAMBAR leg 2). White dashed arrows are trajectories of the main oceanic currents around the Bahamian archipelago. LBB: Little Bahama Bank; GBB: Great Bahama Bank. B: Bathymetric map (leg 2) of the LBB slope and location of core CARKS-20: yellow dot; CARKS-21: red dot (MULDER et al., 2012).

Seismic geomorphological reconstructions at Goban Spur: Implications for Plio-Pleistocene MOW bottom current variability

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Abstract: *DSDP Site 548 on Goban Spur has been investigated using high-resolution single channel sparker reflection seismic data. Alongslope bottom currents are thought to be the driving mechanism for large-scale sediment waves development. These currents are driven on their turn by an enhanced internal tide regime that could be attributed to the MOW introduction, which characterized the presence of a strong pycnal gradient. The integration of the seismic stratigraphy with the DSDP Site 548 downhole geophysical data allowed the proposition of a better chronostratigraphic and lithostratigraphic correlation. The early to late Pliocene sequence (from ~4.2 to ~2.7Ma) shows no morphological evidence of bottom current driven sedimentation. However, from the late Pliocene (i.e. ~2.7Ma) to present, large-scale sediment waves have gradually developed in close association with palaeo-seafloor irregularities, inferring that sedimentation resumed with a marked large bottom current energy increase. The late Pliocene and the middle Pleistocene units contain mass wasting intervals. Although the Goban Spur sediment waves cannot be regarded as a contourite drift as such, the stratigraphic evolution shows striking similarities to well-documented MOW induced contourite drift systems along the northeast Atlantic margin, more especially as an intermediate site between le Danois bank and the Porcupine Seabight.*

Key words: *Goban Spur, sediment waves, bottom currents, Pliocene, Pleistocene, Mediterranean Outflow Water.*

INTRODUCTION

The Mediterranean Outflow Water (MOW) constitutes one of the major intermediate water masses of the northeast Atlantic. At Goban Spur, it Typically spreads at mid water depths (i.e. ~800 to 1200m) and flows northward toward the Rockall trough, together with the overlying Eastern North Atlantic Water, where they join the Gulfstream north eastern branch (Figure 1). Below the MOW, salinities rapidly decrease to a minimum located at about 1800m water depth, signing the southeastward flowing Labrador Sea Water (LSW). Since the early Pliocene, the MOW controlled sedimentation along its pathway in the form of extensive Contourite Depositional Systems (CDS) that developed at least as far as the Porcupine Seabight. CDS are various in morphology and composition as a result of the interaction between contour currents, associated hydrodynamic processes (e.g. internal tides), and the seabed (Rebesco et al., 2014).

IODP Exp. 307 has proven that MOW established favourable conditions for the development of large cold-water coral (CWC) mounds in the Porcupine Seabight since the late Pliocene (Huvenne et al., 2009; Thierens et al., 2010). However, the precise timing of MOW introduction remains difficult to assess due to regionally large hiatuses at the CWC mound base. DSDP site 548 (i.e. 1256m water depth) on Goban Spur recorded a more complete Pliocene to Pleistocene sequence. It is forming a gentle terraced, sediment starved environment ranging depths from 1000 to 1600m. Currently located at the MOW lower interface; the Goban Spur smooth morphology may have implied limited bottom currents and seafloor interactions.

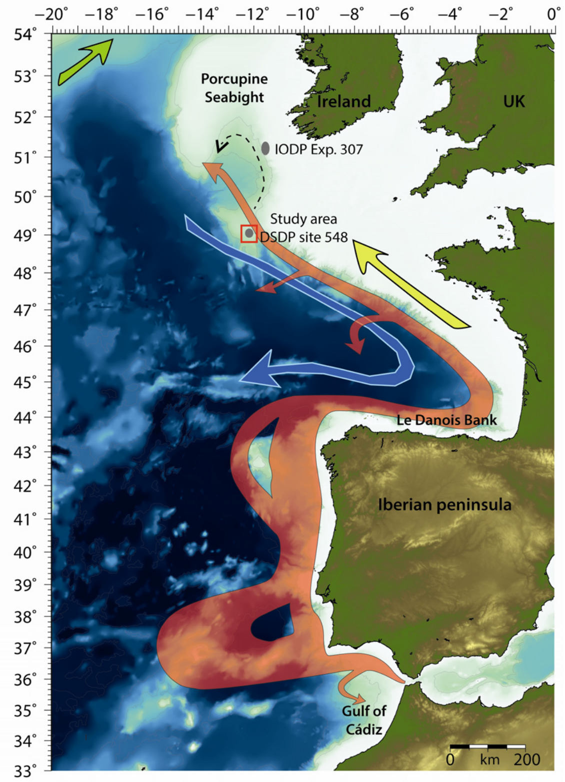

FIGURE 1. North eastern Atlantic map with major water masses (modified from Iorga and Lozier 1999). Green: Gulfstream north eastern branch; yellow: Eastern North Atlantic Water; red: warm and saline MOW; blue: colder and less saline Labrador Sea Water.

DATA AND RESULTS

This study uses a network of ~200km long high-resolution single channel sparker seismic data centred around DSDP site 548, as well as high resolution swath bathymetry data. Downhole log geophysical data from DSDP site 548 have been correlated with the interpreted seismic stratigraphy to obtain a realistic Time/Depth chart. Three seismic units have been differentiated within the middle Miocene to late Pleistocene sedimentary record, and are separated by erosional amphitheatre like structures respectively correlated to the late Pliocene (~2.7Ma) and middle Pleistocene (~0.5Ma). Seismic unit 3 is fairly homogenous along the study area and has been given an early/middle Miocene to late Pliocene age. Seismic unit 2 is bounded by previously cited erosions attributing an overall early Pleistocene age, and is characterized by the formation of a complex series of sediment waves. Seismic unit 1 is erosion free and late Pleistocene in age, where similar sediment wave field than unit 2 developed (Figure 2).

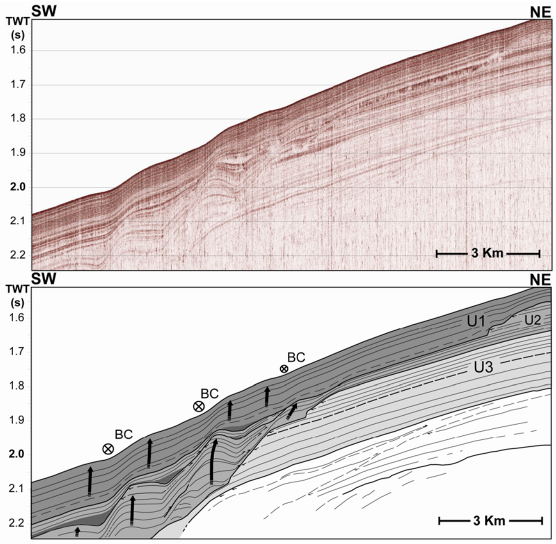

FIGURE 2. Seismic profile GS120610 and seismic stratigraphic interpretation showing sediment waves development within seismic units 1 and 2.

The sediments waves found in units 2 and 1 developed at current depths ranging between 1200 and 1600m. They are asymmetric with an elongated downslope-facing flank. They are ~1.5km in wave length and do not exceed 30ms amplitude. They vary from parallel to somewhat oblique to the slope (less than 20°) and show a clear upslope migration. Waves strictly developed against the steep palaeo seafloor irregularities.

DISCUSSION

Erosional unconformities, limiting unit 2, are interpreted as submarine landslide scars. They are contemporary with the late Pliocene revolution (LPR) and after the middle Pleistocene revolution (MPR). Both periods were characterised by dramatic sea level lowering which may have triggered mass wasting events throughout sediment accumulation and over-steepening induced slope instabilities.

Sediment wave morphology is strongly dependant of steep palaeo-escarpments, they have an overall NNE migration, and amplitudes generally decrease toward the wave field edges. Later observations are rather typical for bottom current processes. A turbiditic origin is ruled out since turbiditic systems are absent at Goban Spur.

Sediment waves range current depths corresponding to the MOW lower interface where a strong pycnal gradient is formed. Such interface may have developed an enhanced internal tide/wave regime that could be involved in the waves formation. Khelifi et al. (2009) proved that MOW was already present at site 548 (i.e. ~1250m depth) within the course of the middle Pliocene. However, the absence of morphological structures within unit 3 suggests a limited bottom current regime. The base of sediment waves at Goban Spur is correlated to the first occurrence of CWC within the Belgica mounds province (Porcupine Seabight) which was also followed by a lengthy erosional or sediment bypass period (Huvenne et al., 2009). Despite space/time MOW migration must be expected, especially during the late Pleistocene, our results suggest it has considerably influenced both sites from the late Pliocene.

CONCLUSION

The bottom currents variability at Goban Spur is representative for the MOW palaeoceanography the North-East Atlantic Ocean. Bottom currents became energetic enough from the late Pliocene to present to lead to the formation of large-scale sediment waves.

Submarine landslides at Goban Spur are contemporary with global climatic reorganizations during the late Pliocene and middle Pleistocene.

The near-to-complete lower Pleistocene sequence at Goban Spur corresponds to an erosive or non-depositional period within the Porcupine Seabight.

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Large sediment waves on the Gulf of Valencia continental margin (NW Mediterranean): internal structure and evolution

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Abstract: *Several fields of sediment waves have been recently observed over the Gulf of Valencia (NW Mediterranean) continental margin. Based on their morphology and internal structure, two different sets of sediment waves can be distinguished. Large sediment waves with 500 to 1000m wavelengths and 2 to 50m wave height are developed on the foreset region of the prograding margin clinoform, being found from 250 to 850m water depth. Additionally, over the outer shelf region, a second group of sediment waves also develops; displaying wavelengths in between 400 m and 800m and heights of 2 to 4m. Eustatic cycles control the development of the sediment waves on the outer continental shelf, which show several erosional truncations and growing stages. However, the sediment waves over the continental slope region seem to continuously evolve through time, at least since the Early/Lower Pliocene, without being affected by sea level changes.*

Key words: *NW Mediterranean, sediment waves, prograding margin, eustatic changes.*

INTRODUCTION

Sediment waves have been described all over the world in many different marine sedimentary environments. Few cases of sediment waves being developed on continental slope regions have been reported and described. Some of them were first misinterpreted as a result of gravitational slope failure. This is for example the case of the “Humbolt slide” (Lee et al., 2002) or the sediment undulations on the Landes Plateau (Faugères et al., 2002).

In the NW Mediterranean Sea, sediment undulations have been observed over the Gulf of Valencia continental slope and were also initially related to creep-like deformation (Díaz del Rio et al., 1986). However, recently acquired swath bathymetry and seismic profiling data allowed determining that these sediment undulations are sediment waves. Contemporary hydrodynamic data of the study area have determined the presence of strong near-inertial internal wave activity (van Haren et al., 2013), which presumably is the most likely mechanism for the sediment wave development. This study offers new information for the morphological, stratigraphic and architectural characterization of these sediment waves, providing a record of internal wave activity throughout the Pliocene and Pleistocene.

DATA

Detailed swath bathymetry data from the Valencia Trough (Fig. 1A) was used to analyze the geomorphology of the Gulf of Valencia continental margin, while the internal structure of the sedimentary prograding wedge was interpreted from a variety of seismic reflection profiles, providing different penetrations and resolutions. 3.5kHz parametric sub-bottom profiles (TOPAS), single-channel (Sparker), and multi-channel (Airgun) seismic reflection profiles were used to analyze the continental slope sedimentary record (Fig. 1B).

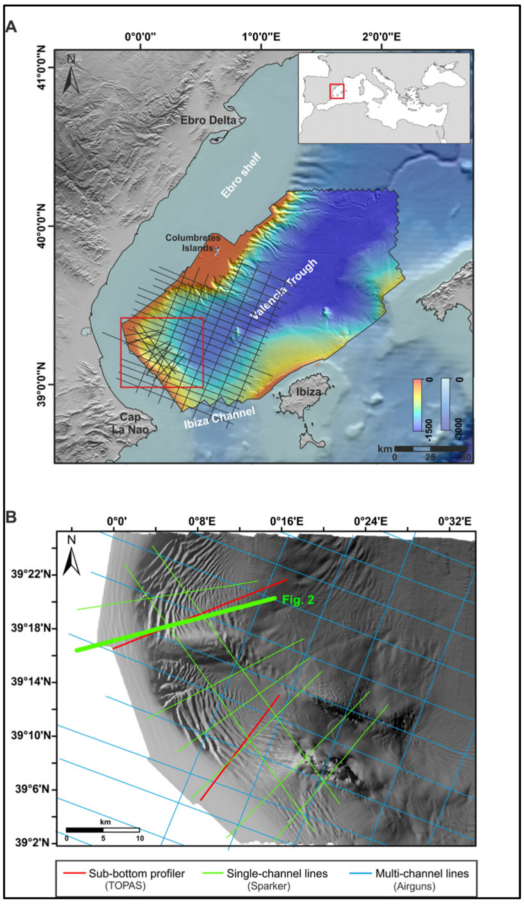

FIGURE 1. A) Bathymetric map from the Valencia Trough showing the study area (red square) and the grid of seismic profiles (solid lines). B) Shaded relieve morphology of the study area indicating the different sources of the seismic reflection profiles used in this study.

RESULTS AND DISCUSSION

Several fields of sediment waves occur over the Gulf of Valencia continental margin. The best developed sediment waves occur on the continental slope, from 250m depth to the continental rise, at 850m depth (Fig. 1B). Morphological parameters determined from the multibeam data show that the sediment wavelengths range between 500 and 1000m, with the largest ones observed on the uppermost part of the slope. Maximum wave heights of up to 50m are observed on the upper-slope, decreasing downslope to just 2m high in the continental rise. Analysis of their internal structure shows continuous internal reflectors, with waves merging down-section and sediment wave packages decreasing in thickness downslope (Fig. 2A). Sediment waves on the lower part of the slope are aggradational, and become up-slope migrating sediment waves on the upper part of the slope.

The outer continental shelf displays sediment waves that are smaller in length and height, ranging between 400 and 800 m and from 2 to 4m, respectively. These sediment waves show a clear up-slope migrating pattern. Several sediment depositional units can be distinguished in seismic reflection data. Some of these units show successive development of sediment waves, which are truncated by erosive surfaces, apparently linked to eustatic sea level oscillations (dark blue lines in Figure 2B). Such erosive surfaces can be followed downslope into conformable strata of the sediment waves on the slope.

Over the continental slope, apparent constant bedform growth is observed in the different units between two successive erosional unconformities (Fig. 2A), suggesting that sea level variations have not affected the sediment waves development. These conspicuous features are observed on the foreset region of the prograding margin clinoform, and have been preserved in the sedimentary record since the Early/Lower Pliocene. Assuming that internal wave activity is the main mechanism for sediment transport and deposition over the Gulf of Valencia slope, and hence for the formation of these sediment waves, this oceanographic process might have been present in this sector of the margin almost since Zanclean reflooding of the Mediterranean Basin, following the Messinian desiccation event ~5.6Myrs ago (García-Castellanos et al., 2009).

ACKNOWLEDGEMENTS

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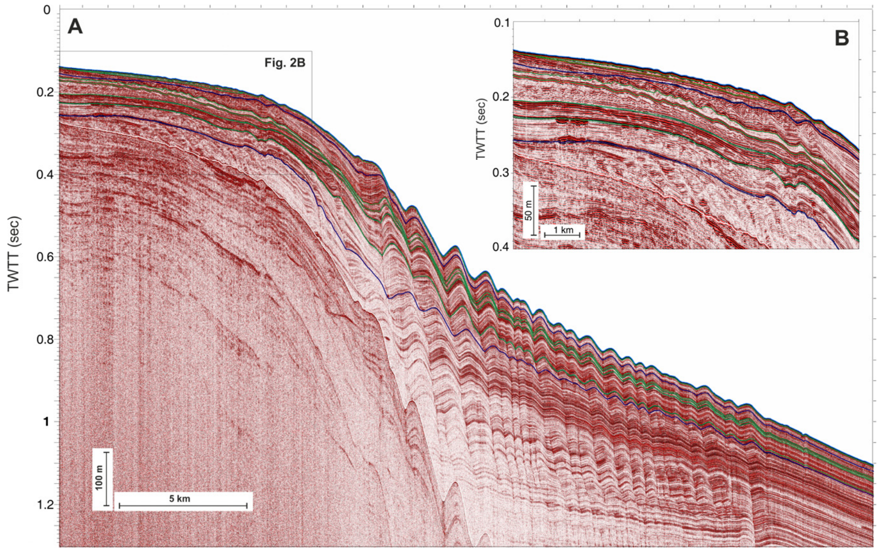

FIGURE 2. A) Single-channel line (Sparker) showing the two sets of sediment waves found on the Valencia continental margin. B) Detail of the various developing stages of the outer shelf sediment waves, truncated by erosional surfaces (dark blue lines). Dark green lines delimit the different sediment depositional units.

Giant Mudwaves in the NW Argentine Basin (South Atlantic)

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Abstract: *A large field of giant mudwaves was mapped in the NW Argentine Basin for the first time. The field is subdivided into buried and surficial part affected by different circulation patterns. It is suggested that global changes in climate and bottom circulation resulted in formation and burial of several mudwave "generations" revealed in the study area.*

Key words: *contourites, bottom currents, Antarctic waters, continental rise, South Atlantic.*

INTRODUCTION/BACKGROUND

Mudwaves are widespread on the Argentine Basin characterised by a highly dynamic oceanographic regime. The mudwave fields in the southern and central part of the Basin are well studied while those in the North remain poorly understood (Flood and Shor, 1988).

This work characterizes a new large field of giant mudwaves in the NW Argentine Basin. The field ranges from 3400 to 4000m water depth. It partly covers the Santa Catarina Plateau (SCP) and extends into the Santos Basin. Bottom circulation in the study area is generally controlled by water of Antartic origin, the Lower Circumpolar water (LCPW) that extends below 3500m water depth. (Morozov et al., 2010) (Fig. 1). Above the LCPW the North Atlantic Deep Water (NADW) is identified.

DATA AND RESULTS

The mudwave field has been mapped on base of very high resolution seismic profiles (4kHz) and multibeam data. Seismic profiles revealed that mudwaves are not only confined to the seafloor, also buried (draped) mudwaves can be identified within the sediment column down to 60m below the seafloor, in the northern part of the field. The wave field covers about 42000km^2 of the sea-floor (~35000km^2 excluding buried area).

The surficial mudwaves represent roughly symmetric sediment mounds with wave heights of 10 to 60m, wavelengths of 2–5km and a crest length up to 30km. No migration evidence is observed. The crest lines of the waves are sinuous and often bifurcated. Mudwaves are oriented with their long axes in NW-SE direction at an angle of 5° to 45° respect to regional contours. The biggest waves are found on the SCP slopes (Fig 2.A). Wave height decreases toward the plateau summit and to the centre of the Santos Basin. Buried mudwaves are overlapped by acoustically stratified deposits with roughly horizontal parallel high-amplitude reflectors (Fig. 2B).

The base of the southern plateau slope is mostly characterized by chaotic seismic facies with hummocky relief (Fig. 2A).

Four sediment cores were retrieved (during cruises 33, 43, RV "Akademik Ioffe"; cruise M29/2, RV "Meteor"). They indicate that surface sediments are generally composed of muddy contourites. Cores from the buried area recovered in in their upper parts a 26-cm thick turbidite sequence (GeoB2112-3, 4010m; Bleil et al., 1993) and a thick layer of homogenous muds interpreted as hemipelagites (AI-3153, 4030m). A core collected on the northern slope of the SCP (AI-3154, 3592m) contains numerous thin silt-enriched layers and that one retrieved from the plateau summit (AI-2443, 3410m) is characterized by muddier sediments. All the cores recovered Pleistocene deposits in their lower parts (as inferred from the planktic foraminiferal data). A preservation of foraminifera test varies along the cores with some intervals of strong test dissolution.

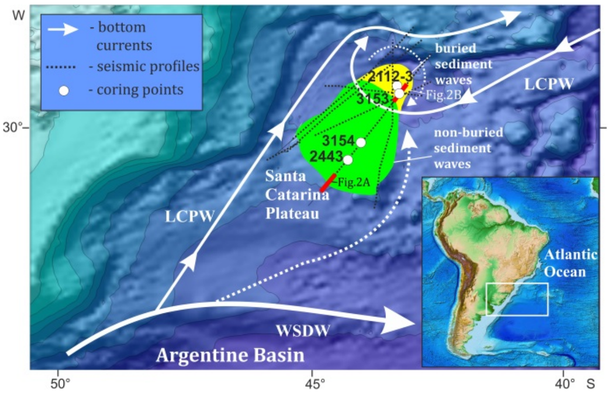

FIGURE 1. Bathymetric chart of the study area with sketched regional bottom circulation and location of mudwave field, coring points and seismic profiles. LCPW – Lower Circumpolar Water; WSDW – Weddell Sea Deep Water.

DISCUSSION

Symmetric shape of mudwaves suggests either low current velocities insufficient to produce migrating features or interplay between contour and internal tidal currents (which are internal waves with tidal periodicities (Dykstra et al., 2012)). Formation of giant mudwaves implies long-term quasi-persistent action of high-velocity flow (Flood and Shor, 1988). It means that the first suggestion is incorrect. Internal waves occur on the density boundary between waters of Antarctic and North Atlantic origin. A transition zone between these waters affects the slopes of the SCP. Wave height and grain-size variations indicate also topographic control of flow velocity. The SCP as a large topographic obstacle causes turbulence and a flow velocity increase.

Bedding patterns typical for internal tide deposits were not observed in cores. Deposition of contourites in the study area is related to bottom currents of Antarctic waters and their interface with the waters of North Atlantic origin.

The buried part of the mudwave field is embraced by a large gyre formed by a return branch of the LCPW (Fig. 1). Mudwave burial is a result of increased deposition of contourites in the centre of the gyre. During the last deglaciation an intensity of the LCPW return branch decreased due to lower production of the Antarctic waters. It led to domination of hemipelagic settling and deposition of hemipelagites recovered by the core AI-3153. This suggestion does not contradict to planktic foraminiferal data.

Seismic profiles RC1605, RC1610 revealed several generations of buried mudwaves underlying the modern wave field. It means that evolution of the observed deposition system is a cyclic alternation of sediment wave formation and burial. Such alternation is considered to be related to global changes in bottom circulation and climate.

CONCLUSIONS

Formation of the giant non-migrating mudwaves is controlled by sea-floor topography, strong bottom and internal tidal currents.

Mudwave burial is a result of contourite deposition in the centre of the large gyre formed by the return branch of the LCPW. Global changes in bottom circulation and climate in the past could result in a cyclic alternation of mudwaves formation and burial.

ACKNOWLEDGEMENTS

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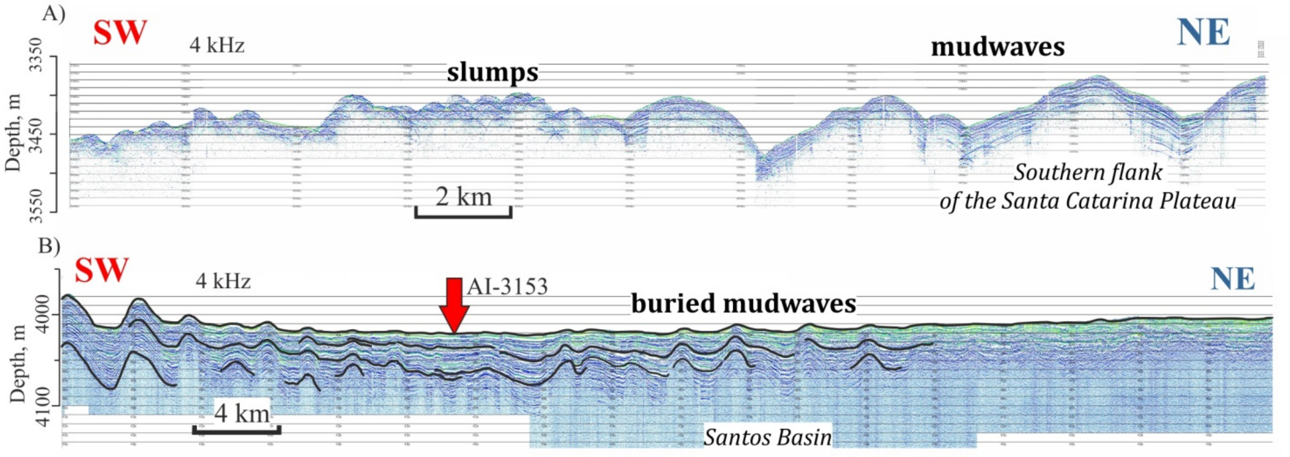

FIGURE 2. Fragments of very high resolution seismic profiles: A) sediment waves on the southern slope of the Santa Catarina Plateau; B) draped and buried mudwaves in the Santos Basin. Location of the seismic profiles shown on Fig. 1.

Clean and well sorted sands in the deep Argentine Basin (SW Atlantic): the role of the Antarctic Bottom Water

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Abstract: *A thick deposit of clean and well sorted quartz-rich sand found in the Argentine Basin (SW Atlantic) at about 5300m water depth is interpreted as a contourite drift. A set of cores from the Argentine basin, continental rise and slope have been studied to reconstruct the source-to-sink route of these sediments. The region of Bahia Blanca is proposed as the probable source area. Sediments were transferred to the continental rise within downslope gravity flows, captured by the Antarctic Bottom Current and transported to the deep basin. The fine components of the sediment were removed by bottom flows acting in the deep basin, leaving a lag of sand.*

Key words: *SW Atlantic, Argentine Basin, deep sands, AABW.*

INTRODUCTION

The occurrence of extensive, several meters thick deposits of clean and well sorted sand have been observed recently at the deep oceans (Rebesco et al., 2014). In the Argentine Basin, at ~ 5300m water depth, accumulation of sand were first identified in the seventies and interpreted as turbidites associated with the downslope processes of the adjacent margin (Ewing and Lonardi, 1971). Now, we revisited this interpretation on the basis of (1) current knowledge on contouritic processes acting at the Argentine margin (e.g. Hernandez-Molina et al., 2009), (2) increased understanding of the sediment facies draping this margin (e.g. Bozzano et al., 2011), and (3) an integrated view of the role of bottom currents and benthic storms in altering the sedimentary processes. The objective of the study is to identify the source area of the sands lying on the deep basin and to reconstruct their source-to-sink route.

STUDY AREA

This study is focused on the Argentine margin and basin, between Bahia Blanca (BB) and Mar del Plata (MdP) locations. Here, the shelf is 350-400km wide; the slope is dissected by the Mar del Plata and Bahía Blanca canyon systems; the continental rise ranges from 4000 to 5000m and the Argentine Basin depths exceed 5000m (Fig. 1). The margin is swept by south-originated waters (Malvinas current, Antarctic Intermediate and Bottom Waters), flowing toward the north and by the Brazilian current and North Atlantic Deep Water that flow to the south. The basin is between the mean frontal positions of the Brazil and Malvinas Current Extensions (40ºS), where both currents flow to the east (Reid et al., 1977).

MATERIAL & METHODS

Four cores were collected by the Argentine Navy Hydrographic Survey (SHN): one in the deep basin (C5, at 5283m), one in the BB continental rise (C9, at 4534m), and two in the BB lower slope (T407, at 1960m and T409, at 2638m). The lithological information stored at GeoMapApp (http://www.geomapapp.org) on several other cores located in the same area was also used (Fig. 1). Grain-size analyses were performed on discrete samples from SHN cores with a CILAS laser particle size analyzer at the University of Buenos Aires and sand fraction composition was determined under a binocular. The surface of 10-20 quartz grains from selected samples will be investigated under a Scanning Electron Microscopy at the University of La Plata. Other cores from BB slope and rise hopefully will be obtained in an oceanographic cruise planned for June-July 2014.

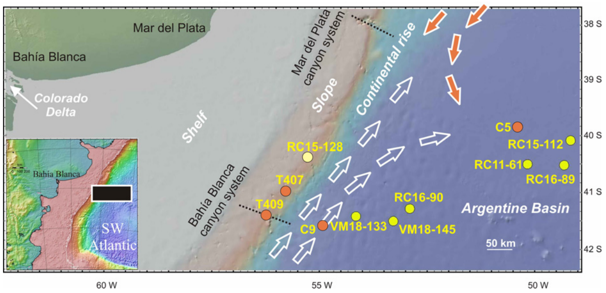

FIGURE 1. The study area with location of SHN cores (red dots) and other cores (yellow dots). Surface circulation is shown by white (Malvinas Current) and red (Brazilian Current) arrows.

RESULTS

Deep basin. Core C5 is formed by clean and well-sorted fine sand dominated by quartz grains. Medium and coarse sand proportions increase from top to bottom (10-40% respectively). Among other cores located nearby, we found that core RC11-61 displays medium to coarse grained quartz and that cores RC15-112 and RC16-89 also contain sand with thickness of up to 7 meters in core RC15-112.

Bahia Blanca continental rise. Core C9 is dominated by fine sediments with a lens of fine sand at 256-273cm as the only exception. Core RC16-90 contains 185cm of moist and unconsolidated sand, consisting mainly of abundant sub-rounded to rounded quartz grains, frequent rounded dark minerals and occasional igneous rock fragments. Also, sorted and rounded medium to coarse grained quartz-feldspathic sand occurs as layers of variable thickness in cores VM18-145 and VM18-133.

Bahia Blanca Slope. Cores T409 and T407 display up to 1.5m of fine sand. This consists in abundant sub-angular to sub-rounded quartz and feldspars grains, frequent dark minerals, glauconite, and foraminifera in core T407. Core RC15-128, located northward at 2041 m water depth, is made of 630cm of pure sand with sub to rounded quartz grains, igneous rock fragments and granules, gravel and pebbles of sedimentary rock.

DISCUSSION

The finding of medium to coarse -grained and well-sorted sands at deep depths implies the persistence of strong and stable bottom currents, entailing large amount of resuspended sediments (Hollister and McCave, 1984). In the Argentine continental rise, plausible mechanisms for sediment entrainment in deep contourites involve the reworking of downslope gravity- turbiditic and debris-flows and the resuspension from benthic storms.

Downslope gravity flows characterize the entire margin. Turbiditic deposits are associated with the MdP and BB canyons; evidences of debris flows have been found in the BB (unpublished data) and MdP (e.g. Krastel et al., 2011) slopes; mixed turbiditic-contouritic deposits have been described for BB continental rise (Hernandez-Molina et al., 2009). Thus, a large amount of sediments is available for being reworked by bottom currents. Resuspension from abyssal storms in general occur where high surface eddy kinetic energy (EKE) and strong near-bottom mean flow coexist (Hollister and McCave, 1984). Both conditions are fulfilled in the study area. The region has unusual high levels of both surface and abyssal EKE (Weatherly, 1993). The good size sorting observed in the sands is probably achieved along repeated benthic storms with periodic resuspension-transport-deposition events. In the basin, average values of current speed of 16 cm.sec^{-1}, with a few peak values > 30 cm.sec^{-1}, have been reported at 5415m water depth (Richardson et al., 1993); this current speed allows fine components to be removed from the drift (Hollister and McCave, 1984).

As for the source area of the abyssal sands, likely candidates are MdP and BB regions. Sediments from MdP margin consist in muds with very fine sands as the coarsest size; dark minerals and angular grains of feldspar are abundant, with less quartz (Bozzano et al., 2011). Both grain-size and composition make MdP sediments dissimilar to those found in the deep basin. The margin off BB seems a more plausible source area. Today, BB coastal region is covered by dunes and mantles of loess and sands of volcano-pyroclastic mineralogical composition (Zarate and Blasi, 1993). The Colorado River formed a large deltaic system that was very active when sea level was 130m lower than today (e.g. during glacials). Huge amount of coarse materials was probably accumulated at the shelf where they underwent successive cycles of erosion and deposition until they reached the present shelf-slope transition. Afterward, debris and turbiditic flows transferred these sediments downslope where were captured by bottom currents flowing northward along the continental rise.

CONCLUSIONS

- Clean and well sorted sands found in the Argentine Basin are part of a large contourite drift.
- Bahia Blanca region is proposed as a plausible source area for these deep sands.
- Along its source-to-sink route, sediment size-sorting was achieved by repeated resuspension, transport and deposition events favoured by benthic storms.
- In the Argentine Basin both magnitude and direction of bottom flows allow to remove the fine components of the sediment, leaving a lag of sand.

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The Kveithola Drift (western Barents Sea): Preliminary results from the CORIBAR Cruise

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Abstract: *The CORIBAR cruise (08/2013) addressed ice dynamics and meltwater deposits by coring inside the narrow (100km long, 13km wide) glacially eroded Kveithola Trough, NW Barents Sea. During this cruise, geophysical data (PARASOUND sub-bottom and multibeam profiles) and sediment cores were also collected from the Kveithola Drift. This drift is a complex morphological sediment body confined to the innermost part of the Kveithola Trough. It consists of two main depocenters separated by a buried glacigenic grounding-zone wedge. The internal acoustic reflections show a drastic thinning, i.e. long-term condensation, towards the northern flank of the Kveithola Trough. Here, a distinct E-W running moat is developed which underlines the strong influence of dense bottom currents on sedimentation. On the contrary, some of the characteristics of sedimentary facies and preserved biota in the surface sediments of the Kveithola Drift hint to a stagnant environment, strongly affected by low-oxygen conditions. The PARASOUND data and sediment cores from this intriguing sediment drift are expected to contain a high-resolution record of the drift formation processes as well as the Holocene palaeo-environmental changes.*

Key words: *Shallow-water contourites, ice-stream trough, dense-flow cascading, Barents Sea, Holocene.*

INTRODUCTION

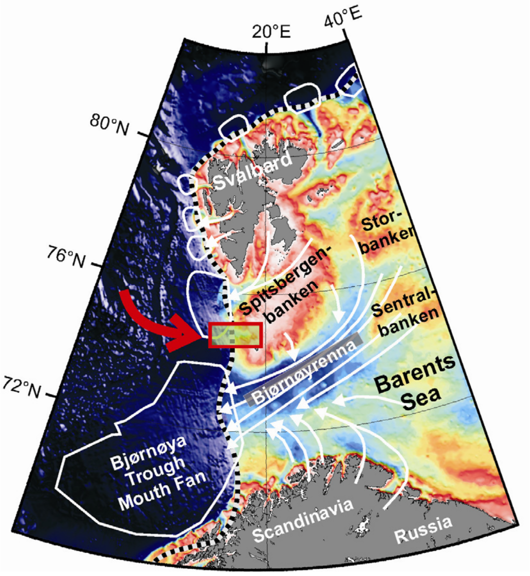

FIGURE 1: Overview map showing the western Barents Sea. Box + arrow indicate the Kveithola Trough (modified from Andreassen et al., 2008).

Whether contourite deposition can occur in shallow waters, i.e. on continental shelves, is debated. Nevertheless, current-controlled sediment bodies in shallow waters may show a shape and internal geometry very similar to those found in the deep ocean. We present here an outstanding example of a contourite drift which has formed under favourable morphological and bottom-flow conditions inside a partly filled glacigenic palaeo-ice-stream trough.

DATA AND RESULTS

The Kveithola contourite drift is located in the innermost part of the Kveithola Trough. This trough has formed during the past glacial cycles and extends about 100km from the shallow Barents Shelf towards the open Norwegian Sea (Fig. 1). The trough is 13km wide and 200m deeper than the surrounding shallow shelf. Whilst grounding-zone wedges and glaciomarine deposits have formed during deglacial times (Rebesco et al., 2011; Bjarnadóttir et al., 2013), a drift body has grown during post-deglacial times, i.e. after the modern ocean conditions have established on the Barents Shelf (Fig. 2; Fohrmann, 1996; Bjarnadóttir et al., 2013).

During the CORIBAR expedition (RV Maria S. Merian, 08/2013), we run a dense grid of PARASOUND sub-bottom echosounder profiles across the contourite drift and took 8 sediment cores (Hanebuth et al., 2013). The aim was to analyse the environmental processes involved in the history of this depocenter in terms of bottom-flow pattern and intensity, of material source and transport routes, and of palaeoceanographic control.

The body shows two major depocenter separated by the transverse-oriented elevation of a buried grounding-zone wedge, with the western major accumulation centre being 35m thick. The lateral continuity of the sub-bottom reflectors in combination with high-resolution sediment-core scans (magnetic susceptibility, density, XRF) allows for a dense-spaced and robust correlation framework.

Whilst the southern margin of the contourite body is rising and attached to the southern flank of the Kveithola Trough, the northern margin is controlled by a well-developed moat (Fig. 2). The internal strata pinch out here and bed condensation clearly indicates how the confined bottom current has controlled deposition here from the very beginning.

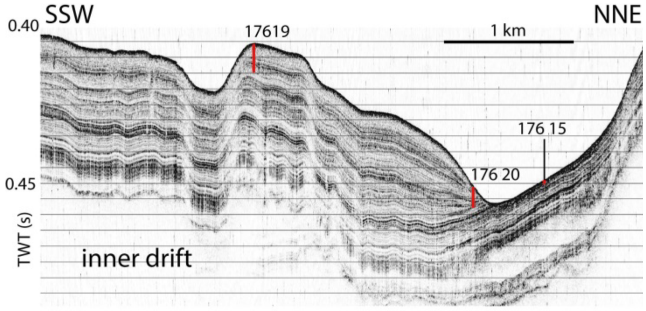

FIGURE 2: CORIBAR PARASOUND profile across the inner part of the Kveithola Drift. Note the abrupt pinch-out of the internal reflectors towards the northern flank where a pronounced moat has formed. The locations of some GeoB sediment cores are indicated by red bars.

The contourite body itself shows a two-stage stratigraphic formation history. The upcoming analysis of the sediment cores, which cover all stratigraphic levels of the contourite drift, will allow insight into the stratigraphic changes as well as into lateral variability of bottom sediment transport control for the entire time of formation.

CONCLUSIONS

A former modelling study has suggested that the gravity-driven bottom-flow conditions inside the modern Kveithola Trough result in a complex pattern of bottom-flowing eddies (Fohrmann, 1996). By combining our long-term architectural investigations and short-term depositional pattern with existing oceanographic data sets and the former bottom-flow simulation, we will be able to investigate:

- How this contourite drift has formed
- Which major environmental forces have control on sedimentation;
- How these conditions have fluctuated on short time-scales;
- How they have varied during the past several thousands of years.

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Contourites in the Middle Caspian Sea?

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Abstract: *New high-resolution seismic profiles revealed detailed structure of the Quaternary sediments of slopes and basin of Central Caspian Sea. Comparison of some observed sediment structures with typical accumulative drifts, erosion moats and sediment waves of different genesis, allows re-interpreting of recent seismoacoustic, geological and hydrological data from viewpoint of contourite conception. Such approach results in revealing of several contourite systems for the first time in the Caspian Sea.*

Key words: *Caspian Sea, moat, sediment waves, drift, gravity flow.*

INTRODUCTION

The Caspian Sea is considered to be the greatest lake of the world, although it is composed of salt water and lying on oceanic crust. It covers area of ~371,000km^2 and its maximum depth is 1025m. This setting allows us to speak about the "Shallow-water and lake contourites" problem, which is rather poorly presented in literature. At the same time, the Caspian Sea has high hydrocarbon potential with long-going explorarion on shallow shelf and planned exploratation on shallow shelf and planned exploitation in local deepwater basins. The latter fact links our study with "economic relevance of contourites within hydrocarbon systems", while possible geohazards for underwater constructions and pipelines takes us to "influence of the lateral and temporal variability of contourite sedimentation on slope (in)stability".

By geography and geology the Caspian Sea is divided into three distinct parts: the Northern, Middle and Southern Caspian Sea (Fig. 1). The natural borders of these regions are large basin-crossing structural highs: i.e. the Mangyshlak Threshold and the Apsheron Threshold. Our study is focused on the continental rise and slopes of the Middle Caspian Sea, where high resolution seismic surveys with sparker and narrow-beam parametric sub-bottom profiler "SES-2000 standard" were carried out (Merklin and Levchenko, 2005; Putans et al., 2010). The Middle Caspian Sea is characterized by a counterclockwise circulation of surface currents (Fig. 1). Although deep-water currents are poorly studied there, it is proposed that the surface circulation patterns control bottom circulation. Thus, a contour current is flowing along the western slope roughly from NNW to SSE, while along the eastern slope it is flowing from SSE to NNW. Recent hydrological (Ambrosimov et al., 2010) and mineralogical (Kozina et al., 2013) studies revealed this bottom current along the western slope with a maximum velocity 0.5m.s^{-1}. Strong upwelling of cold deep water is observed near the eastern slope.

Our study is the first effort to consider sedimentation processes in the Caspian Sea in relation to countorite deposition. Taking the Middle Caspian Sea, we carefully examine some bedforms, similar to typical contourites features observed worldwide (Deep-Water Circulation, 2010).

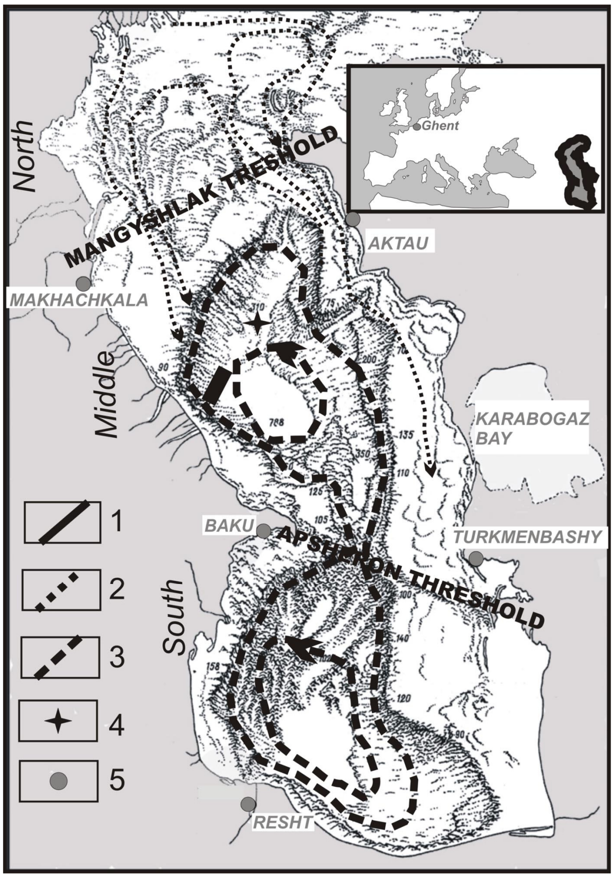

FIGURE 1. Caspian sea.1 – profile, fig.2, 2-shelf currents, 3-contour currents, 4-deep well, 5-city.

RESULTS AND DISCUSSION

Various sediment waves were distinguished recently in high resolution seismic profiles collected in the Middle Caspian Sea (Levchenko et al., 2008; Levchenko and Roslayakov, 2010; Putans, 2013). The largest (~150km x 50km) sediment wive field is situated on the western slope. It seems to be formed by gravity-driven downslope turbidity currents in contrast to typical contourite sediment waves in oceanic abyssal plains and continental rises, which are generated by along-slope flowing bottom currents (Deep-Water Circulation, 2010; Borisov, 2013). The sediment wave field terminates at the slope break towards the lower slope, of which the general morphology is similar to that of the contourite Ewing Terrace on the Argentina continental slope (Deep-Water Circulation, 2010).

Distinctive depositional features with discordant inner reflectors and curved down basal reflectors occurs near the base of the western slope of the Middle Caspian Sea and two recent scours were revealed closer to the slope (Fig. 2). They likely represent contourite features - drift and moats respectively (Deep-Water Circulation, 2010, Borisov, 2013). Presumably, these features, as well as the terrace above, were formed by a Coriolis-driven western branch of the alongslope current.

One of most spectacular features of the Middle Caspian Sea is a large system of channels/canyons near the Mangyshlak Threshold (overall Volga, Terek and Ural fan). Several fields of sediment waves on levees (Fig. 2) seem to be formed by the well-known mechanism of overspilling from underwater channels (Putans, 2013).

Regular undulations occur on the eastern slope of the Middle Caspian Sea as well, but they have rather not sinuous but rectangular shape associated with post-sedimentary plastic deformation, gravitational folds or creep (Levchenko and Roslayakov, 2010). However, taking in account strong bottom currents there and the similarity of these undulations with wavy structures on the Namibian continental slope interpreted as sedimentary waves (Deep-Water Circulation, 2010), possible distribution of contourites should be evaluated more careful.

CONCLUSIONS

Re-interpretation of recent high-resolution seismic profiles correlated with sediment cores reveals *for the first time in the Caspian Sea* several contourite systems with typical structures as drifts, moats, terraces and sediment waves. However, the detailed distribution pattern of these contourite systems is a question of future detailed studies (multibeam bathymetry and bottom currents measurements).

ACKNOWLEDGEMENTS

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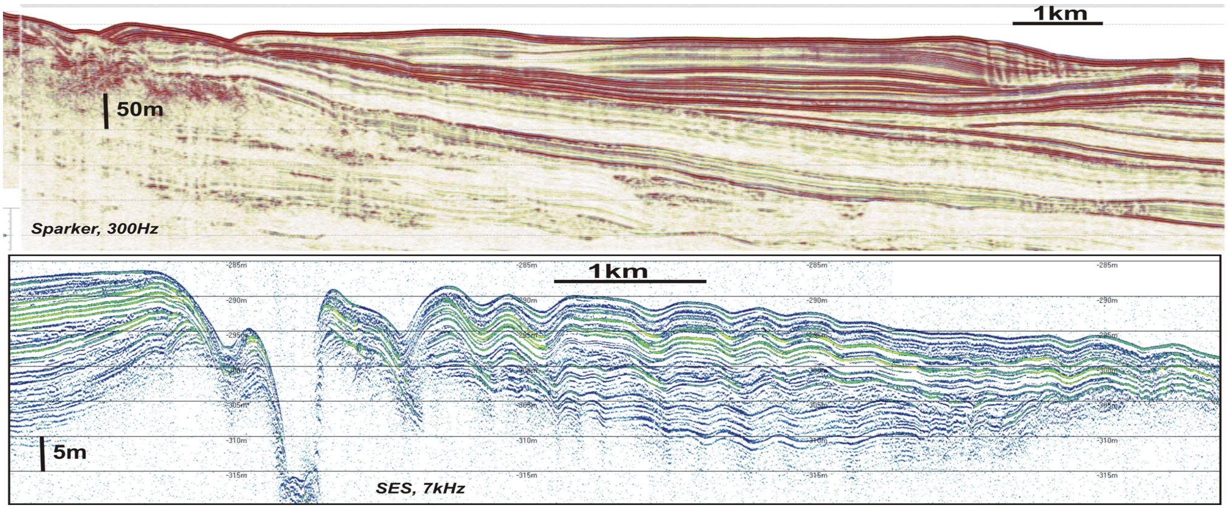

FIGURE 2. Contourite drift beside foot of the western slope (above); sediment waves on channel levees near the Mangyshlak Threshold (below).

Deep-water depositional characteristics and relationship with bottom currents at the intersection of Xi'sha Trough and Northwest Sub-Basin, South China Sea

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Abstract: *Simulated flow field characteristics at 2000m depth, at the intersection of the Xi'sha Trough and the Northwest Sub-Basin, show a major anticyclonic gyre. These westward flowing deep currents sweep the South China Sea northern margins until they encounter the Xi'sha Trough and the Xi'sha Uplift. Some of them flow into the Xi'sha Trough and continue going westwards; others change their heading towards to the south and sweep the Xi'sha Uplift eastern margins. In the eastern margins, current velocities could exceed 2cm.s^{-1} as a result of bottom current intensification (after being deflected by the uplifted morphology). Hydrodynamics over the remaining parts of the Xi'sha Uplift zone (south of the Xi'sha Trough) are complex. Fortunately, high-resolution 2D seismic data enable to reveal the depositional characteristics of bottom currents below 1800m depth in this area, whereas marginal troughs and confined drifts are recognized in the vicinity of the obstacle terrains. Major troughs formed north of those obstacles, indicating mainly westward flowing bottom currents in this area. This study focuses on the analysis of deep-water depositional products, created by bottom currents and the relationship with the South China Sea Deep Water Circulation.*

Key words: *contourites, bottom currents, flow field characteristics, Xi'sha Trough, South China Sea*

INTRODUCTION AND BACKGROUND

The intersection of the Xi'sha Trough and the South China Sea (SCS) Northwestern Sub-Basin (112.5°E to 114.5°E and 17.5°N to 18.5°N) represents a critical location in the SCS deep-water sedimentary dynamics, due to the convergence of the Xi'sha Trough, the SCS northwestern continental-oceanic transition zone and the abyssal plain (Fig. 1a, b). The major SCS Intermediate Water (350 to 1500m depth) sweeps the SCS northern margins from west to east, while the South China Sea Deep Water circulation (>1500m depth) is known to flow westward (Fig. 1a). Previous studies on deep-water depositional characteristics and relationship with bottom currents at the intersection of Xi'sha Trough and Northwest Sub-Basin are rare. This study focuses on the analysis of deep-water deposits created by bottom currents in this area, and their original relationship with the South China Sea Deep Water Circulation (>1800m depth) and the sea floor topography changes.

DATA AND RESULTS

The flow field characteristics at the intersection of Xi'sha Trough and Northwestern Sub Basin are derived from the HYCOM+NCODA Global 1/12° Analysis (GLBa0.08) data (Fig. 1b), which shows the circulation at 2000m depth as an anticyclonic gyre. The conductance-temperature-depth data and seawater temperature and salinity features indicate that these currents could belong to the westwards SCS Deep Water circulation (Chen et al., 2014). When encountering the Xi'sha Trough and the Xi'sha Uplift, some of these currents flow into the Xi'sha Trough and continue going westwards. Others change their heading towards to the south and sweep the Xi'sha Uplift eastern margins, with current velocities exceeding 2cm.s^{-1}. It is also noted that weak eastward currents flow along the southern wall of the Xi'sha Trough, and the hydrodynamic situation over the Xi'sha Uplift zone is complex.

High-resolution 2D seismic data enable to reveal the depositional characteristics of bottom currents below 1800m depth in the Xi'sha Uplift zone (A-A', B-B' and C-C' in Fig. 1). It mainly consists of marginal troughs and confined drifts that developed in vicinity of different obstacles (O1, O2, O3n and O3s in Fig. 1c1). Marginal troughs are 2-3 km wide and ~30m deep, showing non-depositional or erosive features. Drift deposits developed associated to the marginal troughs, flanking the troughs (Fig. 1A-A') or being confined between two obstacles (Fig. 1B-B', 1C-C'). The drifts show parallel, continues reflectors with mid-high amplitudes, and they have thickness of 30 to 50ms TWT). Small scale depressed features (furrows, depth <10m) can be observed on top of the drift deposits.

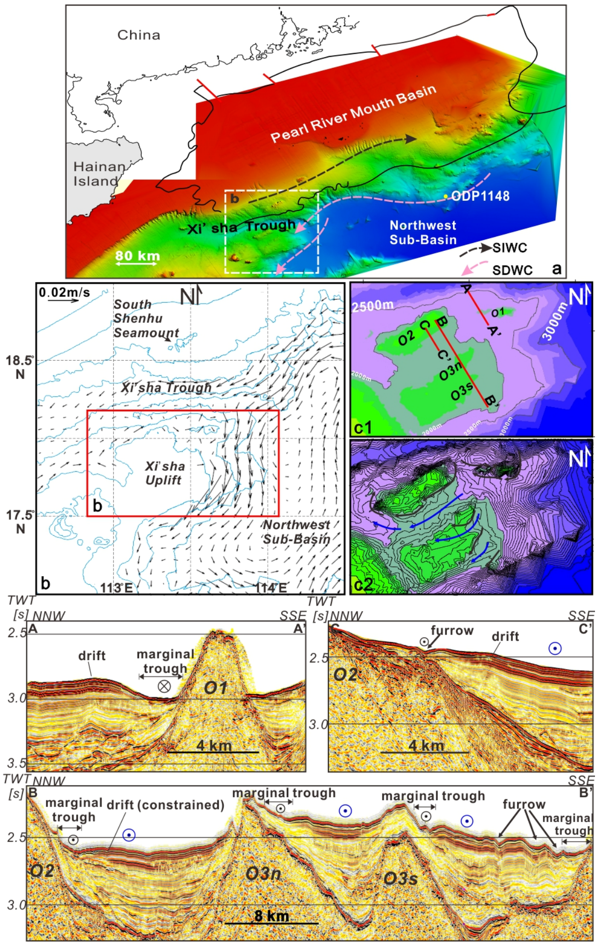

FIGURE 1. a=Bathymetry of the study area (SIWC=South China Sea Intermediate Water Circulation, SDWC=South China Sea Deep Water Circulation); b=Simulated flow field characteristics and velocity vectors at 2000m in the study area, the scale is 0.02m.s^{-1}; c1=Bathymetry of the study area, showing the locations of the seismic profiles (the vertical scale was converted from two-way travel time to depth using a P-wave velocity of 1500m.s^{-1} for the water column), c2=possible pathways of bottom currents (black arrows represent intensified currents with erosion and blue arrows represent currents which allow sedimentation); AA', BB', CC'=NNW-SSE oriented profile showing the contourite drifts and marginal troughs; O1=obstacle1, O2=obstacle2, O3=obstacle 3.

DISCUSSION

Because of geostrophic balance, the along-slope current will be intensified as the cross-slope topographic gradient enlarges. In the northern hemisphere, the flowing currents would be intensified on the left-hand side of the obstacle or slopes, when looking downstream, which means and impinging flow to the southern flank of the uplifts (Hernández-Molina et al., 2006). This explains the occurrences of relatively accelerated SCS Deep Water currents, exceeding 2cm.s^{-1}, east of the Xi'sha Uplift zone (and also, northeast of the Xi'sha Trough whereas is out of the study area).

The marginal troughs that formed along the southern flanks of O2, O3n and O3s, could be created by streams of separated and more vigorous westward flowing currents on the left side of those obstacles (black arrows in Fig. 1c2). Meanwhile, the drifts flanking the southern margin of O2 and those being confined between obstacles could be deposited by relatively distant westward flowing currents (blue arrows in Fig. 1c2). Such westward flowing directions could be consistent with the flow field characteristics of 2000m depth in the study area. Although the main direction of the flow is southwestward, the flow north and northwest of Xi'sha Uplift zone is just opposite. The marginal trough and drift deposits north of O1 may indicate a stream of eastward flowing currents (illustrated in black arrows in Fig. 1c2), which might be related to the weak currents along the northern wall of the Xi'sha Trough (Fig. 1b).

Thus, bottom currents in opposite flowing directions and under different hydro-dynamic conditions (e.g., being intensified to generate erosion or slowed down for deposition) have generated the different contourite features described above.

CONCLUSION

This study introduces the characteristics of deep-water deposits and simulated flows (>1800m depth) at the intersection of Xi'sha Trough and Northwest Sub-Basin, SCS. When passing the Xi'sha Uplift zone southwards, parts of the SCS Deep Water currents show a major westward direction, which generate marginal troughs and confined drifts in vicinity of the obstacle terrains.

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We would like to acknowledge the Institute of Petroleum Exploration and Development, Nanhai West Oil Corporation for providing geophysical data.

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Interaction between South China Sea deep circulation and the northwestern Pearl River Mouth Basin

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Abstract: *Since Late Miocene the supply of the South China Sea deep water by the Pacific and Indian Ocean waters decreased in the course of tectonic sea basin closing with only shallow waterways remaining as outside connections. A sequence stratigraphic analysis has been applied in the NW Pearl River Mouth Basin (PRMB) using multichannel seismic data collected during R/V SONNE Cruise SO-221 in May 2012. The data show that in the Yitong Ansha (YA) rifted continental block a sedimentary environmental change occurred in Late Miocene when a leeward carbonate reef oriented toward NE is replaced by open shelf conditions influenced by a SW bottom water current interpreted as the SCS-Western Boundary Current. The interaction between the SCS-Western Boundary Current and the basin topography subsiding into different water masses generated a giant elongated detached drift, the YA Drift, fed by a mixed turbidite-contourite depositional system.*

Key words: *South China Sea Western Boundary Current, Yitong Ansha Drift.*

INTRODUCTION

After spreading of the South China Sea (SCS) ceased in the middle Miocene, benthic foraminifer stable isotope records from ODP Leg 184 on the northern slope margin, at 13.87 Ma, suggest a reorganization of regional ocean circulation of the deep Pacific Ocean into the SCS (Wang et al., 2000). The restriction of the Indonesian Gateway and subduction of the Luzon arc beneath the SCS margin maintained exchange of surface water but deep water inflow to the SCS today occurs only through the Luzon Strait originating the SCS Western Boundary Current flowing alongslope toward SW (Fig. 1) The main objective of this study is to associate the sedimentary succession in the NW Pearl River Mouth Basin (PRMB) to the evidences of the Late Miocene current reorganization by establishing a sequence stratigraphic framework including the interaction between current related alongslope transport with gravity driven downslope transport (Brackenridge et al., 2011).

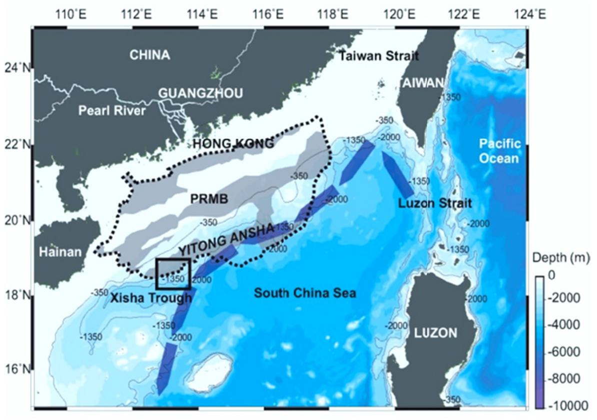

FIGURE 1. Location of the study area in the NW Pearl River Mouth Basin (PRMB) and main direction of the South China Sea Western Boundary Current (blue arrows).

DATA AND METHODS

High-resolution multichannel seismic and bathymetric data were collected during Cruise SO-221 in May 2012 in the Yitong Ansha (YA) rifted continental block in the NW PRMB (Fig. 1). After data processing, the seismic profiles have been interpreted based on seismic facies recognition in the common PRMB lithostratigraphy (Lüdmann and Wong 1999), on sequences distribution and on accumulation rate (Clift et al., 2014).

SEISMOSTRATIGRAPHIC INTERPRETATION

Strong hyperbolic reflections are interpreted as volcanic material injected through the YA continental basement in the middle Miocene during early post-rift phase (Fig. 2). Two satellite basins formed while syn-rift deposits (U6, U5 and U4) were deformed and displaced. A regressive-transgressive clinoform set within U3 on the NE flanks of the volcanic intrusions is interpreted as a leeward carbonatic reef developed from middle toward late Miocene influenced by a surface current directed toward NE. Following the late Miocene reef drowning unconformity, the progradation direction turned toward SW. Mounded onlap terminations at the morphological highs, well defined convex upward onlapping sequences at the low relief together with downlap terminations toward SW at the base of slope of the volcanic intrusions are observed within U2-U1. Such a stacking pattern clearly shows the influence of a bottom current interpreted as the SCS-Western Boundary Current according to similarity of the present day condition with respect to the strata continuity.

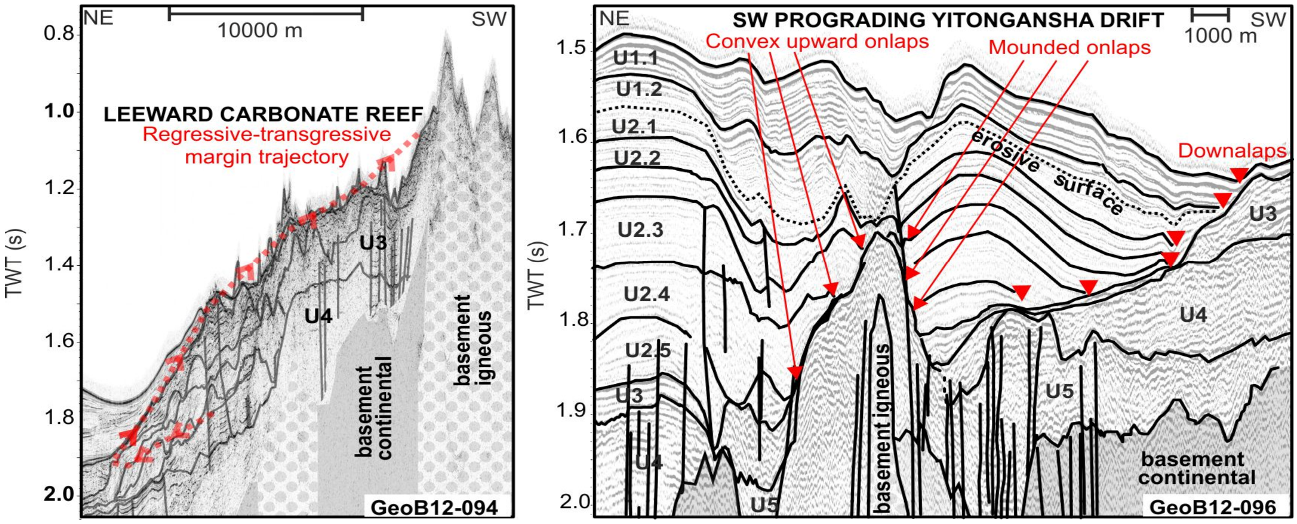

FIGURE 2. Interpreted profile GeoB12-094 on the NE flank of the volcanic intrusions showing the margin trajectory of a leeward carbonate reef formed from Middle to Late Miocene (right). The left image shows part of profile GeoB12-096 along Yitong Ansha Drift prograding SW toward the base of slope of the volcanic intrusion from late Miocene to present..

EVOLUTIONARY STAGES OF THE YA DRIFT

Several sub-units within U1-U2 can be defined, each of them constrained by a distal downlap termination and internally showing a persistent transgressive trend. In the course of the late Miocene (U2.5), a slope fan prograding seaward merged with a wavy sheet unit prograding landward, and formed a giant elongated detached drift, the YA Drift, as a niche-like trap. A debris flow channel with symmetrical levees is incised into unit U2.5. The terrigenous supply from the debris flow channel added to the hemipelagic drift components, resulting in a mixed turbidite-contourite depositional system. The incision became filled at the onset of deposition forming Unit U1.2 of early Pleistocene age when widespread erosion and scouring units occurred (Fig. 2). A dynamic equilibrium *sensu* Preu et al. (2013) between current and particle settling is restored in late Pleistocene within seafloor undulations that in cross section appear as prograding packages infilling the moat and scours in the uppermost Unit U1.1

DISCUSSION AND CONCLUSIONS

The current re-orientation from NE within U3 toward SW within U1-U2 may indicate a change in direction in the late Miocene. An intensification of bottom current activity during the early Pleistocene may be associated to U2.1. However, based on the mean slope subsidence rate (Xie et al., 2006), the igneous intrusions left the surface in late Miocene when the current reorientation is observed. They also move out of the surface circulation (>350 mbsl) during transition from Pliocene to Pleistocene, exactly when erosion, scouring and the moat incision are also observed. When margin subsidence into different water masses modifies the flow regime at the base of slope, it becomes difficult to derive considerations on global scale deep sea oceanic circulation. It can be therefore concluded that:

1) The sedimentary environment succession in the NW PRMB records the chronohistory of the SCS slope margin subsiding from the surface to the lower intermediate water.

2) The effect of subaqueous paleo-topographies which no longer exists must be taken into adequate account before drawing general conclusions on global current regimes.

ACKNOWLEDGEMENTS

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Diagnostic analysis of contourite drifts and contour currents around small-scale topographic features: some examples from the Italian Seas (Mediterranean Sea)

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Abstract: *We analyse here contourite drifts presumably related to a topographic control given by promontories or seafloor depressions (e.g., slide scars) in some Italian Seas. We therefore investigate the local effect of a topographic unevenness (such as a landslide scar) on flow contouring a cape by applying the classical conservation of marine water potential vorticity (PV). We further analyse the presence of non-linear and/or baroclinic instabilities that may lead to erosive or depositional conditions which, in turn, inhibit or favour the formation of contourites. Such an analysis is performed by applying the classical theory for conservation of potential vorticity (PV) in a cylindrical frame, which is able to describe the fluid properties by means of bathymetric curvatures.*

Key words: *Contourites, Bathymetric curvatures, Flow instabilities, Potential vorticity.*

PRINCIPAL TEXT

The complex relationship between currents flowing around bathymetric discontinuities and their related contourite deposits is becoming an interesting and debated topic, both from a sedimentologic and oceanographic perspective. Both scientific communities are therefore seeking to bridge the gap between what the seafloor shows up in terms of contourites and what causes their formation. We analyse here contourite drifts presumably related to a topographic control given by promontories or seafloor depressions (e.g., slide scars) in the Tyrrhenian Sea. The use of bathymetric and seismo-stratigraphic data, numerical and tank experiment, and analytic results allows one to investigate the relationship between the occurrence of contourite deposits and the fluid dynamic processes that are affected by seafloor topographic features.

The surface layer of the Tyrrhenian Sea offshore the Calabrian margin is constituted of the Modified Atlantic Water (MAW). At intermediate depths (200-700m) the Levantine Intermediate Water (LIW) flows geostrophically along the continental margin, contouring the two case study we consider her: Cape Suvero and Cilento Promontory (Figure 1).

Position and occurrence of the analysed contourites drifts, with respect to the cape tip, are here analysed by means of both (i) large scale turbulence caused by promontory itself and (ii) the influence of uneven topography.

We find that Cilento Promontory is characterized by a rather strong turbulence occurring downstream its tip. Such a feature leads to erosive (or non-depositional) conditions in the lee zone, in agreement with the contourite deposits observed in the upstream zone only (Martorelli et al., 2010). Based on the same dimensionless analysis, similar conditions should apparently occur for Cape Suvero. However, for this Cape this is contrasting with the observed presence of deposits downstream the tip (Figure 1). We argue that the influence of a more realistic topography, i.e. the landslide scar, on the local development of contourites can play an important role (Figure 2).

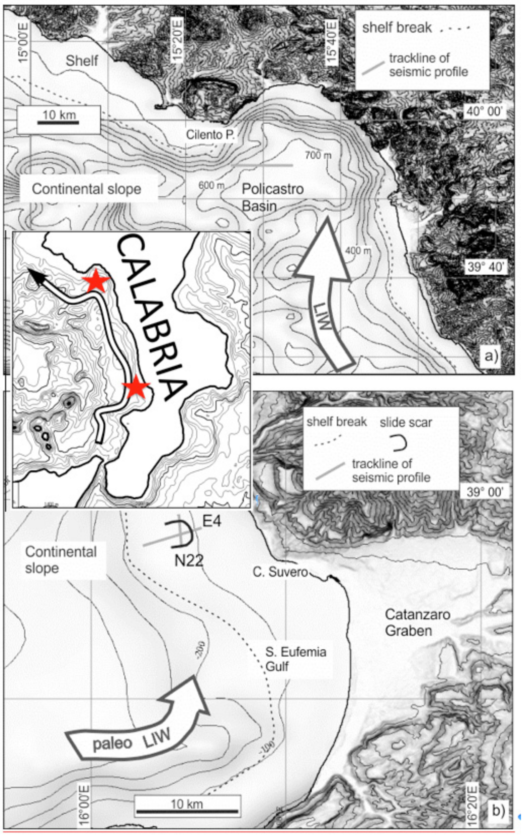

FIGURE 1. Bathymetry and subaerial topography of a) Cilento Promontory study area and location of seismic profile (not shown), and b) Cape Suvero study area and location of seismic profile shown in Figure 2. Inset: sketch of the calabrian margin with the possible pathway of LIW water mass. Red stars indicate study areas of Cilento promontory to the north and Capo Suvero to the south. Bold isobaths 1,000m

Indeed, in the paleo Capo Suvero case, where turbulent phenomena downstream the paleo-cape were inhibited by the larger cape geometry, the slide scar would have favored even more the deposition of drift by generating an anticlockwise circulation over the depression (Figure 2). From the Potential Vorticity (PV) conservation theorem it indeed results that Cape Suvero topographic depression (i.e. the slide scar), induced an anticlockwise rotation (Pedlosky, 1986). The main effect of the slide scar is thus the deviation of incoming current, as this scar would represent a kind of natural obstacle. Consequently, the incoming LIW current (~ 5 cm/s) would be deflected This hydrodynamic pattern implies that in the external, shallower part of the scar the water velocity is largely increased while, in the deepest part, the current is nil or inverted. The resulting deposition will therefore be minimal in the shallow part and is largely increased in the deepest part of the scar. Over time, this process would promote the accumulation of infill drift deposits, the attenuation of the influence of the scar and, at the end, the complete disappearance of the morphological unevenness.

These processes can be generalized in terms of non-linear instabilities that lead to erosive or depositional conditions, which in turn inhibit or favor the formation of conturites. Such instabilities can be generally analized by applying the (PV) theorem in a cylindrical frame, which is able to describe the fluid properties by means of bathymetric (positive or negative) curvatures. All this generalizes previous findings by Martorelli et al. (2010), where contourites were associated to the presence of promontories only. Our work can be seen as a new approach to understand the basic role of any bathymetric curvature in forming contourite deposits by means of classic geophysical fluid dynamics and physical oceanography applications.

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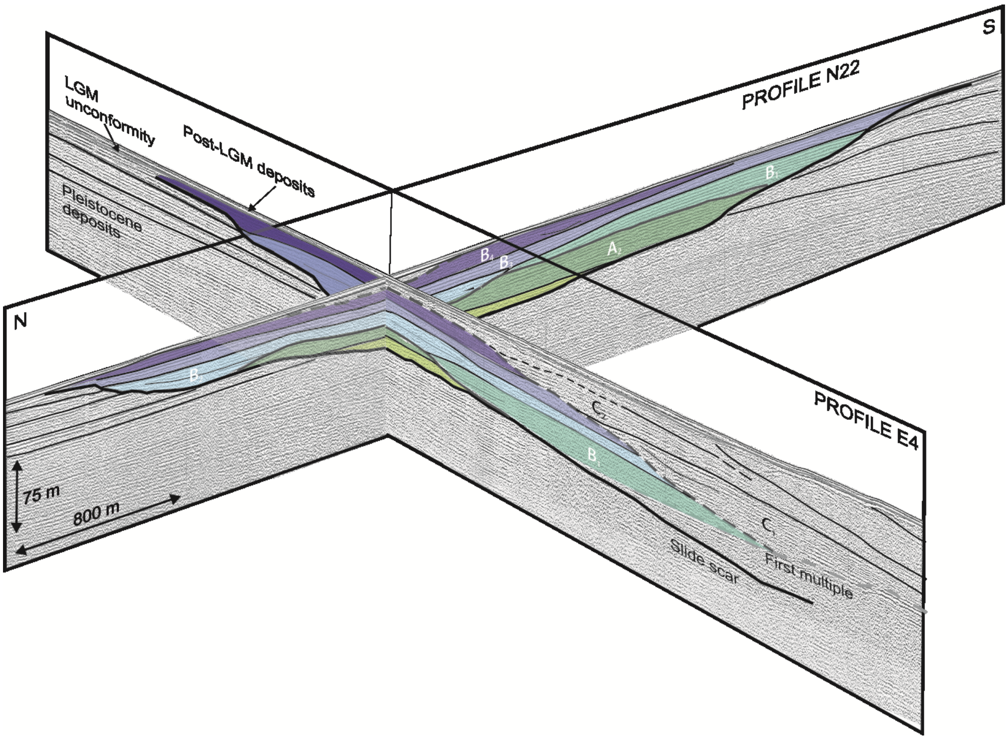

FIGURE 2. Fence perspective of 1kJ Sparker profiles depicting Cape Suvero contourite deposits. View from NE, location in Figure 1 The deposits are infill drifts developed within a slide scar.

Obstacle-related contourite drifts in the El Araiche Mud Volcano field, Southern Gulf of Cadiz

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Abstract: *This study presents geophysical evidence for the existence of at least three different contourite drifts at water depths between 550 and 800 meters in the El Arraiche Mud Volcano field (southern Gulf of Cádiz).The drift systems are affected by local tectonism (e.g. uplift of ridges) and by the presence of both mud volcanoes (e.g. Gemini Mud Volcano) and cold-water corals (e.g. at the foot of the Pen Duick Escarpment).The drift system at the foot of the Pen Duick Escarpment has been studied in detail and originated at the base of the Quaternary, with a major change around the Mid-Pleistocene Revolution. An Antarctic Intermediate Water origin is inferred as the driving mechanism for this drift system and the presence of Mediterranean Outflow Water could not be substantiated. Likewise, at the two more northern drift systems (Renard and Vernadsky drift) Mediterranean Outflow Water is currently not present. LADCP data indicate the presence of slow (<10cm.s^{-1}) bottom currents in the moats of the drifts. The Pen Duick drift experiences a general west to east flow direction, while the Renard and Vernadsky drifts experience an east to west flow direction, implying the last two could possibly originate from the same watermass.*

Key words: *obstacle-related drifts, Antarctic Intermediate Water, El Araiche Mud Volcano Field, seismic stratigraphy, LACDP.*

INTRODUCTION

The northern Gulf of Cádiz is receiving a lot of attention due to IODP Expedition 339 which drilled through the contourite depositional system created by the Mediterranean Outflow Water (MOW) (Expedition 339 Scientists, 2012). The temporal and lateral variation of this contourite system has been described in great detail, e.g. by Llave et al. (2011). In contrast, the southern Gulf of Cádiz, south of the Strait of Gibraltar, is far less studied, although diapiric ridges, cold-water corals and mud volcanoes are present (Van Rensbergen et al., 2005). This study focuses on several small obstacle-related drift systems in the El Araiche mud volcano field (Fig. 1). A description of the different drifts and their relation to the past and present oceanography is the aim of this research.

MATERIAL AND METHODS

A large high-resolution, single channel, sparker, reflection seismic dataset (>1500km), obtained during four campaigns (between 2002 and 2013), and a SIMRAD EM 1002 multibeam dataset (700km²) have been used in order to describe the drift system at the foot of the PDE. The seismic profiles have been processed with the DECO geophysical RadexPro processing software, applying a bandpass and swell filter, spike removal and amplitude corrections.

The oceanography of the El Arraiche Mud Volcano field was interpreted from CTD data from the World Ocean Database (temperature and salinity) (http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html) and displayed in Ocean Data View (http://odv.awi.de/). CTD (SeaBird SBE19) and LADCP (Teledyne RDI ADCP 300kHz) data acquired during the 2013 Belgica campaign "COMIC" were also used in this study.

RESULTS AND DISCUSSION

The multibeam data (Fig. 1) show the presence of several important features: the Renard and Vernadsky Ridge, numerous mud volcanoes (e.g. Gemini Mud Volcano) and channels on the seabed in the area.

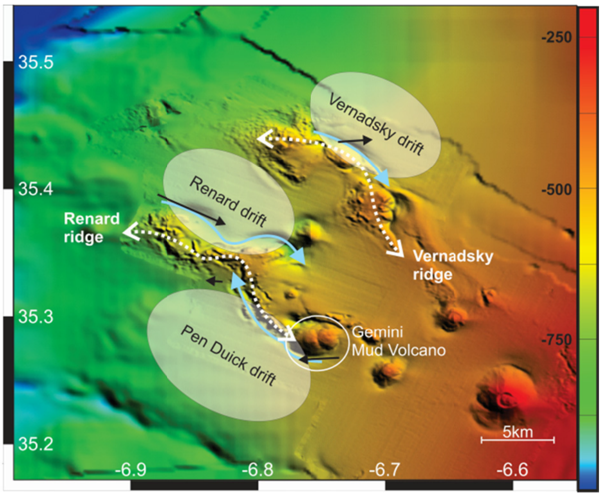

FIGURE 1. Multibeam bathymetric map of the El Arraiche area with indication of the three observed drift systems. The light blue arrows indicate the position of the different moats and the inferred flow directions in them. The black arrows show the direction and relative bottom current strength, derived from the preliminary LADCP data.

Based on the location of the drifts, the moats and the coriolis deflection, the directions of the bottom currents are inferred (light blue in Fig. 1). These are compared to preliminary LADCP-results, acquired during the June 2013 Belgica campaign (indicated by the black arrows in Fig. 1). The highest bottom current velocities (about 8-10cm.s^{-1}) are recorded just north of the Renard ridge. South of the Gemini mud volcano, velocities exceeding 5cm.s^{-1} are recorded. Except for the Vernadsky drift, the inferred direction of bottom currents agree nicely with those observed in the LADCP data.

The seismic stratigraphy of the Pen Duick drift consists of 5 units: the lower 2 are affected by the uplift of the Pen Duick Escarpment (PDE) and the upper 4 units are intersected with mud extrusions from the nearby Gemini Mud Volcano (Fig. 2). The Pen Duick drift consists of a pre-contourite (hemi-)pelagic phase, a phase with sheeted drift deposits (2.6Ma to 0.92Ma) and a phase with mounded drift deposits (920ka till recent). Within unit 3 (920 – 575ka), three small (<50ms TWT) mounds are present, resembling cold-water corals (Vandorpe et al. 2014).

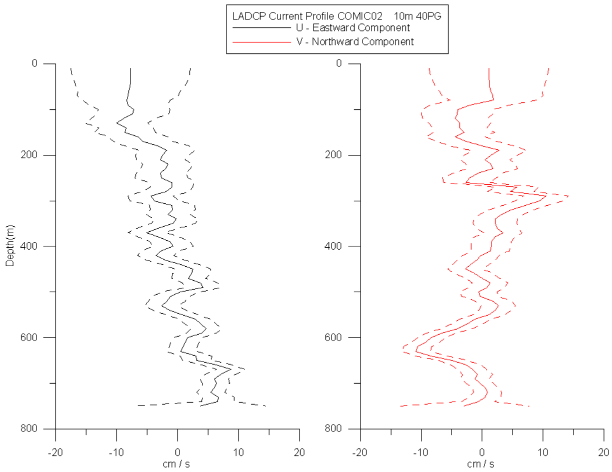

FIGURE 2. Preliminary result of a LACDP profile in the Renard drift (35°22.856'N and 6°50.726'W) at a water depth of 745m.

The chronostratigraphy of the Pen Duick drift differs from MOW-controlled drifts in the Northern Gulf of Cádiz (Llave et al., 2011) and the Le Danois area, Bay of Biscay (Van Rooij et al., 2010). Also, the CTD data do not indicate the presence of MOW at the foot of the PDE (Vandorpe et al., 2014). Both observations indicate that MOW is not involved in the build-up of the drift. Antarctic Intermediate Water (AAIW) is proven to be present in the area (e.g. Vandorpe et al., 2014) and could be intensified by the deflection against the Gemini Mud Volcano and the PDE. The Renard and Vernadsky drifts are not necessarily influenced by the same bottom currents as those responsible for creating the Pen Duick drift due to the contrasting direction (west- versus eastwards) of the bottom currents. Although, a secondary flow pattern around the complex topography of the Renard Ridge is also a possibility (Martins et al. 2014). Which bottom currents and which water mass are involved in the build-up of the Renard and Vernadsky drifts is the aim of this ongoing research.

CONCLUSIONS

The El Arraiche mud volcano field yields several examples of obstacle-related drift deposits. The Pen Duick drift is probably created by the deflection of AAIW against two topographies. The Renard and Vernadsky drift are not necessarily influenced by the same water mass as LADCP data indicate a different current compared to the Pen Duick drift, but a complex flow pattern around the Renard Ridge cannot be excluded.

ACKNOWLEDGEMENTS

The authors would like to thank the FWO for financing this research (KaN Contourite-3D) and the captain and crew of the R/V Belgica.

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The Ioffe Calcareous Contourite Drift, Western South Atlantic

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Abstract: *The high resolution seismic profiling during cruise 32 of the R.V. Akademik Ioffe (2010) revealed the Ioffe contourite drift deposited by Antarctic Bottom Water (AABW) current flowing out from the Vema Channel. Alternating stratified and transparent seismic units are separated by unconformities. Core AI-2436 retrieved near the drift top, at the water depth of 3800m, recovered Upper Pliocene – Quaternary section of nanno-foraminiferal ooze with foraminiferal sand interbeds interrupted by long-term hiatuses. Along with unconformities, stratigraphic hiatuses suggest erosion by intensified bottom currents.*

Key words: *seismic profiling, sediment core, AABW, hiatus, unconformity.*

INTRODUCTION/BACKGROUND

The high-resolution SES-2000 deep seismic profiling during the R.V. Akademik Ioffe cruise 32 (2010) discovered a contourite drift (named Ioffe drift) over the Rio Grande fracture zone ridge, northward of the Rio Grande Rise, western South Atlantic (Fig. 1). The elongated sedimentary body has a thickness up to 300m. It is traced at water depth range from 3790 to 3980m.

DATA AND RESULTS

The sediment core AI-2436 (25° 51.6'S, 34°01.40'W, water depth 3800m) retrieved near the drift top recovered about 6m of nanno-foraminiferal ooze intercalated with foraminiferal sand interbeds.

We distinguish five seismic units (SU) within the upper drift structure recorded by SES profiles to a depth of 60m. They are separated by angular discontinuities (Fig. 2). The uppermost SU-1, about 10m thick, consists of an acoustically stratified sequence with high-amplitude continuous parallel reflectors. The unit concordant to the bottom surface covers the underlying deposits with more or less apparent angular unconformity. Its thickness slightly decreases to the margins. On the drift summit reflectors become weaker and more irregular. SU-1 wedges out on the ridge slopes at water depths 3850–3980m in our profiles. There is no evidence of reflectors truncation. Core AI-2436 penetrated the upper half of the seismic unit and recovered Upper Pliocene nanno-foraminiferal ooze at its bottom (Ivanova et al., in prep.). A strong reflector about 6m below the sea floor (mbsf) likely corresponds to the hiatus at the Pleistocene/Pliocene boundary. Reflectors within the SU-1 correlate with long-term hiatuses inferred from foraminiferal and nannofossil stratigraphy, as well as with the prominent foraminiferal sand beds. The same is likely true for the lower part of the SU-1 showing similar seismic patterns. Extrapolating the average sedimentation rate for the upper part of the seismic unit to its lower part, we assume that the SU-1 may include the entire Pliocene section.

SU-2 is recorded below the SU-1 on the NW and NE drift slopes. Weak reflectors of the unit truncate against the unconformity surface at its upper boundary suggesting erosion before the onset of SU-1 accumulation (Fig. 2). The unit thickness decreases toward the drift margin. Almost acoustically transparent SU-3, with faint discontinuous reflectors visible only on the drift summit, underlies both upper units throughout the studied part of the drift. Its thickness increases from the drift summit (10–15m) to gentle NE slope (25–30m) thus suggesting another sedimentation mode, as compared to that of stratified units. The distinctly stratified SU-4, about 20m thick, is well developed on the drift summit and wedges out on its NE slope (Fig. 2) being cut by an unconformity (erosion surface?). It contains internal unconformities. SU-5 is hardly visible below the SU-4 on the drift summit owing to insufficient sensitivity of the SES profiler, but demonstrates distinct parallel stratification with basin fill patterns at the NW slope break, where it directly underlies SU-1 or even crops out (Fig. 2).

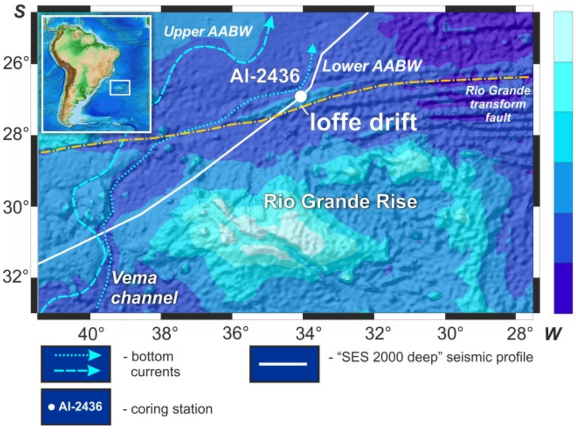

FIGURE 1. Bathymetric chart of the study area with sketched regional bottom circulation, location of the seismic profile and coring point.

DISCUSSION

High resolution seismic profiling and multiproxy studies of the core AI-2436 revealed typical contourite features of the Ioffe drift, such as morphology, internal stratified structure with numerous unconformities, stratigraphic hiatuses, alternation of calcareous sediment layers of different color and grain size distribution from fine-grained foram-nanno ooze to foraminiferal sand. The calcareous contourite drift was deposited as a result of biogenic calcareous material transport by the eastern branch of the Antarctic bottom water (AABW) flow (Morozov and Tarakanov, in press). The biogenic material is mainly derived from the Rio Grande Rise where planktonic foraminiferal and nannofossil assemblages identical to those in core AI-2436 (Ivanova et al., in preparation) are studied at the DSDP site 516 (Barash et al., 1983). Stratigraphic hiatuses in the core, as well as unconformities in seismic profiles indicate episodes of considerable increase in the AABW bottom current velocity. Stratified seismic units and layered sedimentary structure of the core suggest pulsating sedimentation of contourites driven by the bottom current fluctuation.

CONCLUSIONS

The Ioffe calcareous contourite drift is deposited on the Rio Grande fracture zone ridge by the eastern branch of the AABW bottom current bifurcated near the outlet from the Vema Channel.

Long term hiatuses in the core section and angular unconformities in seismic profiles indicate that the drift accumulation was several times interrupted by erosion owing to the strong increase in bottom current velocities.

ACKNOWLEDGEMENTS

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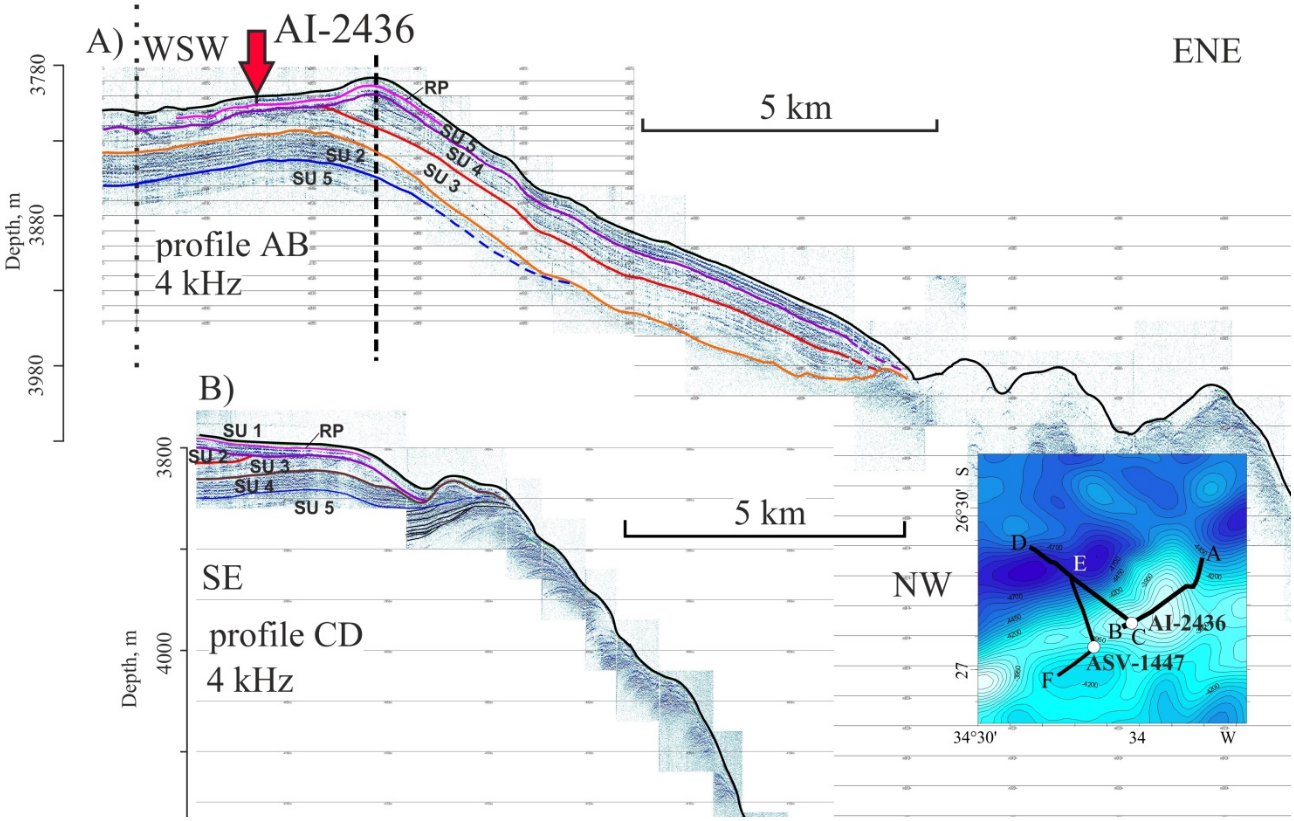

FIGURE 2. Seismic profiles running roughly along (A) and across (B) the Ioffe drift crest.

Contourites at the eastern Agulhas Ridge and Cape Rise seamount shaped by Southern Ocean derived water masses

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Abstract: *Constituting a topographic barrier the Agulhas Ridge has a strong influence on the exchange of water masses between high and lower latitudes in the South Atlantic. While Antarctic Bottomwater (AABW) and Circumpolar Deepwater (CDW) originating in the Southern Ocean provide the inflow of cold water masses in larger water depths, the Agulhas leakage is the main source of warm and salty waters carried towards the Subpolar North Atlantic. In order to track past changes in this circulation pattern 5400km of high-resolution multichannel seismic reflection data were acquired during RV Maria S. Merian cruise MSM 19/2 in the Agulhas Ridge area. Here we present first results from the eastern plateau of the ridge and the area between the plateau and the Cape Rise Seamount. Via crosscorrelation with ODP Leg 177 drillsites, prominent reflectors marking the early Oligocene, the middle Miocene and the base of the Pleistocene were identified. Sediment drifts deposited between these erosional surfaces indicate steady contour current acitivity at various depth levels. Extensive current derived deposits in this area and a mounded drift northwest of the Cape Rise Seamounts formed by clockwise circulating bottom water appear to have been built contemporaneously by AABW flow after the early Oligocene.*

Key words: *Seismic stratigraphy, Contourite drift, Agulhas Ridge, Thermohaline circulation.*

INTRODUCTION

The Agulhas Ridge forms part of the Agulhas-Falkland Fracture Zone (43°S/9°E - 41°S/16°E) showing an elongated form. The ridge is of tectono-magmatic origin (Hartnady and le Roex, 1985) and it rises more than 2000m above the surrounding seafloor. As a topographic obstacle the ridge has a strong influence on the exchange of water masses between high and lower latitudes. While Antarctic Bottomwater (AABW) and Circumpolar Deepwater (CDW) originating in the Southern Ocean provide the inflow of cold water masses in larger water depths (e.g. Cater et al., 2008) (Fig. 1A), the Agulhas leakage is the main source of warm and salty waters carried towards the Subpolar North Atlantic as the upper limb of the Meridional Overturning Circulation (Biastoch et al., 2008). The southwestern part of the ridge is characterized by up to four parallel segments separated by deep depressions, which are filled with up to 1s TWT of sediments. Here the ridge shows only a thin sedimentary cover. In contrast the northeastern Ridge Plateau is covered with > 1000m of sediment. Here we present high-resolution seismic profiles from this eastern Agulhas Ridge plateau and the hitherto unexplored area between the plateau and the Cape Rise Seamounts (Fig. 1B).

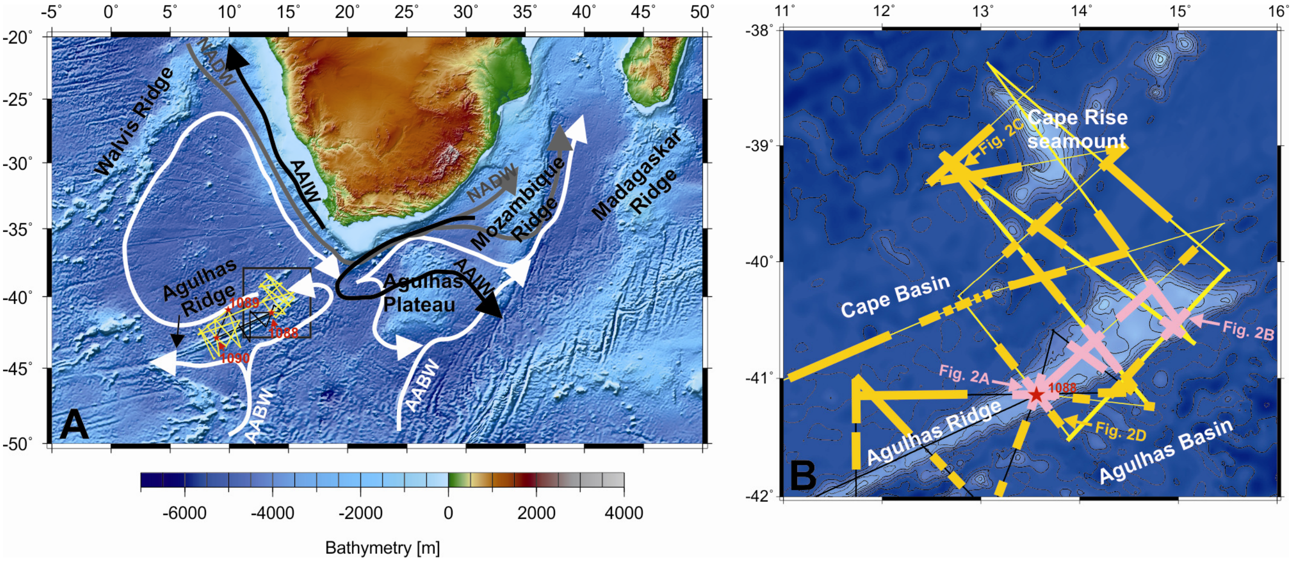

FIGURE 1. A. Bathymetric map with the general circulation scheme of deep-water masses south of Africa. (AABW = Antarctic Bottom Water; AAIW = Antarctic Intermediate Water; NADW = North Atlantic Deep Water) and locations of reflection seismic profiles shot in 1998 (black lines) and 2011 (yellow lines). B. Detailed bathymetry image of the eastern Agulhas Ridge. Intervals with current influenced sediment deposits are marked by orange (> 4500m water depth) and pink (~ 2000m water depth) bars. Stars indicate the positions of ODP Leg 177 drill sites.

DATA

In order to track past changes in the paleo-circulation pattern 5400 km of high-resolution multichannel seismic reflection data were acquired during RV *Maria S. Merian* cruise MSM 19/2 in the Agulhas Ridge area. Seismic processing comprised Common Depth Point (CDP) sorting with a CDP spacing of 25m, velocity analysis (every 50 CDP) for normal moveout correction, stacking, and time-migration.

Sites 1088, 1089 and 1090 of ODP Leg 177 (Gersonde et al., 1999) were crossed during profiling to enable a correlation of the seismic data with geological information. Based on this crosscorrelation and a reconnaissance survey (e.g. Wildeboer Schut and Uenzelmann-Neben, 2005), prominent reflectors marking the early Oligocene, the middle Miocene and the base of the Pleistocene were identified.

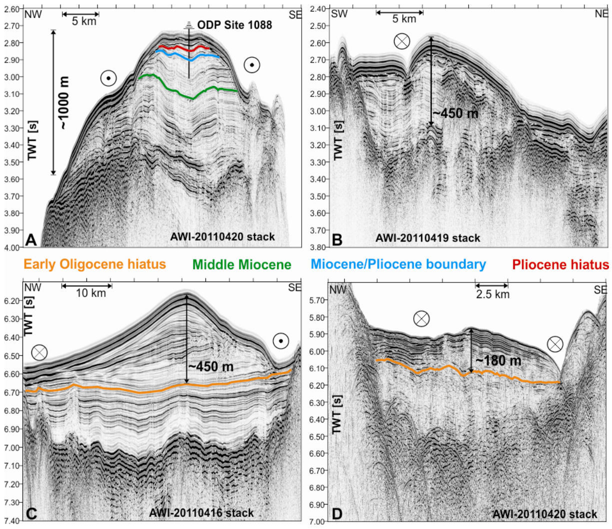

FIGURE 2. Examples of sediment drift types present at ~ 200 m (A, B) and > 4500 m (C, D) water depth with inferred current direction

RESULTS AND DISCUSSION

The Agulhas Ridge area is chararterized by current derived sedimentary features occurring mainly in waterdepth levels of ~2000m and >4500m.

In ~2000m water depth, on the eastern Ridge Plateau the sedimentary sequences are up to 1500m thick and well layered. In places, strong erosion and a wedge-out of sequences at the seafloor can be observed indicating erosion due to current activity. Based on correlations with ODP Site 1088 prominent reflectors on the ridge plateau represent the Miocene/Pliocene boundary and a Pliocene hiatus (Fig 2A). Furthermore a reflector at ~3s TWT is estimated to be of Middle Miocene age (Wildeboer Schut and Uenzelmann-Neben, 2005). In contrast the Cape Rise Seamount shows a flat top without a significant sediment cover.

In > 4500m water depth numerous sediment drifts with variable shape are observed. Extensive current controlled deposits in the Cape Basin occur as confined drifts between the Agulhas Ridge and Cape Rise seamounts and as mounded and sheeted drifts further to the West (Wildeboer Schut et al., 2005). Northwest of the Cape Rise Seamount we observe a developed mounded drift with a height of ~450m and a width of ~50km. The drift is separated from the seamount by a moat (Fig. 2C). Together these features point towards a clockwise circulating bottom water gyre in that area. In general, drift formation commenced after deposition of a pronounced unconformity identified as an erosional horizon formed by the onset of AABW flow in the early Oligocene (Wildeboer Schut et al., 2005). Thus the mounded drift appears to have been formed contemporaneously with the extensive current controlled deposits north of the Agulhas Ridge. Steady build-up of the drift structure with parallel to subparallel layers indicates that the current direction did not substantially change after the early Oligocene implying that the bottom current in the Oligocene followed the same trajectory as present-day AABW/CDW does.

In contrast to the large drift deposits in the Cape basin smaller, confined drifts showing more erosional features are found south of the Agulhas Ridge (Fig 2D). This may indicate higher flow speeds of the AABW in the Agulhas Basin.

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Bottom currents-controlled sedimentary archives in the southeast Weddell Sea

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Abstract: *Understanding the transport and deposition of sediments brought to the Antarctic continental shelves by major ice streams helps provide constraints on past ice sheet history. In this study, we investigate a series of iceberg erosional and current reworked features along the continental margin of the southern Weddell Sea to understand glacial sedimentation processes from the middle Miocene to the present. The Crary Trough Mouth Fan (CTMF), channel systems, levee deposits, and giant elongate mounded sediment drifts are investigated using high-resolution seismic reflection, sub-bottom profiler and swath bathymetry data. The formation of the giant elongate mounded sediment drifts is ascribed to the semi-enclosed drainage basin, large glacial trough-Crary Trough, paleo-ice streams, plenty of sediment supply, sufficient accommodation space, intensified bottom current (WSBW) and Coriolis effect. The well-developed networks of gullies and channels that we observe cut into the continental shelf edge of Dronning Maud Land were formed during incision by sediment-laden meltwater and associated with sediment gravity flows from the base of ice sheets grounded at the shelf edge. A remarkable increase in mass transport deposits (MTDs) in the late Miocene and middle Pliocene strata is related to collapses of the CTMF, ice advances, overpressure of rapid accumulation of sedimentary as well as the steep topographic gradients.*

Key words: *Weddell Sea, seismic reflection data, elongated mounded drift*

INTRODUCTION

Glacially derived depositional and erosional features and deposits reworked by ocean currents dominant the seafloor and upper sedimentary strata of the continental margin of the southeastern Weddell Sea. The prominent glacial trough located on the Filchner Shelf, the Crary Trough, is 100-150km wide, 800m deep, and extends from beneath the Filchner Ice Shelf to the continental shelf edge (Fig. 1). The associated Crary Trough Mouth Fan (CTMF) formed when grounded ice reached the continental shelf edge as fast-flowing ice streams, delivering large volumes of sediments directly to the upper slope. The margin of the southeast Weddell Sea is dominated by gullies and channels eroded by melt water and/or dense shelf water flowing down-slope or by turbidity currents originating from debris flows (Hillenbrand et al. 2009) (Fig. 1).

This paper aims to describe the seismic features of the continental margin of the southeast Weddell Sea by focusing on the depositional history of the giant elongate mounded sediment drifts and mass-wasting deposits off the Crary Trough. These findings will be used to draw conclusions concerning the glacial sedimentary processes that have influenced the margin's shape. We use high-resolution seismic, sub-bottom profiler and bathymetry data to investigate the sedimentary characteristics.

DATA AND RESULTS

The most prominent pattern of linear wedge-shaped sediment accumulations is interpreted as a set of giant, elongate-mounded drifts. Elongate-mounded drifts have built up in the southeastern Weddell Sea since the middle Miocene.

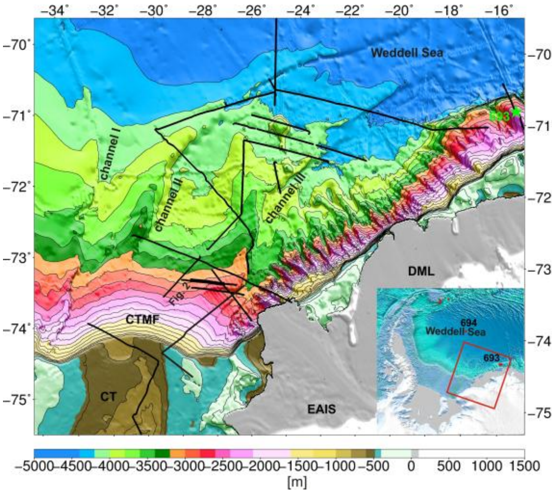

FIGURE 1. Bathymetry map of the southeast Weddell Sea. Black lines are the seismic reflections lines. Green stars = Drilling site; CT = Crary Trough; CTMF= Crary Trough Moth Fan; DML = Dronning Maud Land; EAIS = East Antarctic Ice Sheet.

These drifts are characterized by sinuous bathymetric highs running nearly perpendicular to the southern margin (Fig. 1). Together with seismic reflection profiles, the bathymetric pattern constrains the drifts to be more than 150km wide, 700km long, and 1km thick (Fig. 1). These drifts are typically externally asymmetric in shape, with a steeper and rougher eastern face and a gentler, smoother western face (Fig. 2). The drift in figure 2 is located on the NW margin of Channel III, close to the CTMF. Its steep side is characterized by relatively high amplitude reflectors that terminate laterally at the seafloor. In contrast, the more gentle side shows parallel or sub-parallel internal reflectivity, which conforms to the sea floor above WS-u6. Hummocky or chaotic reflectivity is observed at both sides of the mound and is interpreted as buried channels underneath the unconformity WS-u6. It appears that the mound has migrated to the west since the middle Miocene, perhaps due to Coriolis effect.

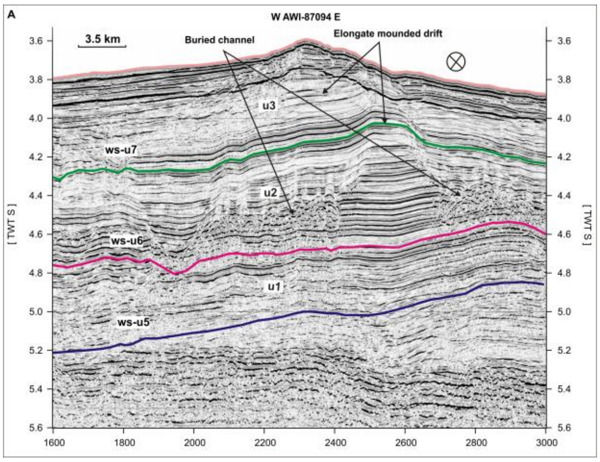

FIGURE 2. Example of the elongate mounded sediment drift see the location on Fig. 1.

DISCUSSION AND CONCLUSIONS

The elongation trend, direction and degree of progradation of giant elongate-mounded drifts can vary with respect to the sediment supply, contours of the margin, interaction between topographic variability, the current system and intensity, and the Coriolis effect (Rebesco et al., 1997; Stow et al., 2002; Uenzelmann-Neben, 2006).

The great quantity of terrigenous sediment discharged to the continental slope and rise by ice streams and channel system in this way was further modified by bottom currents. Cold, dense WSBW forms with melted ISW (Ice Shelf Water) under the Filchner-Ronne Ice Shelf, flows out northwards, and branches out along the basin floor. The position and morphology of drift deposits are controlled by the pre-existing seafloor, which controls and directs the various branches of the bottom currents initially (McCave and Tucholke, 1986). The direction of the bottom currents is also interacted with drift topography subsequently. Thus, we affirm the NE-SW trends of the giant, elongate-mounded drifts and channels (Channel II and Channel III) were probably associated with the northeast flow direction of the WSBW in the southeast Weddell Sea. Data on the WSBW mass in the southern Weddell Sea is limited; we think that it could flow in any direction between the northwest and northeast. AABW circulates along the continental margin and flows towards the west in the southeast Weddell Sea, where it has contrived the asymmetric geometry of the drift bodies under the influence of the Coriolis force.

The unique sedimentation environment of the southeast Weddell Sea, with its semi-enclosed drainage basin, large glacial trough, (paleo-)ice streams, abundance of sediment supply and accommodation space, intensified bottom currents (WSBW, AABW) and Coriolis effect are the keys for developing its giant elongate-mounded sediment drift.

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Early Miocene glaciation in the Amundsen Sea, Southern Pacific: A study of the distribution of sedimentary sequences

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Abstract: *The distribution and internal architecture of seismostratigraphic sequences observed on the Antarctic continental slope and rise are results of sediment transport and deposition by bottom currents and ice sheets. Low energy input of detritus via a palaeo-delta originating in an area of the Amundsen Sea shelf and deposition of this material on the continental rise under sea ice coverage (60-21Ma) was followed by glacial erosion in the hinterland of this part of West Antarctica (21-14.1Ma), resulting in a larger depocentre and an increase in mass transport deposits. A higher sediment supply along a broad front with a focus via two palaeo-ice stream troughs resulted from a polythermal ice sheet. In the eastern Amundsen Sea rise the glaciogenic debris was shaped into levee-drifts by a re-circulating bottom current. A reduced sediment accumulation in the deep-sea subsequent indicates a reduced sediment supply probably in response to a colder and drier ice sheet (14.1-4Ma). A dynamic ice sheet since 4Ma delivered material offshore mainly via Abbott Trough and Pine Island Trough West. Interaction of this glaciogenic detritus with a west-setting bottom current resulted in the continued formation of levee-drifts in the eastern and central Amundsen Sea.*

Key words: *West Antarctic Ice Sheet, sedimentary sequences, sediment drifts, bottom water circulation, glacial development*

INTRODUCTION

Because of modern global warming and their possible contribution to sea level rise and flooding of low lying coastal areas both Antarctic and Greenland ice sheets have moved into the focus of public and scientific interest. Research has concentrated on short-term dynamics of the ice sheets in order to understand their vulnerability to a changing climate by collecting multi-disciplinary data. Little has been known about the long-term development especially of the West Antarctic Ice Sheet (WAIS), which as a marine based ice sheet generally reacts more sensitively to both atmospheric and oceanic warming than the largely terrestrial East Antarctic Ice Sheet. Information on the early phase of WAIS formation and the Cainozoic glacial history in the greater Amundsen Sea is scarce. A cold Antarctic Counter Current has bathed the Amundsen Sea implying a cold climate for that area during the Paleogene. Uenzelmann-Neben and Gohl (2012) presented indications for a pre-Miocene sea-ice cover in the Amundsen Sea based on the study of sedimentary features imaged by seismic reflection data. We here add to the discussion of the transition from pre-glacial to glacial deposition in the Cainozoic by analysing depositional patterns and the distribution of the sedimentary units.

RESULTS

Palaeo-seafloor highs and depocentres will be presented and discussed. Shape and location of a depocentre relative to the continental slope and older depocentres reveal the loci of major sediment accumulation and allow conclusions about transport pathways and processes. A depocentre-oriented parallel to the slope is interpreted to document primarily along-slope sediment transport, while a depocentre perpendicular to the slope is interpreted to indicate down-slope sediment transport. Accumulation rates computed for the depocentres are combined with observations of the occurrence of sedimentary features in the study area, such as sediment drifts and mass transport deposits (mtd), that have been reported previously (Uenzelmann-Neben and Gohl, 2012).

The top of the basement shows a high in the area of the Marie Byrd Seamounts (MBS). This high extends slightly NE-wards. The deepest basement is observed between Pine Island Trough West (PITW) and Abbott Trough (AT). Above the basement, 4 sequences are characterized, ASR-1 to ASR-IV, from older to younger. Unit ASR-I shows a broad depocentre (2000m) parallel to the continental slope, which does not extend far into the ocean. The thickest parts of the depocentre (> 2500m) can be observed a) continent-wards of the MBS in front of the Dotson-Getz Trough (DGT), b) between PITW and PITE, and c) in front of AT. The base of unit ASR-II also shows a high in the MBS area. This high is smaller than the one observed for the basement. We observe an extension towards the SE (to the slope offshore from PITW) rather than towards the NE. The deepest part of the horizon is located in the NE of the area of investigation with two smaller troughs seaward of PITW. Unit ASR-II again shows a broad depocentre (500m) parallel to the continental slope, which extends further into the ocean than unit ASR-I's depocentre. The thickest parts of the depocentre (> 750m) can be observed a) in the NE offshore from PITE, b) in three locations in front of

PITW and further to the W, and c) in front of AT. Two of the three thick depocentres have been deposited in up to 250m deep troughs but the westernmost depocentre directly indicates an increased sediment input. The foci of the depocentres have shifted relative to those of unit ASR-I except the one in front of AT.

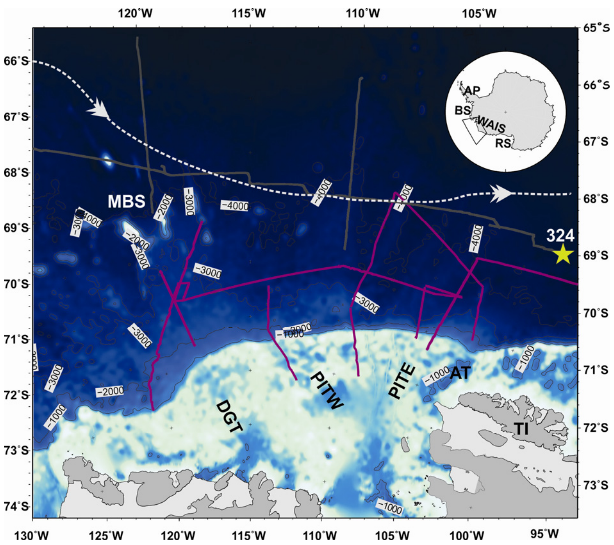

FIGURE 1. Bathymetric map of the Amundsen Sea (Nitsche et al., 2007). The seismic line locations are shown in purple (AWI) and grey (JNOC), the yellow star refers to the location of DSDP Leg 35 Site 324 (Shipboard_Scientific_Party, 1976). The light grey dashed line shows the approximate path of AABW (Orsi et al., 1999). AT = Abbot Trough, DGT = Dotson Getz Trough, MBS = Marie Byrd seamount area, PITE= Pine Island Trough East, PITW = Pine Island Trough West, TI = Thurston Island. Insert map shows the area presented. AP= Antarctic Peninsula, BS= Bellingshausen Sea, RS= Ross Sea, WAIS= West Antarctic Ice Sheet. Modified from Uenzelmann-Neben and Gohl (2014).

The MBS area appears still elevated at the base of unit ASR-III but is less pronounced. The shallowest part is found closer towards the continental slope. Similar to the base of ASR-II that of ASR-III lies relatively deep in the NE. For unit ASR-III we observe two depocentres (500m) that coincide with locations where ASR-II had been thickest: a) in front and slightly west of PITW, and b) in front and slightly west of AT. Depocentre a) is parallel to the shelf break and the continental slope, while depocentre b) is oriented perpendicular to shelf break and continental slope. For the base of unit ASR-IV we observe a broad high, which extends eastwards from the MBS and is oriented parallel to the shelf break. The NE is characterised by a deep lying base of ASR-IV, which is less pronounced and deepens towards the deep sea. Unit ASR-IV shows depocentres only in the eastern part of the study area, where they cover about the same areas as the depocentres in unit ASR-III. Three depocentres are located between AT and PITW and are oriented perpendicular to the continental slope. The thickest parts (> 500m) are found on the continental slope.

CONCLUSIONS

Via the analysis of seismic reflection data from the continental slope and rise (Figure 1) and the study of thicknesses and depocentres of four sedimentary units we reconstructed sediment input (pathways and hence source areas on the shelf, amount) and sediment transport processes and inferred climatic and oceanographic changes. The oldest unit ASR-I (> 21Ma) shows a narrow depocentre parallel to the continental slope interpreted to represent low energy input. A focus in deposition near 106°W was attributed to sediment supply through a palaeo-delta, which later became PITE. Sediment drifts observed in the elevated MBS area indicate an active water mass with a density between that of today's AABW and LCDW. This points towards a significant sea ice cover but not full glacial conditions for the period before 21Ma.

For unit ASR-II (21-14.1Ma) a strong increase in sediment input documented by a larger and thicker depocentre is interpreted as evidence for glacial conditions in West Antarctica already during the Early Miocene. Warming as the result of the MMCO resulted in a wet-based ice sheet and led to a higher sediment supply, which was supplied from the shelf along a broad front but with a main pathway through PITE and AT. Most of the material was transported onto the eastern Amundsen Sea rise where it was shaped into levee-drifts by a re-circulating bottom current. Unit ASR-III (14.1-4Ma) is characterised by two smaller depocentres seaward of AT and PITW and reduced sedimentation rates. The onset of stronger cooling after 14Ma resulted in a cooler and dryer based ice sheet leading to less glacial erosion and less material input.

A dynamic ice sheet since 4Ma characterised by growth and decay during cold and warm phases, respectively, is documented by a strong increase in sedimentation rates with material dominantly being supplied to the rise via AT and PITW. The pulsed glaciogenic debris input from the shelf interacted with a west-setting bottom current on the rise resulting in the continued formation of levee-drifts in the eastern and central Amundsen Sea.

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Water mass footprints in uneven turbidite system development in the Alboran Sea

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Abstract: *Multidisciplinary work between oceanography, geomorphology and sedimentology has uncovered evidence explaining the uneven development of the turbidite systems (TSs) in the Alboran Sea. Nine TSs have been mapped in the Spanish margin, ranging from sandy to mixed sand-mud fans, and which become sandier towards the Strait of Gibraltar; in contrast TSs do not develop in the Moroccan margin, where three canyons incise the continental slope but there is no TS formation. We interpret that the uneven development of TSs in the two margins and their variable architectures are conditioned by the interaction of alongslope with downslope processes. Two different interaction scenarios with varying intensities are proposed.*

Key words: *Alboran Sea, turbidite system, contourite, oceanography.*

INTRODUCTION

The Alboran Sea (SW Mediterranean) is a semi-enclosed basin bordered by the Spanish and Moroccan margins where Atlantic and Mediterranean water masses meet and interact. Ever since marine geology research began in this area, about 25 years ago, a question has remained unanswered: why does only the Spanish margin develop turbidite systems (TSs) even though the hinterlands of both countries have similar geographic and climatic characteristics and their continental shelves also have similar deposits. In this work, we tentatively propose an answer, which has been made possible thanks to the multidisciplinary studies of oceanography, geomorphology and sedimentology.

DATA

We have analysed approximately 2000 single and multi-channel seismic records at different resolutions, from the ICM-CSIC (*http: //www.icm.csic.es/geo/gma/ SurveyMaps/*) and SIGEOF (*http://www.igme.es/ internet/sistemas_infor/BASESINTERNET/sigeof.htm*) databases. All the seismic profiles were integrated into a Kingdom Suite project.

Additionally, more than 3000 CTD (conductivity, temperature, depth) profiles, available on Sea Data Net (http://www.seadatanet.org/Data-Access) and other platforms (such as the Medatlas II database, http://odv.awi.de/en/data/ocean/medatlasii/), have been analysed using the Ocean Data View software.

RESULTS AND DISCUSSION

Detailed mapping of the sedimentary systems characterizing the Alboran Sea (Fig. 1) has revealed that continental slopes are made up of contourites. However, they show an important difference from a morpho-sedimentary point of view: the uneven development of TSs. Nine TSs (15 to 99km long) have been mapped in the Spanish margin (Fig. 1). In contrast, TSs do not develop in the Moroccan margin, where the Ceuta canyon and the two relatively shorter Al Hoceima and Trois Fourches canyons are the only submarine valleys incising the slope. We began from the premise that the uneven development of TSs on the two margins and the variable architecture of the fans are a result of the unequal interaction between alongslope and downslope processes. Several indicators were analysed so that the different dynamics governing both margins could be understood, in order to reinforce or allow us to reject this interpretation:

Oceanographic context: The present-day circulation is defined by three major water masses: 1) the surficial Atlantic Water (AW), (down to 150–200m water depth) that describes two anticyclonic gyres, Western and Eastern; 2) low density (LD) Mediterranean water, formed by the Western Intermediate Water (WIW) and Levantine Intermediate Water (LIW), which on the Spanish continental slope only extends down to 600m water depth; and 3) the underlying high density (HD) Mediterranean water, formed by the Western Mediterranean Deep Water (WMDW) and which is largely restricted to the Moroccan margin (below 180m water depth), deep basins and the Spanish base-of-slope (below 600m water depth) (Millot 2009 and references therein).

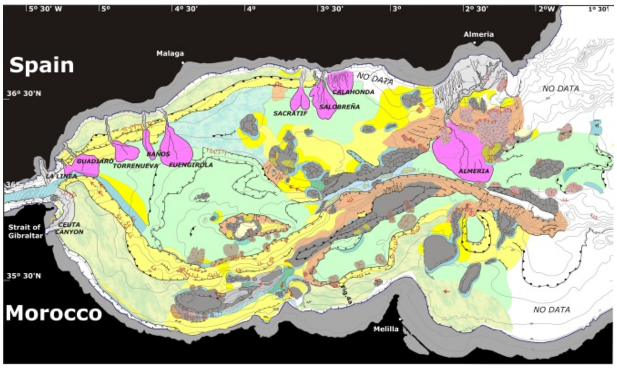

FIGURE 1. Geomorphologic map of the Alboran Sea. The purple colour indicates turbidite systems (TSs). Note the lack of TSs in the Moroccan margin.

Sedimentary context: The continental slopes mostly comprise alongslope plastered drifts with striking terraces formed under the action of the LD (Spanish margin) and HD water masses (Moroccan margin). The plastered drifts connect to a deeper plastered drift on the Western Spanish base of slope, and to sheeted drifts in the basins, all formed under the action of the HD waters. In this scenario, the TS feeder canyons cross the continental slope eroding the terraces and the alongslope plastered drifts. Canyons mouth directly into fan lobes on the base of slope and in adjacent basins, with aggrading and migrating leveed channels interrupting the lateral continuity of the plastered and sheeted drifts. The abrupt transition is always coincident with features sculpted by contour currents.

Comparative morphoarchitecture of TSs in gross plan view: The comparative patterns of the TSs distributed along the Spanish margin highlight their similarities and longitudinal differences. The similar features are the canyons, mostly characterised by non-leveed margins. The differences are mostly related to the shift in fan lobe architecture, from a single linear to lower sinuous leveed channel in those fans close to the Strait of Gibraltar, to a single main leveed channel linked downslope to distributary channels in the others. The channel pathways are mostly rectilinear, although sinuous channels are more frequent in the fans located in the east. The architecture, dimensions, and plan-view morphology of the TSs elements based on Reading and Richard's classification (1994) suggest that the sedimentary composition of the fans ranges from sandy to mixed sand-mud, becoming sandier towards the Strait of Gibraltar.

CONCLUSIONS

Based on the oceanographic and sedimentary contexts, as well as the overall architecture and geometry of the TSs, we can distinguish two scenarios where there is interaction between alongslope and downslope processes, occurring at different intensities. These scenarios help us understand the potential mechanisms that may have been conditioning the uneven development of TSs.

1) *The Spanish margin scenario, where the interaction has conditioned the fan architecture and its variability.* In this scenario when sediment arrives to the sea, the finest fraction is pirated by the AW. The dynamic of the two anticyclone gyres and the well-developed isopycnal and related processes (e.g., internal waves) between the Atlantic and Mediterranean waters represent potential mechanisms for maintaining the fine sediment in suspension and dispersing it in the nepheloid layer throughout the Alboran Sea. Piracy would result in fine sediment deprivation in the downslope flows feeding the fans, explaining the lack of defined levees in the canyon margins and the sandier fans towards the Strait of Gibraltar, where the currents are faster. The importance of piracy depends on the intensity of the currents. Thus, the interplay between the unequal activity of the AW (its eastwards velocity decrease) and its two anticyclonic gyres (Eastern-permanent versus Western-semi-permanent), as well as the LD and HD accelerating toward the Strait of Gibraltar, would favour significant piracy from the gravity flows outbuilding the fan lobes in the west. This would explain the trend of the western fans from mixed sand-mud-rich to sand-rich.

2) *The Moroccan margin scenario, where the interaction is stronger and has conditioned the lack of TSs.* In this scenario, the interplay between the piracy by the Atlantic anticyclonic gyres, more sediment in suspension, and dispersion due to the enhanced density contrast between the AW and HD Mediterranean waters, together with the waters of the HD core impinging and accelerating along the Moroccan margin due to being forced to flow upslope, all favours intense alongslope sediment transport. This intense transport prevents the convergence of sediment along the Moroccan margin, inhibiting the local occurrence of potential erosive gravity flows and leading to the formation of canyons and/or their related fan lobes.

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Morphological characterization of contourite and mass-wasting recent processes at the Guadalquivir Bank Margin uplift, Gulf of Cadiz

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Abstract: *The Gulf of Cadiz records the interplay of a variety of sedimentary processes related to the circulation of water masses. The most important one is the Mediterranean Outflow Water (MOW) that exits the Mediterranean Sea, but other water masses also affect the seafloor, with complex variations along time and space. This work studies the interplay between oceanographic and gravitational sedimentary processes on the Guadalquivir Ridge, based on bathymetry and high-resolution seismic profiles. A series of morphological features including flat terraces, circular/elliptical depressions, semi-circular scarps and valley-shaped features are analysed in order to better understand the interaction between water masses circulation and mass-wasting processes of the Gulf of Cadiz.*

Key words: *Gulf of Cadiz CDS, morphology, oceanography, swath bathymetry.*

THE GULF OF CADIZ: GEOLOGICAL AND OCEANOGRAPHIC SETTING

The Gulf of Cadiz is located at the Atlantic side of the Strait of Gibraltar. It records the interplay between sedimentary processes and the oceanographic dynamics. The Gulf of Cadiz Contourite Depositional System (CDS) is related to the maintained flow of the Mediterranean Outflow Water (MOW) as it overspills into the Atlantic Ocean. In this complex system along-slope processes dominate over mass wasting, turbidity currents and pelagic/hemipelagic settling processes. The CDS is composed of differentiated morpho-sedimentary sectors, each showing different depositional and/or erosional features (Hernández-Molina et al., 2006). Terraces have been identified on the middle slope, associated to the flow of distinct cores of the MOW and the interphases between water masses (Hernández-Molina et al., 2014).

The oceanography of the Gulf of Cadiz is dominated by the warm saline MOW exiting the Mediterranean Sea (Baringer and Price, 1999). The MOW accelerates through the strait of Gibraltar and it flows along the Gulf of Cadiz continental slope towards the west Iberian Margin. Along the mid-slope of the Gulf of Cadiz, the velocity is locally enhanced and split by interaction with diapiric ridges. In the Gulf of Cadiz the MOW is overlaid by the Eastern North Atlantic Central Water (ENACW), the modified Antarctic Intermediate Water (AAIW) and the Surface Atlantic Water (SAW) (Hernández-Molina et al., 2014). The interaction of the water masses with the seafloor presents a high spatial and temporal variability.

The Guadalquivir Bank Margin uplift is characterized by two main SW-NE aligned reliefs located on the middle slope of the Gulf of Cadiz. that reaches minimum depths at the Guadalquivir Bank, at the western extreme of the ridge (275m), and close to the eastern extreme at the Gamboa Dome (350m) (Fig. 1). The ridge is cut by the Diego Cao Contourite channel that forms a 4-5km wide, SE-NW oriented channel. It delimits two relatively flat contourite sheeted drifts (SD): the Faro SD at the east (~ 600m) and the Bartolomeo Dias SD, at the west (~750m).

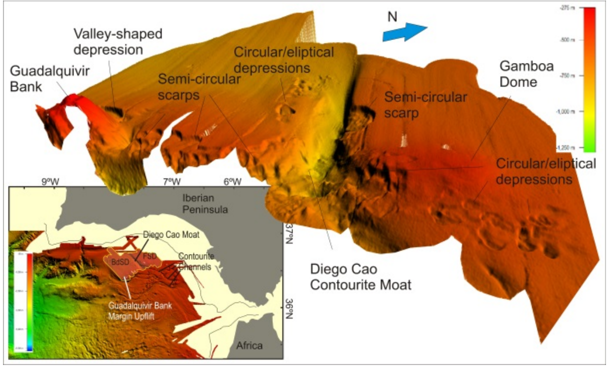

FIGURE 1. Study area and 3D bathymetric model analysed in this study. BdSD: Bartolomeu Dias Sheeted Drift; FSD: Faro Sheeted Drift.

MORPHOLOGICAL FEATURES

High resolution data reveal the existence of a variety of features. Semi-circular scarps up to 10s of km long, occur at the SE side of the Guadalquivir Bank Margin uplift (Fig. 2A, B). They occur at depths of 640 to 750m and form steep steps of up to 80m of height and 5km of length. They are in some cases overlapped one on each other at different depths. Truncated reflectors indicate recent erosion on the scarps. The most remarkable scarp occur at the SW side of the Bartolomeo Dias SD, at the rim of the Diego Cao contourite channel (Fig. 2C). It is about 5km long and up to 100m deep, with steep walls of up to 20º. Inside the semi-circular space delimited by the scarp there is a secondary step, and a deeper, valley-shaped incision to the SE side. Truncated reflections occur at the walls of the scarp, and no deposit associated to it can be identified.

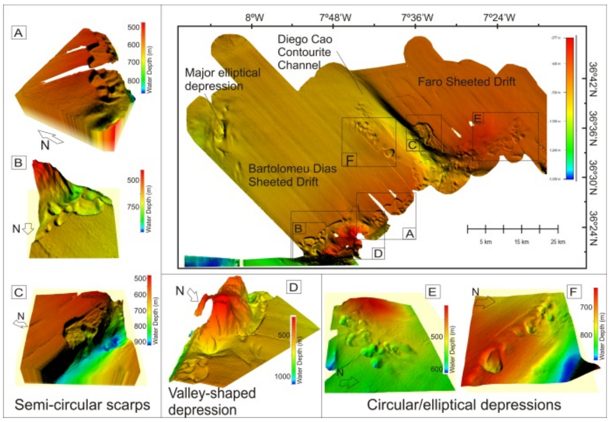

FIGURE 2. Bathymetric model and 3D blocks showing the main features analysed in this study.

A valley-shaped depression surrounds the N side of the Guadalquivir Bank (Fig. 2D). It is about 30km long, with incision depths of up to 200m and it runs parallel to the shape of the bank main relief. Truncated reflections occur at the northern wall, that erodes the Bartolomeu Dias sheeted drift.

A series of elliptical to circular-shaped depressions occur at the SE side of the Gamboa Dome, aligned in a WSW-ENE direction, at depths of 480 to 550m (Fig. 2E). They are 10s of meters deep, up to 3km wide and have steeper SW walls. Seismic profiles show truncated reflections on the walls. A series of circular- to elliptical-shaped depressions also occur at the eastern side of the Bartolomeu Dias SD, close to the rim of the Diego Cao channel, roughly parallel to it (Fig. 2F). They occur at depths of 650 to 750m on the SD, have maximum widths of 2km and depths of up to 100m. They have generally steeper SE walls (up to 20º) showing truncated reflections on seismic profiles. A major elliptical depression, oriented N-S occurs at the NW part of the Bartolomeu Dias SD (Fig. 2, regional map). It is 5km long and 3km wide and reaches depths of 150m, with steeper eastern wall, up to 16º and a smoother western wall (<8º). Smaller depressions with N-S to WNW-ESE orientations occur at the surroundings of the major depression, with diameters of less than 2km and depths of up to 20m. Walls show truncated reflections on seismic profiles.

DISCUSSION AND CONCLUSIONS

The interaction between the circulation and the bathymetry of the Gulf of Cadiz middle slope is responsible for the major erosive and depositional features. Diapiric ridges (Cadiz and Guadalquivir), diapiric intrusions, and structural features determine the seafloor shaping that affects and is affected by the water masses circulation. The step-like profile of the middle slope can also be related to the circulation of water masses and their interphases. The morphological features presented in this study are the result of the MOW interaction with the morphology, in particular of the effect of the slopes delimiting terraces, morphological highs and the Guadalquivir Bank uplift on the circulation of the northernmost branches of the MOW Lower Core. Scarps are interpreted as mass-wasting features, where the triggering factor is the erosive action of the currents as they are accelerated by interaction with morphological highs and slopes. Resulting mass-wasting deposits would be transported by the currents to deeper areas of the Gulf of Cadiz. The valley-shaped depression around the Guadalquivir Bank can be interpreted as a contourite moat related with the acceleration of the current by the interaction with the high. Circular-elliptical depressions result from the complex interaction of the current with the topography. The current intensification as it impinges on the slopes delimiting terraces and morphological highs produces asymmetric flows surrounding the obstacles and irregular flow patterns that may produce the erosion of contouritic deposits (Turnewitsch et al., 2013). Mass-wasting and contouritic deposition may have interplayed during the development of these features, as suggested by the erosive surfaces overlaid by prograding deposits. Collapse processes resulting from structural deformation may also be responsible for the origin of the depressions at the SE side of the Gamboa Dome.

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Bottom currents influenced deepwater canyons in the northern of Baiyun Sag slope, South China Sea

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Abstract: *Most submarine canyons are documented as erosive features that deeply cut into the shelf margin, and are considered as important conduits for the transfer of sediment to the lower slope and abyssal plain. In this study we investigate a series of submarine canyons developed on the shelf margin in the Pearl River Mouth Basin. High-resolution 2D seismic and borehole data have been used to investigate the morphology and stacking pattern of these submarine canyons. Seventeen canyons oriented NNW-SSE, approximately perpendicular to the regional slope, have been distinguished. They evolve from V-shaped in the upslope part to U-shaped morphology downslope. Numerous buried channels can be distinguished below the modern canyons showing an auto-cyclic progression in the scouring-filling and vertical stacking, indicating that canyons experienced a cyclic evolution with several cutting and filling phases of varying magnitude. Infilling evolved from high to low energy deposits. The low energy deposits form asymmetric, eastward prograding bodies developed on the western flank of the buried channel. The remarkable asymmetry between the two flanks of canyons may result from the interaction between turbiditic current within canyons and along slope bottom currents that flow northeast-ward along the margin.*

Key words: *deepwater canyons, morphology controlling factors, turbidity, bottom currents.*

INTRODUCTION

Submarine canyons represent long narrow strips of deep negative relief on the seabed, and are common types of sedimentary systems on the continental slopes. Down-slope gravity processes in submarine canyons have been widely documented (Huang et al., 2012).

The Pearl River Mouth Basin (PRMB) formed in the northwestern South China Sea and underwent a recent (i.e. from early Miocene) period of subsidence forming the present Baiyun Sag. Together with sea level variations, this led to a northward migration of the PRMB depocentre as well as canyon valley formation within the Baiyun Sag northern slope after 21Ma (Pang et al., 2005). However, the Baiyun Sag northern slope canyons exhibit buried laterally migrating channels suggesting a very strong along slope bottom currents influence over the entire turbiditic and canyon system (Cunningham et al., 2005).

This study investigates a series of submarine canyons that developed within the Baiyun Sag northern slope from late Miocene to present (Fig. 1). Based on 2D multi-channel seismic profiles and borehole data, we investigate the morphology, sedimentary architecture, and particularly the unidirectional migration features of the submarine canyons, in order to understand mechanisms dominating canyons dynamic.

DATA AND RESULTS

This study made use of a data set of over 15,500km of multi-channel 2D reflection seismic profiles covering an area of >72,000km^2. This data set was provided by China National Offshore Oil Corporation (CNOOC) Shenzhen Branch in order to characterize seabed morphology. The seabed map has been obtained converting the seismic seabed reflector from two-way travel time to depth using a P-wave velocity of 1,500m.s^{-1} for the water column.

The Baiyun Sag northern slope is affected by seventeen sub-parallel modern canyons, ranging water depth from ~500m to 1,700m (Fig. 1). Most of these canyons are oriented NNW-SSE. They are about 20-50km long for 1 to 7km wide. These deeply cut canyons are V-shaped at the canyon heads and widen to U-shaped downstream. They are asymmetrical with steep walls on their eastern flanks and stepped convex upward walls on the western sides.

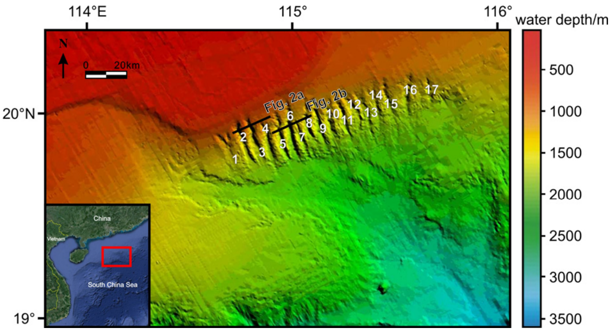

FIGURE 1. 2D multi-channel seismic derived seabed geomorphological map of the north slope of the Baiyun Sag canyons.

The crests between canyons are smooth and rounded in the shallower water near the shelf break to sharp downstream (Fig. 2a). Further to the south, these canyons are much wider and deeper (U-shaped), showing a combination of erosional and depositional characteristics (Fig. 2b).

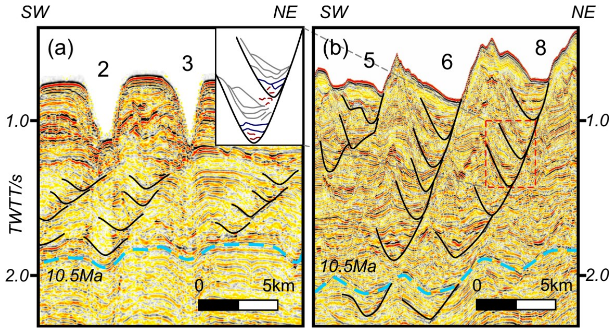

FIGURE 2. Seismic profiles from the north slope of Baiyun Sag near the shelf break (a), and further to the south (b). See Figure 1 for exact location. Both profiles show buried channels and their respective internal morphology.

Buried channels, with some of them even predating the 10.5Ma sequence boundary, are asymmetric with a rounded smooth western flank and a steeper eastern flank. Buried channels erosive bases are stacked and progressively offset toward the northeast, with more erosive eastern flanks. Infilling within these channels display a complex architecture suggesting an evolution of repeated erosion, infilling, offset, and subsequent re-excavation (Fig. 2). Three different seismic facies are distinguished in the channel infilling. The base is generally characterized by very low amplitude highly discontinuous reflectors. Medium- to very high-amplitude sub parallel reflectors are then recognized and form a relatively flattened channel bottom. They are overlain by a series of seismic reflectors dipping and prograding towards the east. These lateral accretionary packages are characterized by low to medium amplitudes, a high degree of continuity, and are parallel to sub parallel to each other.

DISCUSSION

The V-shaped segments close to the canyon heads are evidently erosional. To the south, both seabed and buried channels indicate cycles of erosive and depositional processes. Such erosive/depositional cycle within the canyons may reflect lateral migration of the sedimentary system, possibly induced by sea level variations. Within the subsequent fall in sea level, the study area would be erosion-dominated with newly developed erosive channels. Conversely, rising sea level may have induced progressive energy decrease, allowing deposition and filling of the channels. During periods of enhanced sediment input, perhaps during low stands of relative sea level, mass transport deposit may have occurred, forming the low amplitude, chaotic reflection at the channel base. Following this very high-energy MTD's, mass flow and channelized turbiditic flow would have been common, thereby favoring the formation of thick, continuous high amplitude reflectors, representing intermediate energy environment deposits.

Asymmetric eastward prograding muddy sediment packages on the western walls of the buried channels, as well as focused erosion toward the eastern walls suggest the influence of northeast-ward flowing along slope bottom currents. The growth and preservation on these lateral inclined packages may have occurred during periods when turbidity currents along the canyon axes were diminished, perhaps during highstands of relative sea level, in low-energy environment. Such episodic sea level changes may have resulted in the interplay of downslope turbidity currents and bottom currents, which significantly contributed to the change between the vertical aggradation and lateral migration developed in the canyons. Such northeastward alongslope bottom currents in the study area are known since the Miocene within the intermediate-upper deep water (350-1,350m) (Shao et al., 2007).

CONCLUSION

The north slope of the Baiyun Sag features high slope gradients and a complex geomorphology, intensively crosscut by canyon valleys. Buried channel show cyclic alternation of erosive and depositional periods evolving from very high to relatively low energy environment.

The northeastward offset direction of the canyons and their asymmetry is attributed to bottom currents flowing from the southwest to the northeast. In effect, the lateral inclined packages are clinoforms formed as bottom currents sweep muddy sediments from the slope and outer shelf across the slope, over the canyon rims and into the canyons.

A persistent north-eastward traveling bottom current during highstands and increased turbidity currents during lowstands together shaped the unidirectional development of the buried channels in the north slope of the Baiyun Sag.

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High-resolution seismic stratigraphy, multibeam bathymetry of the Capo Vaticano region (Tyrrhenian Sea) coupled with oceanographic data: interplay between alongslope bottom currents and downslope processes

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Abstract: *We shows preliminary results from high-resolution seismic reflection profiles (1.5kJ Sparker and Chirp), multibeam bathymetry and oceanographic surveys (CTD and ADCP) carried out in 2011 and 2013 south Capo Vaticano (southern Tyrrhenian Sea, Italy). The collected data reveal the widespread occurrence of contourites on the upper slope-outer shelf sectors. These newly discovered contourites are interbedded with hemipelagic deposits and locally with turbidite and/or mass wasting deposits. The interaction between along slope bottom currents and downslope processes can be observed both on the seafloor and within buried depositional sequences of upper Pleistocene age. Sequence stratigraphic interpretation suggests that Capo Vaticano contourite deposits developed within high-order depositional sequences formed during upper Pleistocene eustatic cycles, possibly during lowstand phases.*

Key words: *contourites, turbidites, sequence stratigraphy, topographic control.*

The multibeam bathymetry and high resolution seismic reflection profiles (chirp and 1.5kJ sparker) collected during two oceanographic cruises carried out in 2011 and 2013 off Capo Vaticano (Urania R/V, CNR) reveal various types of bottom-current features comprising both depositional elements (sediment drifts) and erosional elements (Fig. 1), forming at least four contourite depositional systems.

The newly discovered contourite deposits are located south to Capo Vaticano, offshore the Petrace river and Capo Vaticano, between ~500 and 95m water depth. The sediment drifts are rather small in size (up to 10km long and 2km wide). Most are elongate separated drifts aligned roughly parallel to the regional bathymetric contours. Erosional elements comprise moats, abraded surfaces and depressions. On the upper continental slope the deposits are affected by widespread gravitative instability produced by several shallow slides, covering a seafloor surface > 20km^2.

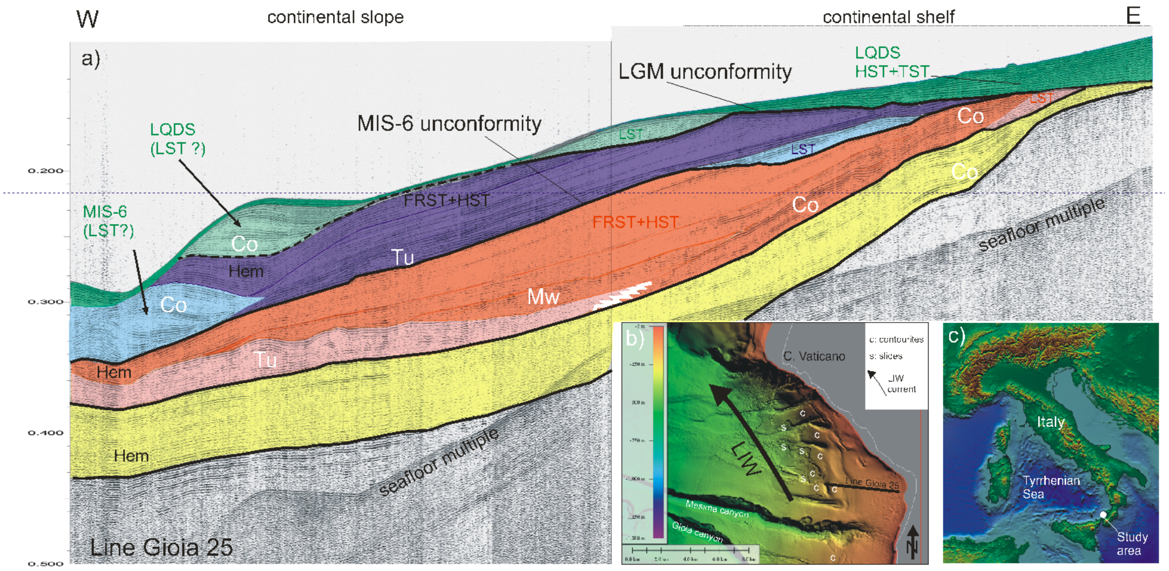

FIGURE 1. a) Selected sparker profile across the Capo Vaticano offshore showing contourite deposits (Co), hemipelagites (Hem), turibidites (Tu), mass wasting deposits (Mw) and major unconformities separating upper Pleistocene depositional sequences; b) Shaded relief of the Capo Vaticano offshore area with indication of contourites (c) and slides (s); c) Location of the study area.

The spatial distribution of sediment drifts and erosional features suggests an origin from north-northwestward-flowing bottom currents, related to the Levantine Intermediate Water (LIW in Fig. 1) and to a surficial current, both fitting with current flows observed by CTD and ADCP measurements carried out in the 2013 survey (TyGraF cruise, Urania R/V) in the framework of the Ritmare project (http://www.ritmare.it).

Capo Vaticano contourites are interbedded with hemipelagic deposits and locally with turbidite and/or mass wasting deposits (Fig. 1). Across the study area, lateral heteropies with turbidite and/or mass wasting deposits are present, suggesting interaction between along slope bottom currents and downslope gravitative processes. Such interactions can be either observed within recent deposits or in buried upper Pleistocene deposits.

Along the south eastern Tyrrhenian margin, other contourite deposits have been described from the Capo Suvero offshore (Amelio and Martorelli, 2008) and NW to the study area (Marani et al., 1993). The contourites described in this study confirm the relevance of bottom-current processes and contourite formation for the upper Pleistocene-recent stratigraphy of this continental margin. Moreover their presence highlights the relevance on contourite development of the topographic control exerted by local morpho-structures, such as headlands (i.e. Capo Vaticano; Martorelli et al., 2010) and canyons (e.g., the Gioia-Mesima canyon system), as well as the complex interplay between hemipelagic, turbidite and contourite sedimentation.

Classic high-resolution sequence stratigraphic interpretation suggests that Capo Vaticano contourite deposits developed within high-order (e.g., fourth-order) depositional sequences formed during upper Pleistocene eustatic cycles, possibly during lowstand phases (Fig. 1). A more detailed analyses of the high-resolution seismostratigraphic dataset will attempt to better define systems tracts within depositional sequences and arrangement of the observed contourites within system tracts.

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(Paleo)circulation models in the Alboran seas during the Pliocene and Quaternary

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Abstract: *A multiple Contourite Depositional System has been defined in the Plio-Quaternary sedimentary register in the Alboran Sea. This multiple system formed by the Atlantic and the low density and high density Mediterranean Waters, which shaped the margins and basins since the opening of the Gibraltar Strait. Three different (paleo)circulation scenarios are proposed since then: the Atlantic water Flooding;the Pliocene circulation, characterized by immature low and high density Mediterranean waters and a strong countercurrent in the Western Basin; and the Quaternary circulation, characterized by tabular Mediterranean water masses with multiple current dynamics,an increasing influence of density contrasts, and climate shifts causing major vertical and horizontal displacements of their interfaces.*

Key words: *contourites, Alboran Sea, Plio-Quaternary, stratigraphy, paleoceanography.*

INTRODUCTION

The Alboran Sea, located at the westernmost Mediterranean, is characterized by its complex physiography, with two main basins (Eastern, Western), two main intra-slope basins (Southern, Motril) and several morphologic traits (structural and volcanic highs, ridges and plateaus) acting as obstacles to the intermediate and deep flows. Also, its closeness to a main oceanographic gateway (Strait of Gibraltar) conditions its dynamics.

DATA

We have reviewed and analyzed about 2000 seismic profiles, available at the ICM-CSIC (*http: //www.icm.csic.es/geo/gma/SurveyMaps/*) and SIGEOF (*http://www.igme.es/internet/sistemas_infor/BASESINTERNET/sigeof.htm*) databases, comprising single and multi-channel seismic records with different resolutions. All seismic profiles were integrated in a Kingdom Suite project.

In addition, more than 3000 CTD profiles (conductivity, temperature, depth), available in open-access on Sea Data Net (*http://www.seadatanet.org/Data-Access*) and other platforms (as the Medatlas II database, *http://odv.awi.de/en/data/ocean/medatlasii/*), were analyzed using the Ocean Data View software.

RESULTS

The detailed stratigraphy study allowed us to attain a new stratigraphic architecture, in agreement with the conclusions reached by Ercilla et al. (1994), who suggested the Plio-Quaternary sedimentary evolution was controlled mainly by the interplay of tectonics, sea-level changes, and a complex ocean circulation, the latter being governed by climate shifts (Fig. 1).

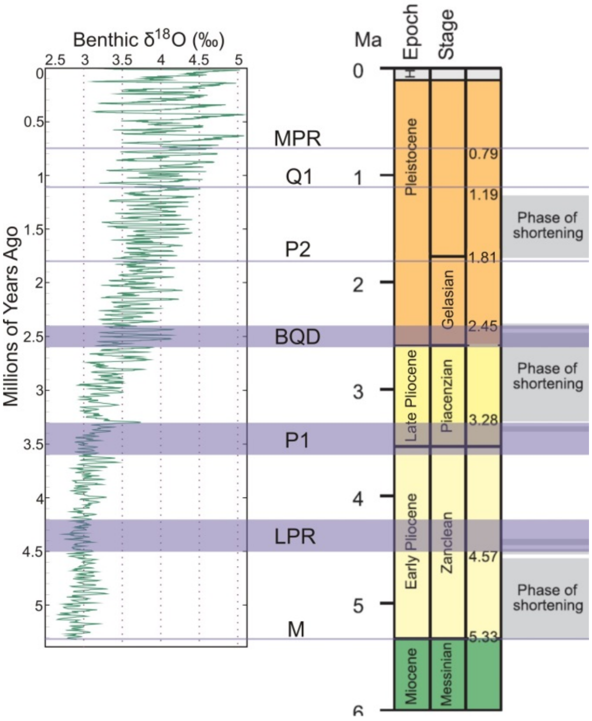

FIGURE 1. Modified from Lisiecki and Raymo, 2005 (left) and from Martínez-García et al., 2013 (right). Influence of tectonic pulses and climate shifts in the newly defined boundaries.

On the other hand, our CTD analysis allowed to discern the Atlantic Waters –AW– and the Mediterranean low density –LD– (Western Intermediate Water –WIW–, Levantine Intermediate Water –LIW–) and high density –HD– (Western Mediterranean Deep Water –WMDW–) waters (Millot, 2009), to deduce their pathway, to observe the superimposed hydrological and geological structures (Fig. 2), and to highlight the importance of interfaces.

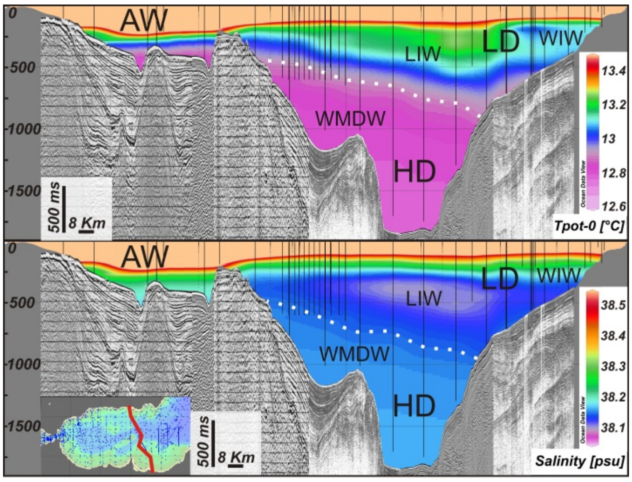

FIGURE 2.Main water masses superimposed to the geological features observed in a mosaic of seismic profiles cutting S-N the Eastern Basin

DISCUSSION

The cross-disciplinary studies carried out between geomorphology, stratigraphy and physical oceanography conducted in the Alboran Sea have changed the interpretation of sedimentary processes governing the long-trend morphosedimentary records of the margins and deep-sea areas of the study area. In contrast with previous interpretations, this study highlights the governance of the water masses and their interfaces on the sedimentation of the margins and basins of the Alboran Sea during the Pliocene and Quaternary, previously considered as a local influence (Ercilla et al., 2002).

The results obtained from analyzing the intricate relationship between the sedimentary processes and the action of the LD and HD waters were transferred to the paleosurfaces of the main stratigraphic divisions, allowing to define a multiple Contourite Depositional System (CDS) formed by the LD and HD waters and their interfaces with the AW, and dominated by a great variety of depositional and erosive features.

The seismic facies characterizing the CDSs, as well as their temporal and spatial variability suggest the action of LD and HD Mediterranean waters since the beginning of the Pliocene. The results allow decoding of the paleocirculation and indicate that significant relocation of main flow pathways, both longitudinal and transversal, occurred.

CONCLUSIONS

We have inferred three circulation models: 1) during the infilling of the Mediterranean basinby the Atlantic flooding, highly erosive (Estrada et al., 2011); 2) during the Pliocene, when a strong countercurrent occurred in the Western Alboran Basin, eroding the Spanish base of slope; it comprises two stages: 2a) Lower Pliocene, the Western and Southern basins were connected allowing the circulation of tabular HD waters; 2b) Upper Pliocene, the uplift of the SW Alboran Ridge interrupted the connection, favoring the splitting of HD waters into accelerated branches; and 3) the Quaternary model is similar to the present day, characterized by an enhanced density contrast between the LD and HD Mediterranean waters that show multiple current dynamics including a less energetic recirculationof the HD in the Western Alboran Basin and larger vertical and horizontal displacements of the water mass interfaces directly related to 4th-orderglacioeustatic changes. All these mentioned stages reflect variability in the bottom current regimes and related along slope efficiency in transport, deposition and erosion mainly governed by large and small scale margin and basin geometries, and climatic changes.

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Djibouti Ville Drift (SW Mediterranean): Sedimentation and record of bottom-current fluctuations during the Pleistocene and Holocene

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Abstract: *Seismic profiles and sedimentological data (bulk fraction) of two sediment cores recovered from the Djibouti Ville Drift (SW Mediterranean Sea) indicate that bottom currents have played a fundamental role in shaping the sediment drift. The deposits are composed of biogenous to mixed muddy and silty contourites. A grain size analysis of the terrigenous fraction together with mineralogical, magnetic susceptibility, ^{14}C-AMS dating and stable oxygen isotope data have been analysed to reconstruct glacial and interglacial changes in the bottom currents during the last 133kyr. The sharp vertical grain size changes in the moat and drift indicate that there were substantial bottom current acceleration and deceleration events with faster flow speeds being registered in the moat environment. In sediments from glacial periods (MIS2, MIS3, and MIS6) and stadials 5b and 5d, there is a low carbonate content, high levels of terrigenous elements and paleocurrent proxy values suggest faster flows with the exception of MIS4. Deposits from the interglacial period (MIS1) and interstadials 5a, 5c and 5e, have a high carbonate content, low levels of terrigenous elements, and the paleocurrent proxy values indicate slower flows.*

Key words: *drift and moat deposits, sortable silt, paleocurrents, seamount, Alboran.*

INTRODUCTION

The southern sector of the Djibouti Ville Seamount is characterized by the presence of a drift contourite system between 700 and 1075m water depth. This seamount is located on the Motril Marginal Plateau in the South Iberian Margin (Northern Alboran Sea) (Palomino et al., 2011). The contourite system comprises a small elongated separated drift associated to a moat (Fig 1). The Alboran Sea is characterized by three main water masses (Millot, 1999): Atlantic Water-AW (0-200m), Levantine Intermediate Water-LIW (200-600m) and Western Mediterranean Deep Water-WMDW (>600m). The present-day general circulation shows that the drift contourite system is swept by the WMDW although one CTD deployed in summer 2012, registered that it was affected by the interphase zone between LIW and WMDW (Juan pers. comm.). The aims of this paper are to examine the sedimentary dynamic and the glacial to interglacial changes in bottom currents across the drift contourite system.

Two cores (up to 6m long) were recovered from two sedimentary environments, the moat (core PC15, 763m water depth) and the drift (core K3, 712m water depth). They are separated by only 1.5km. The following analyses were carried out on the cores: a) on the bulk fraction: grain size analysis, scanning XRF-derived elemental data and magnetic susceptibility (MS); b) on the terrigenous fraction: grain size analyses (sortable silt, mean and silt/clay ratio) as proxies for bottom current intensity (Hall and McCave, 2000); c) on discrete samples: ^{14}C-AMS data. Additionally, stable isotope δ^{18}O measurements were carried out on the planktonic foraminifera *G. bulloides* in core K3.

RESULTS

The stratigraphic data for core K3 shows that the core spans the past 133kyr. Glacial stages, stadials (5b and 5d), interglacial stages (Holocene) and interstadials (5a, 5c and 5e) can be recognized (Fig. 1A). These stages clearly correlate with the isotope curve for the Alboran Sea (Martrat et al., 2004). The carbonate content is higher (40-49%) in interglacial periods, whereas the sedimentation rate is higher (up to 7.3cm.kyr^{-1}) in the glacial periods, with a general mean value of 4cm.kyr^{-1} (Fig. 1A). The δ^{18}O stratigraphy for core PC15 is not available; the mean sedimentation rate is 3.8cm.kyr^{-1} based on ^{14}C-AMS data.

Both cores have a similar sedimentation rate and there is an absence of lag deposits and hiatuses. Comparing the two cores therefore allows a correlation of the lithological units in the drift-moat system (Fig. 1). Sediment core analysis (MS, Ti, Si, Sr, Ca curves) provides evidence of an along slope trend of six main correlatable sedimentary units (a to f) (Fig. 1B and D). These units are composed of three main types of contourite facies: 1) homogeneous mud (< 8µm mean), 2) thin-bedded fine silt (8-14µm mean) and 3) mottled silty mud (14-20µm mean). The vertical trends of mean terrigenous grain size display maximum peaks which are coincident with the maximum values of the sortable silt (SS) and the silt/clay ratio (S/C)(Fig. 1). The values of these peaks vary between the moat and drift environments. The peaks in the moat are characterized by a coarser grain size (up to 19µm mean, 68% SS, 9 S/C) than in the drift (up to 10µm mean, 48% SS, and 3.7 S/C).

SEDIMENTARY DYNAMICS AND PALEO-CURRENT EVENTS FROM THE PLEISTOCENE TO HOLOCENE

In the Drift Contourite System. The development of the Djibouti Ville Drift is conditioned by the efficiency of deep water circulation in the area in reworking, winnowing, transporting and accumulating terrigenous and biogenous particles. The spatial distribution of the sedimentary facies reveals that muddy and silty contourites characterize both environments (moat and drift) (Fig. 1). The sharp vertical variations in paleocurrent proxies suggest fluctuations in the intensity of bottom currents in both environments. The maximum and minimum values are interpreted as acceleration followed by deceleration of bottom currents, respectively. The moat registers faster flow speeds than the drift, and it displays a wider range of grain size proxy values. This can be seen most clearly in sedimentary unit c (Fig. 1B, D). Between the moat and drift in this unit there is a large and abrupt increase in the sortable silt (from 43 to 75%), mean (from 8 to 16µm)) and silt/clay ratio (from 2 to 8µm) indicating faster flow speeds in the moat. These differences can be interpreted in terms of enhanced hydrodynamic influence over the moat environment.

During glacial/interglacial periods. The vertical trend of the sedimentation rate versus the $\delta^{18}O$ curve from core K3 (Fig. 1A) suggests higher rates during glacial periods (MIS2, MIS4, MIS6). This probably results from an increase in terrigenous supply during periods of low sea levels. In fact, these glacial periods record high values of terrigenous elements (e.g., Ti, Zr, Si, Rb) and a low carbonate content. Additionally, there are indicators of winnowing throughout core K3, such as the presence of poorly preserved planktonic (up to 30% broken tests) and benthic foraminifera. Therefore, the increase in the coarse fraction during cold periods could be best explained by enhanced sediment supply from eolian/fluvial sources and a winnowing effect. During the cold periods (MIS2, MIS3, MIS6) and in stadial 5d in core K3, the silty facies dominates and the grain-size proxy values are higher than those of the warm periods with the exception of MIS4. During this event, anomalous paleocurrent proxy values, high clay content values and an increase in Al intensity are seen (Fig. 1B). A notable feature of paleocurrent proxies is an increase in values at the beginning of MIS4 followed by a sharp decrease in spite of cool conditions, which is supported by the heaviest $\delta^{18}O$ values (Fig. 1A, B). The cause of the anomalous paleocurrent proxy values could be linked to the deepening of the WMDW flow axis. We point out that the deepest WMDW position coincides with an important sea level fall during MIS 4 (-120m). The migration of the flow axis towards a deeper area may imply that the area is affected by the interphase zone between two water masses, LIW and WMDW. As consequence, distinguishing the water masses present during each episode is crucial for the comprehensive interpretation of the paleocurrent proxies observed in the Djibouti Ville Drift. Finally, core K3 provides evidence of drastic acceleration and deceleration of flow speeds over the last 133kyr.

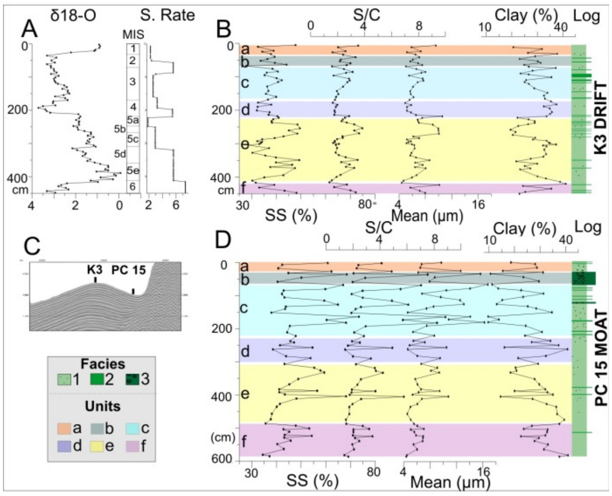

FIGURE 1. Sedimentary records of the Djibouti Ville Drift: A) $\delta^{18}O$ curve and sedimentation rate (cm.kyr^{-1}) in core K3; B) paleocurrent proxies for core K3 and log; C) Airgun seismic profile; and D) paleocurrent proxies for core PC 15 and log.

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A 130,000-year record of Levantine Intermediate Water flow variability in the Corsica Trough, western Mediterranean Sea

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Abstract: *We present here the first record of the inflow, ventilation and vertical fluctuations of the Levantine Intermediate Water (LIW) for the last 130,000 years.*

Key words: *Levantine Intermediate Water, western Mediterranean Sea, past climate changes.*

BACKGROUND

The Mediterranean outflow water (MOW) dynamics, at the geological timescale, is controlled by the integrated evaporative balance of the Mediterranean Sea, itself resulting from the complex interplay between climate and sea-level changes (Rogerson et al., 2013). This controls the variability of the MOW sources from the eastern and western basins: the Winter Intermediate Water (WIW, <200m water depth, mwd) and the Western Mediterranean Deep Water (WMDW, ca 600-1000 to 3000mwd) formed in the Ligurian-Provençal Basin and the Gulf of Lion (western Mediterranean), the Levantine Intermediate Water (LIW, ca 200 to 600-1000mwd) originating from the eastern Mediterranean and entering the western Mediterranean through the Sicilian Channel, and the Tyrrhenian Dense Water (TDW) that enters between LIW and WMDW (Millot, 1999). Although the MOW (e.g. Voelker et al., 2006) and the WMDW variability (e.g. Cacho et al., 2000) have been intensively studied through the last climatic cycle, very little is known about the dynamics of the Mediterranean intermediate waters. This is particularly true for the LIW, which contributes up to 80% to the Mediterranean outflow volume. Therefore, the reconstruction of the dynamics of this water mass is crucial to the evaluation of the impact of the Mediterranean thermohaline circulation on the outflow. We precisely bridge this gap by reconstructing LIW dynamics in the western Mediterranean Sea over the last climate cycle.

DATA

This study is based on the analysis of the Calypso long piston cores MD01-2434 (42°22.51'N/9°47.04'W; 780mwd; 24.9m long) and MD01-2472 (42°36.42N'/ 9°43.97'W; 501mwd; 29.1m long) collected on the lower continental slope of the east Corsica margin during the MD123-Geosciences 1 and MD124-Geosciences 2 cruises of the R/V Marion Dufresne II (IPEV) (Fig. 1). The cores were sampled for grain-size (2.5-10cm intervals, according to the sedimentary facies) and stable isotope measurements (using benthic and planktic foraminifers; 10 and 20cm intervals in core MD01-2472 and MD01-2434, respectively) and radiocarbon dating.

RESULTS AND CONCLUSIONS

Sedimentological and geochemical profiles from western Mediterranean deep-sea sediment cores MD01-2434 and MD01-2472 provide a continuous high-resolution climatic and paleoceanographic record in the Corsica Trough, northern Tyrrhenian Sea, for the last 130,000 years (Toucanne et al., 2012). The inflow, ventilation and vertical fluctuations of the LIW has been reconstructed using sortable silt particle-size data and benthic foraminifer stable isotope analyses. The results reveal that climate changes drove the Mediterranean intermediate circulation on Milankovitch to millennial time-scales according to a cold/faster (and well-ventilated) - warm/slower (and poorly ventilated) pattern consistent with the present-day response of the LIW to seasonal oscillations (Fig. 1). These changes are accompanied at the Milankovitch time-scale by large density-driven fluctuations of the LIW axis, with deepening/shoaling of the LIW axis occurring at time of climate degradation/amelioration, respectively. It is assumed that this variability, both in ventilation and position, reflects the changes of the eastern Mediterranean net evaporation, as well as the propagation to the western Mediterranean of the profound hydrographic adjustments in the Levantine Sea caused by climate forcing. Significant attendant hydrographic adjustments in the deep Ligurian-Provencal Basin and in the Gulf of Cadiz, downstream of the Corsica Trough by considering the genetic relationship existing between the LIW, the WMDW and the MOW, emphasise the LIW imprint on both the WMDW properties and the Mediterranean-Atlantic exchange. This first palaeoceanographic reconstruction of the intermediate water inflow and ventilation in the western Mediterranean almost certainly provides an additional constraint on the role of the eastern Mediterranean hydrographic changes to the whole Mediterranean thermohaline circulation, as well as for the Atlantic Meridional Overturning Circulation and past climate changes.

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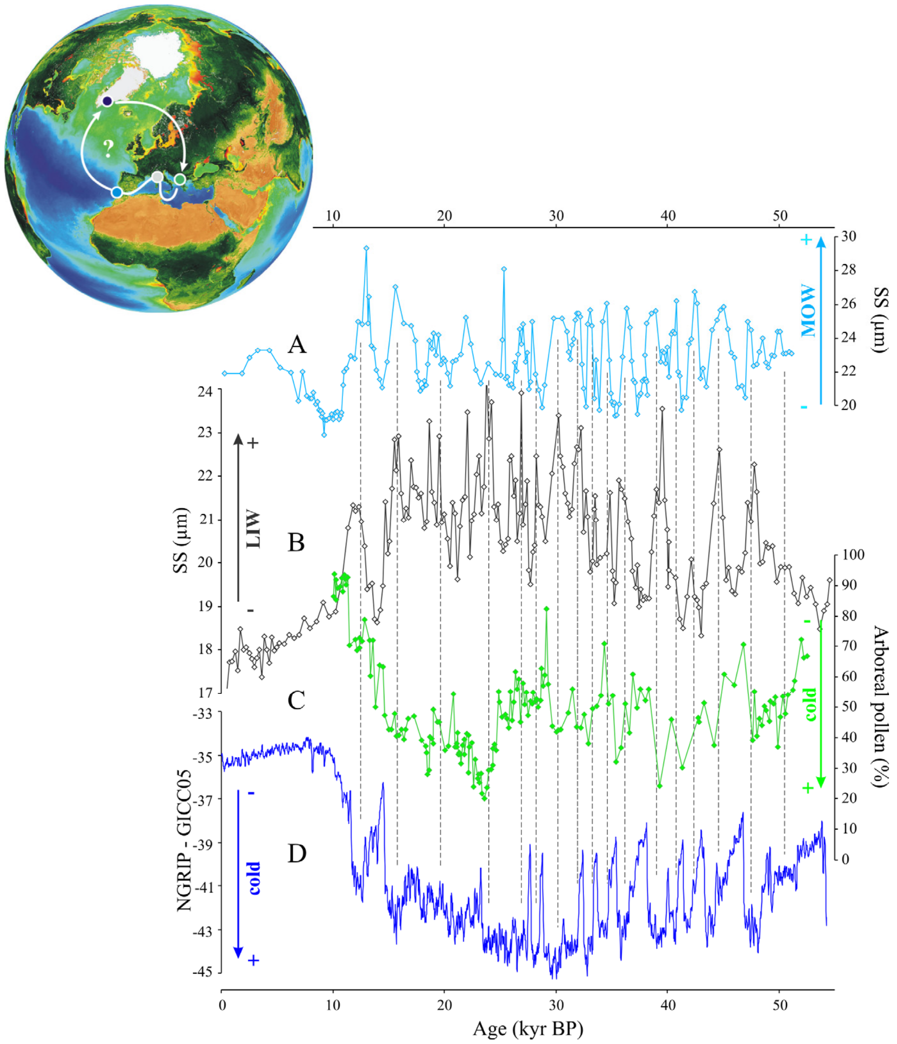

FIGURE 1. (A) Downcore grain-size record (sortable silt, SS) of core MD99-2341 (Gulf of Cadiz) (Toucanne et al., 2007); (B) Downcore grain-size record SS of core MD01-2434 (Corsica Trough) (Toucanne et al., 2012); (C) The pollen percentages of arboreal pollen of core I-284 from Lake Ioannina in western Greece (Tzedakis et al., 2004); (D) NGRIP $\delta^{18}O$ (GICC05 chronology; Svensson et al., 2008).

Onset of Mediterranean Outflow into the North Atlantic

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Abstract: *Sediments cored along the southwestern Iberian margin during Integrated Ocean Drilling Program Expedition 339 provide constraints on Mediterranean Outflow Water (MOW) circulation patterns from the Pliocene epoch to present day. After the Strait of Gibraltar opened (5.33 Ma), a weak and limited volume MOW entered the Atlantic. Depositional hiatuses indicate erosion by bottom-currents related to higher volumes of MOW circulating into the North Atlantic beginning in the late Pliocene. The hiatuses coincide with regional tectonic events and changes in global thermohaline circulation (THC). This suggests that MOW influenced Atlantic Meridional Overturning Circulation (AMOC), THC, and climatic shifts through the supply by contributing a component of warm, saline water to northern latitudes, while in turn being influenced by plate tectonics.*

Key words: *Contourites, Gulf of Cadiz, IODP Expedition 339, Mediterranean Outflow Water, global thermohaline circulation, Atlantic Meridional Overturning Circulation.*

INTRODUCTION

Changes in the Mediterranean Outflow Water (MOW) co-occurred with some shifts in global ocean circulation and climate, but the exact timing of MOW evolution vis-à-vis major climate events remains unclear. This paper interprets the sequence of events very recently identified by Hernández-Molina et al (2014) that established a significant MOW contribution to North Atlantic thermohaline dynamics, and how these dynamics relate to Neogene and Quaternary climatic and tectonic events. This study combines geophysical and drill-core data acquired along the southwestern Iberian margin during Integrated Ocean Drilling Program (IODP) Expedition 339 aboard the RV *JOIDES Resolution*.

DEPOSITS FROM LATE MIOCENE TO PRESENT: SEISMIC RECORDS AND DRILL CORE INTERPRETATION

Major regional discontinuities appear as high-amplitude seismic reflections within late Miocene to present-day sediments around the Gulf of Cadiz (Fig. 1). These discontinuities provide a record of MOW circulation relative to coeval tectonic and environmental events. In seismic records, Pliocene deposits appear as sheeted drifts, overlying a weakly reflecting Miocene unit that progrades downslope (Fig. 1). The late Pliocene to early Quaternary section records significant synsedimentary deformation associated with two discontinuities that define erosional surfaces (Fig. 1). Quaternary deposits are distinguished by high amplitude seismic reflections and show clear upslope progradation.

The predominant sedimentary facies in the late Miocene to present-day sedimentary record include pelagites, hemipelagites, contourites, turbidites, debrites and slump deposits. Contourites constitute up to 95% of Quaternary deposits, and about 50% of the recovered Pliocene succession. This facies includes sand-rich, silt-rich and mud-rich contourites, deposited at moderate (20-30 cm/ky) to very high (> 100 cm/ky) sediment accumulation rates. Dolomitic mudstone and dolostones are rare, but also occur in drill core material. The chronostratigraphy and absolute ages of key horizons, namely several depositional hiatuses and stratigraphic boundaries derive from shipboard bio- and magnetostratigraphic analyses of core samples collected at IODP Expedition 339 sites. Two depositional hiatuses (Fig. 1), evident at 3.2 - 3.0 Ma and 2.4 - 2.1 Ma, indicate that MOW did not significantly circulate into the North Atlantic until the late Pliocene and early Pleistocene. A latter event, occurring at 0.9 - 0.7 Ma, suggests the existence of an additional Pleistocene phase of MOW intensification.

CONCLUSIONS

The results presented here show that initial MOW circulation, into the Atlantic following the opening of the Strait of Gibraltar, was relatively weak. Significant interaction between MOW and the North Atlantic did not begin until the late Pliocene. The establishment of MOW added relatively salty water at intermediate depths and contributed to enhanced THC and AMOC. The addition of the warm, salty MOW component reduced pole-to-equator temperature gradients during the mid-Pliocene warm period (3.2 -3.0 Ma), during the early Pleistocene (2.4 - 2.0 Ma), and at 0.9 - 0.7 Ma. These climatic events coincide with widespread depositional hiatuses, pronounced changes in the sedimentary stacking pattern and establishment of the present-day sea-floor morphology (Fig. 1). Hiatuses and shifts in depositional processes are related to regional tectonic events and margin instability. Similar changes in deep water sedimentation and tectonics have been described in association with other margins and basins around the same time in both the Northern and Southern hemispheres, demonstrating that the relationship between climatic shifts and plate tectonic events operates over a wide range of timescales.

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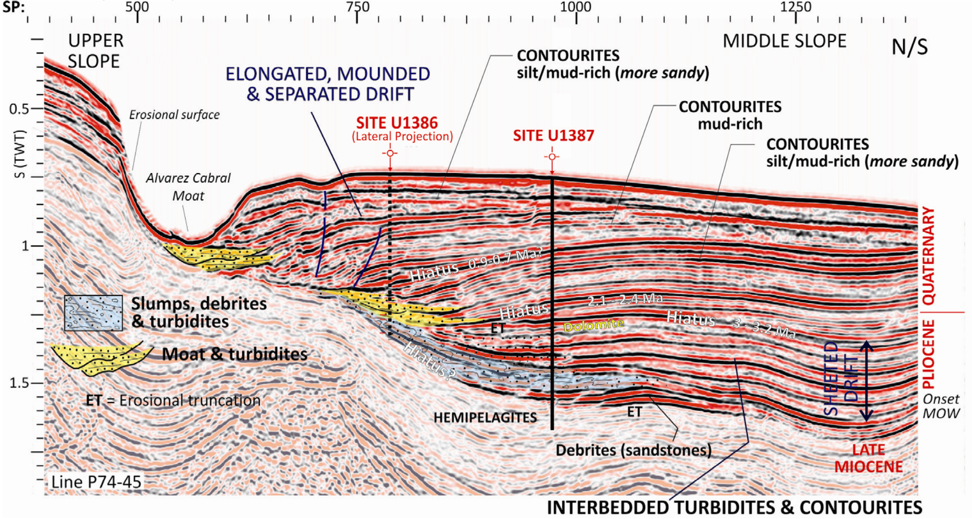

FIGURE 1. Seismic profile showing the major sedimentary stacking pattern, from the Pliocene sheeted drift to the Quaternary elongate and mounded drift, based on the correlation between Sites U1386 and U1387 and the multichannel seismic reflection line P74-45. The hiatuses and main type of contourite drifts are indicated (data courtesy of REPSOL).

Contourite processes associated with the Mediterranean Outflow Water after its exit from the Gibraltar Strait: Global and conceptual implications

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Abstract: *Herein we characterize the eastern Gulf of Cadiz, proximal to the Strait of Gibraltar, using a multidisciplinary approach that combines oceanographic, morphosedimentary and stratigraphic studies. Two terraces (upper and lower) were identified along the middle slope. They comprise of several associated morphologic elements, including two large erosive channels, which determine a new and more detailed understanding of the Mediterranean Outflow Water (MOW) pathway and its deceleration upon exiting the Strait of Gibraltar. There is evidence for along-slope circulation, and an additional secondary circulation oblique to the main flow. The present upper core of the MOW flows along the upper terrace and the present lower core along the lower terrace. However, the lower terrace shows larger and better-defined erosive features on the seafloor than does the upper terrace, which we attribute to a denser, deeper and faster MOW circulation that prevailed during past cold-climate times. Development of the present features was not established until the Late Pliocene-Early Quaternary, when the MOW enhanced, coeval with global cooling, a sea-level fall and an increase in Thermohaline Circulation (THC).*

Key words: *Contourites, Gulf of Cadiz, Strait of Gibraltar, Mediterranean Outflow Water*

INTRODUCTION

Our understanding of the role of deep ocean circulation in the sedimentary evolution of continental margins is rapidly improving. However, gaining knowledge on the processes involved requires that connections be made between contourite features, their spatial and temporal evolution, and the near-bottom flows that form them. In this work we present a multidisciplinary approach recently published by Hernández-Molina et al. (2014) to evaluate the present and ancient processes related to the Mediterranean Outflow Water (MOW) and its evolution in the Gulf of Cadiz after it is funnelled through the Strait of Gibraltar (SG). Morphosedimentary features are identified using swath bathymetry and seismic profiles, and their oceanographic and geologic implications are discussed. Oceanographic analysis was performed using acoustic Doppler Current Profiler (ADCP) and Conductivity, Temperature and Depth (CTD) datasets, integrated with acoustic analysis and numerical simulations. Seismic data and sediment samples collected by dredges, cores and borehole MPC-1 provided details on sedimentology, stratigraphy, evolution and age constraints. Oceanographic data are not include here but can be seen in Hernández-Molina et al. (2014).

CONTOURITE FEATURES

Erosional and depositional contourite features were identified west of the Strait of Gibraltar (Fig. 1). Two zones (eastern and western) are separated by a region of basement highs (BHs), and are coincident with a marked change in margin trend from WSW to NW, as well as the development of a distinct middle slope to the west. Erosional features dominate in the *eastern zone*, comprising a large (3–4 km wide), WSW trending channel (hereafter *Southern Channel,* SC) located along the southern part of the Strait. A smaller northern channel (hereafter *Northern Channel,* NC) also was identified. In the *western zone,* two terraces (*Lower* and *Upper*) are present, each comprising (from landward to seaward): a basinward dipping *erosional surface*, a *channel*, a *smooth mounded drift* adjacent to the channel, and numerous small *furrows* oblique to the channel.

The *upper terrace* is shallower in the east (500 m) and deepens north-westwards (~730 m). It is 13.5–23 km wide and slopes seaward ~0.34° in the east and ~0.18° in the west. The erosional surface is a marked erosive scarp incised into the upper slope with a clear truncation surface. The NC is filled with coarse sandy sediments and becomes more distinctive toward the northwest, where it feeds into the Cadiz and Guadalquivir Contourite Channels (Fig. 1). Its axis slopes from 500 m in the east to 780 m in the NW, and it is bounded on its seaward flank by a drift. The crest of this drift also slopes, from 530 m in the east to 650 m in the west. It is constructed by erosional and depositional phases having a complex internal structure composed of sandy deposits. A series of furrows deviates from the Northern Channel by 30–45°. The *lower terrace* has larger and better-defined features than does the upper terrace (Fig. 1). It also deepens north-westwards from 585 m in the SE to 750 m in the NW. Approximately 9 km wide, it slopes seawards an average of 0.45° in the eastern sector and 0.18° in the western sector. The large and incised SC is ~6 km wide and is characterized by coarse-very coarse sand deposits. It has a broadly sinusoidal shape, WSW to NW trend, and feeds into the Cadiz Contourite Channel in the central sector. The channel axis slopes from 715 m in the east to 780 m in the NW. Seaward of the SC, an associated drift is characterized by irregular morphology and muddy deposits. The drift has a crest deepening westward from 600 to ~830 m. Numerous furrows are evident across the drift, trending at 40–45° from the channel orientation, but they evolve downslope to SW-orientated furrows due to the changing gradient of the lower slope. The onset and evolution of these contourite features is related to a significant regional change in both seismic facies and depositional style occurred during the late Pliocene/early Quaternary, observed in a hiatus from 3.2 to <2.58 Ma (the base of the Quaternary discontinuity, BQD).

CONCLUSIONS

The new morphosedimentary map and the oceanographic, geological and geophysical data that we have presented here have enabled the first-ever detailed mapping of the interaction between the MOW and the seafloor west from the Gibraltar gateway, in the Gulf of Cadiz. MOW circulation combines a main along-slope flow direction with oblique secondary circulation filaments. The present-day flow of the MOW is mainly as the upper core along the upper slope and the proximal part of the middle slope. A denser, deeper and enhanced circulation of the MOW as the lower core is inferred during climatically cold intervals. The vertical displacement of the MOW due to climatic variations explains the formation of the largest erosional features west of the Gibraltar gateway. The presence of extensive sand-rich deposits over contourite terraces has important conceptual implications, both in establishing a facies model for sandy contourites, as well as in assessing their potential for deep-water hydrocarbon exploration.

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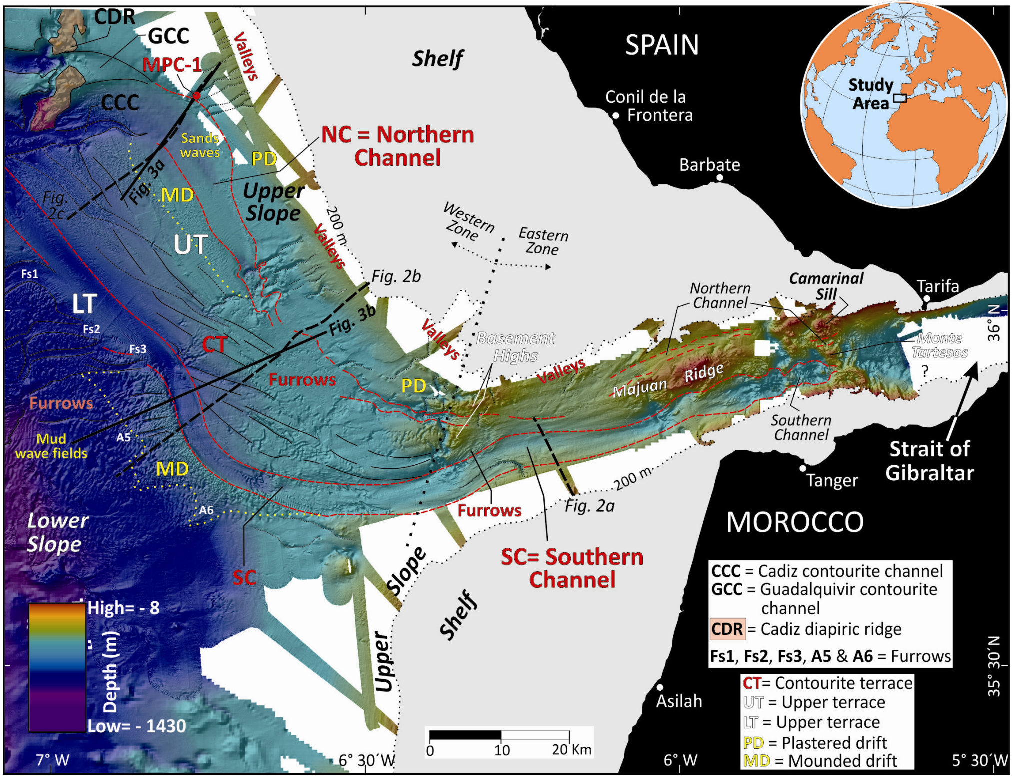

FIGURE 1. Swath bathymetry at the exit of the Strait of Gibraltar. Main depositional and erosive features are shown.

Oceanographic processes and products around the Iberia continental margin: a new multi-disciplinary approach?

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Abstract: *Our understanding of the physical oceanographic processes that affect sedimentation and erosion, e.g. overflows, tide, deep sea storms, vortices, internal waves and tsunamis, is improving. However, the results of such processes on the depositional and erosional features in the ocean are still less extensively studied. In the present compilation an overview of some key physical oceanographic processes and their sedimentary products around the Iberia margin is presented. The oceanographic processes are affecting the shape and evolution of the Iberian continental margin and adjacent oceanic basins, but have nonetheless been somewhat overlooked historically. A better understanding on the effect of the oceanographic processes on e.g. contourite sea-floor features, their spatial and temporal evolution, and the near-bottom flows that form them is needed in order to understand how the Iberian continental margin functions. It is proposed that more intensive collaboration studies between specialist from Geology, Oceanography and Benthic Biology in multi-disciplinary approach should be prioritized in the near future combining oceanographic data, sea-floor morphology, sediment and seismic characterization and benthic biologic mapping. This will be essential to improve our knowledge of the permanent and intermittent processes around Iberia and evaluate their conceptual and regional role in the margin evolution over time and space.*

Key words: *Iberian margin, oceanographic processes; bottom current; sedimentary products*

INTRODUCTION

Bottom currents are often a persistent process with a net flow *along-slope* (or following the local bathymetry), but can also be variable in direction and velocity on short time scales. They are affected by a number of persistent processes, such as overflows, tides and internal tides but also intermittent processes such as giant (vertical) eddies, deep sea storms, (horizontal) vortices, internal waves and solitons, tsunamis, rogue and cyclonic waves. An overview can be found in Rebesco et al. (2014). The various forcing mechanisms modulates the bottom current speed and direction, and serve to develop local and regional hydrodynamic signatures (*cores*, *branches*, *filaments*, *eddies*, *vortices*, *local turbulence*, *internal waves*, *helicoidal flows*, *vertical columns*, etc.) that control the sedimentary and erosional processes and associated sedimentary facies. Most of those oceanographic deep-water processes are rarely observed but believed to be capable of generating depositional and erosional features in many contexts, at both short and long term scales.

We present here a compilation where we describe persistent and intermittent oceanographic processes associated with the bottom-current circulation along the Iberian continental margin and adjacent oceanic basins, including some examples and their potential role in the sedimentary processes. This compilation has allowed us to present some suggestions for future deep-water sedimentation studies and related applied research. Importance of these processes is highlighted and its research and applied implication discussed.

A MULTI-DISCIPLINARY APPROACH IS NECESSARY

Bottom current-controlled depositional and erosional features have been shown by e.g. Hernández-Molina et al. (2011) to be common along the Iberian continental margin. The bottom-current circulation around the Iberian is affected by a number of permanent and intermittent oceanographic processes (Fig. 1), which are not fully understood, but they appear to be important in controlling the sedimentary facies and shaping the seafloor.

Based on these results it is suggested that a better understanding of the oceanographic processes related to bottom currents and its associated products are required. The hitherto underestimated pervasiveness role of these oceanographic processes in the sedimentary stacking pattern on continental margins in long-term has to be also seriously reconsidered in future decades. The only way to achieve that along the Iberian margin is trough a more intensive collaboration between specialists from Marine Geology, Oceanography and Benthic Biology. Further, long-term multi-disciplinary measurement programs are needed in order to understand the evolution of the continental margin and predict its future and stability. Such collaboration represent a major challenge since the disciplines have separate short-term objectives, focus areas and terminology.

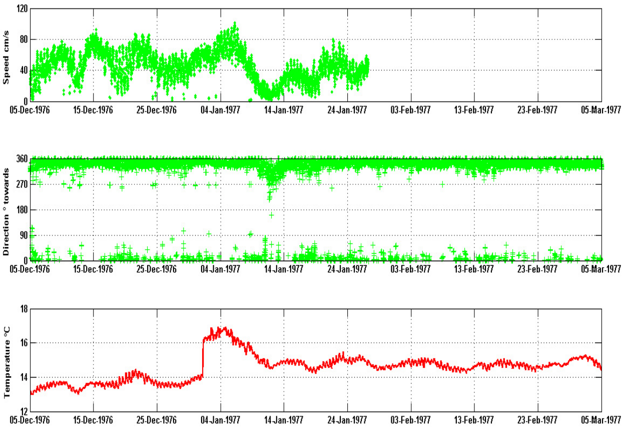

FIGURE 1. Time series observations of the near-bottom current (78 m above the seafloor) at the Eastern Gulf of Cadiz (554m water depth) showing a strongly directional MOW towards the NNW with speeds up to 1 m.s^{-1}. A clear semi-diurnal tidal periodicity with a spring-neap tidal cycle is observed, which also modulates the near-bottom temperature. The jump in the temperature record is presumable due to the mooring turnaround operation and the sampling of a slightly different water parcel.

In addition, as in many marine sciences, the future perspectives depend on the technological development, allowing more accurate and detailed studies of the water column, seafloor, and on samples retrieved from the contourite deposits (Rebesco et al., 2014). For example, exciting new developments in the field of seismic oceanography will allow to couple these in-situ observations to a 2D (or even 3D) insight in the oceanographic processes. An integrated acoustic approach coupled with oceanographic data such as CTD or (L)ADCP and moorings should be considered. A better characterisation of the contourite products will soon be fully linked to advances in marine geophysics, making high-resolution 3D seismics, multibeam and backscatter data more readily available for academic purposes as well as even more detailed observations of seafloor morphology and benthic communities from Automated Underwater Vehicles (AUV) and ROVs. These evolving methodologies will likely be essential for mapping oceanographic processes associated to the bottom-current circulation and correlate them with seafloor contourite morphologic features and benthic communities.

AN APPLIED RESEARCH?

Multi-disciplinary studies for understanding of oceanographic processes associated to the near bottom-current circulation have important implications in applied research. For example, economic interest of sandy contourites can be explored and evaluated. Sandy contourites differ from deep-water turbidite sands that currently dominate the deep-water oil and gas plays. There exists a potential economic interest that can be explored and evaluated in the near future. A better evaluation of the potential of sandy contourite systems as reservoirs for oil and gas, as well as the potential of muddy contourites both as source rocks for hydrocarbons and as unconventional reservoirs are other potential focus areas. These new findings could herald a paradigm shift in exploration targets in deep-water settings.

Moreover, the frequent association of contourite deposits, both sandy and muddy, with cold-water coral mounds may also be regarded as an interesting unconventional reservoir. Therefore, it is also important to better elucidate the role of oceanographic processes associated to the bottom-current circulation and its variability due to climate on the ecological health status of deep-water ecosystems, such as reefs. An emerging field that requires more insight in deep bottom water circulation is the renewed exploration phase for metalliferous resources, which also have been also identified along the Iberian margin. More knowledge about their formation with respect to bottom currents and seafloor morphology is required in order to perform predictive mapping of these marine resources.

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Deep water circulation around the Iberian continental margin: state of art and future implications

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Abstract: *Numerous and frequent examples of deep water bottom-current processes and products have been recorded in the recent evolution of the Iberian margins, comprising both erosive (terraces, abraded surfaces, channels, furrows and moats) and depositional (separated, sheeted, plastered and confined drifts) features of variable dimensions, depending on a variety of geological and oceanographic contexts. Most of them are related to the influence of the Mediterranean water masses, especially by the interaction of the Mediterranean Outflow Water with the seafloor. Despite their important scientific implications (stratigraphy, sedimentology, paleoceanography, paleoclimatology), geological hazards and economic potential, there is no full knowledge about the specific morphologic details of these features and its evolution as well as their relation with water masses and associated interphases. So, future multidisciplinary work has to be done between geologist and oceanographers for understanding the bottom current influence along the Iberian margin.*

Key words: *Contourites, Iberian margin, bottom currents, sedimentary processes, control factors*

INTRODUCTION

The Iberian margins lie under the influence of several water masses interacting along the upper and middle continental slopes and, although in minor intensity, also under the lower slope and abyssal plains. In all these domains, extensive, complex and often poorly known contourite features of large dimensions and diverse sediment thickness are occurring in different geologic contexts. These features are mainly formed under the influence of the Mediterranean water masses, especially by the interaction of the Mediterranean Outflow Water (MOW) with the seafloor (Hernandez-Molina et al., 2011).

MAIN CONTOURTIE EXAMPLES AROUND IBERIA

Several water masses are interacting along the upper and middle continental slopes and, although in minor intensity, also on the lower slope and abyssal plains around Iberia, developing main drifts or Contourite Depositional Systems (CDSs): SW Ceuta CDS Alboran Sea (Ercilla et al., 2002), in the Gulf of Cadiz (the most studied so far, Roque et al., 2012; Brackenridge et al., 2013; Hernandez-Molina et al., 2014; among others), western margin off Portugal (Pereira and Alves, 2011), in the Galician margin (Ercilla et al., 2011); in the Ortegal Spur, and in Le Danois Bank or "Cachucho" (Hernandez-Molina et al., 2011). These are mainly muddy separated, sheeted, plastered and confined drift. Described erosive contourite features comprise terraces, abraded surfaces, channels, furrows and moats. All of them are mainly generated by the Mediterranean water masses along the Iberian margin, especially formed under the influence of the Mediterranean Outflow Water (MOW) with the seafloor (Fig. 1). Their genesis and facies models are still not fully established, despite its enormous potential for the location of hydrocarbons and mineral resources (Stow et al., 2011).

DISCUSSION: CONTROL FACTORS AND IMPLICATIONS

In the development of both depositional and erosional contourite features more controlling factors than only the bottom-current velocity have to be taken into account, including: *Local margin morphology* particularly inherited of geological features, facilitate local water mass interaction with the seabed. During the Pliocene and lower Quaternary, tectonics have represented a long-term factor, conditioning the drift stratigraphy, architectural changes and the location of large-scale contourite features; *Sediment supply,* by possible multitude of sources, each with a time-variable aspect; *Pycnoclines* interaction with the seafloor, internal waves, and its implications with *glacioeustatic changes*, which significant influence in the outbuilding of contourites features ate the Iberian margin, especially during the Quaternary.

Contouritic sediments are generally fairly continuous and yield relatively high-temporal resolution records, due to the enhanced accumulation rates within contourite drifts. Therefore, these sediments hold the key for valuable information on the variability in ocean circulation patterns, current velocities, oceanographic history and basin interconnectivity. Besides, submarine slope instability is commonly related to the distribution, composition and physical properties of contourites. On the other hand, fine-grained contourites, related to both sealing facies/permeability barriers and source-rock accumulation play an important role in the characterization of deep-water petroleum systems.

The role of bottom currents circulation in shaping the seafloor and controlling the sedimentary stacking pattern on the Iberian continental margins has noticeable increased during the last 20 years, although the work for a better define diagnostic criteria in contourite features identification and facies models is far from being finished. Despite their important scientific implications (stratigraphy, sedimentology, paleoceanography, paleoclimatology), geological hazards and economic potential for its potential mineral and energy resources, the conceptual models associated with these features and contouritic deposits along the Iberian margin are still pending to be proposed, there is no full knowledge about the different oceanographic processes which could drive bottom currents and also there is the need to document the big variety of contourite features and facies models, their evolution over time and space. A future advance both in new technologies and integrated studies (geology, oceanography and benthic biology) is expected.

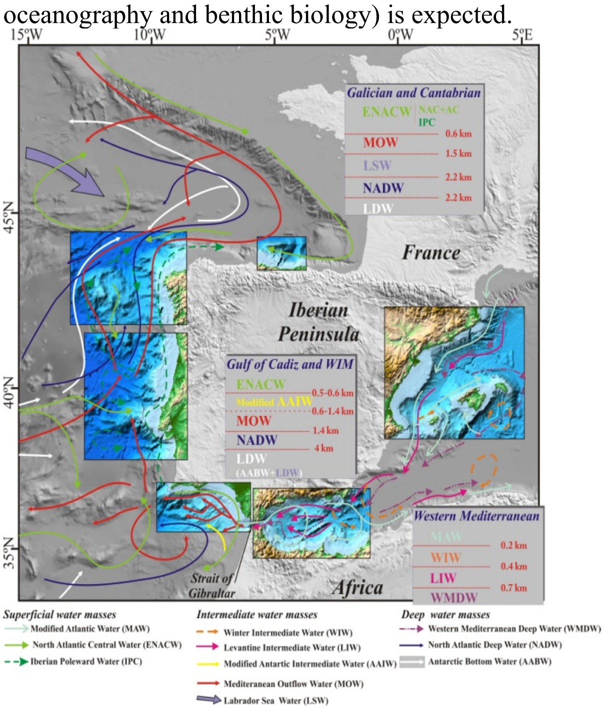

FIGURE 1. *Surficial, intermediate and deep-water circulation around the Iberian Continental Margin. (Modified from Hernández-Molina et al., 2011) and location of the studied areas.*

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This contribution is a product of the IGCP-619 and INQUA-1204 projects and is partially supported through the CTM 2008-06399-C04/MAR (CONTOURIBER), CGL2011-16057-E (MOW) and CTM 2012-39599-C03 (MOWER) project, and partially supported through the Continental Margins Research Group (CMRG) at Royal Holloway Univ. of London (UK).

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Sediment plume monitoring in the Clarion-Clipperton Zone

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Abstract: *OD Nature has a vast experience in monitoring and modelling Suspended Particulate Matter concentration in shelf areas. In the framework of the JPI-Oceans cruise with the RV Sonne in the Belgian, French and German concession zones for deep-sea mining in the Clarion-Clipperton Zone, this experience will be used to monitor sediment plumes, caused by deep-sea mining exploration activities.*

Key words: *Sediment plume monitoring, deep-sea mining, Clarion-Clipperton Zone*

INTRODUCTION

In the coming years, deep-sea mining will be an important economic activity that will exploit the deep-sea for precious metals or rare earth minerals. Belgium has foreseen legislation, to allow the International Seabed Authority to grant a 15 year concession of 77,000km² in the Clarion-Clipperton Zone (CCZ) in the North-East Pacific Ocean, for polymetallic nodule mining. The concession agreement stipulates that a program of oceanographic and environmental baseline studies should be executed, involving annual cruises to the area for environmental research and data gathering to make an assessment of the potential environmental impact of exploration and subsequent exploitation possible. The mining of mineral resources will create a near-bottom turbid plume that could lead to redeposition of sediments in the vicinity of the mine site, potentially burying benthic organisms, both in the near and far field. Long-range lateral and vertical dispersion of fine-grained particles is possible. The effects on the deep-sea ecosystem of the sediment plume dispersion are at present not known.

The Royal Belgian Institute for Natural Sciences (RBINS), Operational Directorate Natural Environment (OD Nature) is involved in the monitoring of the sediment plume characteristics. The monitoring will be executed in the framework of the JPI-Oceans RV Sonne cruise to the German, France and Belgian concession zones in the CCZ in 2015. Landers and instrumentation from the RBINS-OD Nature will be made available for the cruise and the data collected will be analysed afterwards.

SEDIMENT PLUMES ON THE CONTINENTAL SHELF

The RBINS-OD Nature has a vast experience in measuring Suspended Particulate Matter (SPM) concentration and in the analysis of complex data sets. Since the beginning of 2004, more than 1800 days of moorings were performed in the southern North Sea, using a benthic lander, equipped with a series of oceanographic sensors (Figure 1). From autumn 2009, a permanent coastal observatory has been installed, near the entrance of Zeebrugge harbor. Other moorings have been carried out, both at very nearshore areas and at more offshore locations. The collected data increased the understanding of cohesive sediment dynamics in response to tidal and meteorological forcing, during various weather conditions and from short (turbulence) to long (seasonal variations) time scales (Fettweis et al., 2010; Baeye et al., 2011). The observatory significantly contributes to the general and permanent duties of monitoring and evaluation of anthropogenic activities on the marine ecosystem, a legal commitment of Belgium, both nationally and internationally (e.g., EU Marine Strategy Framework Directive, OSPAR).

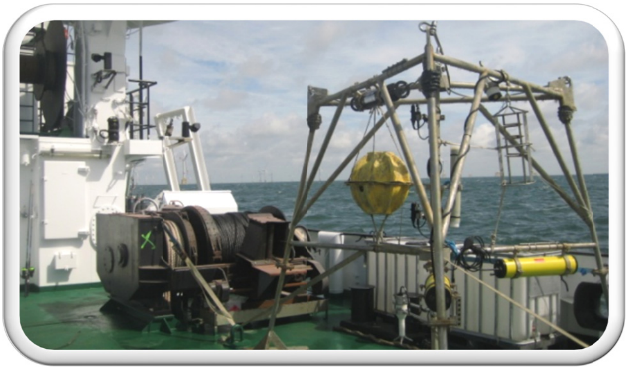

FIGURE 1. Benthic bottom lander, used in the Belgian nearshore area.

Experience also exists in the design of spatio-temporal monitoring strategies that combine high-resolution acoustic seabed mapping with transect-based quantification of flow and turbidity variation. New technologies are used for mapping (AUV, Wave Glider) and ground-truthing (ROV). This has been applied to the study of sediment plumes derived from extraction activities (Van Lancker et al., 2014).

Furthermore, RBINS-OD Nature operates numerical models for the simulation of sediment transport in the southern Bight of the North Sea. The models have been used e.g., to setup the fine-grained sediment balance of the Belgian Continental Shelf (Fettweis and Van den Eynde, 2003), to assess the impacts of aggregate extraction on the sediment transport (Van den Eynde et al., 2010) or to model the dispersion of the disposal of fine-grained dredged material (Van den Eynde and Fettweis, 2006). An operational model is being set up that can be used to optimise the dredging and disposal operations (Van den Eynde and Fettweis, 2012).

SEDIMENT PLUMES IN THE DEEP-SEA

The monitoring in the CCZ is intended to collect SPM mass concentration using optical and acoustic backscatter sensors and particle characteristics using holographic cameras. The Optical Back Scatter (OBS) voltage reading can be converted to SPM mass concentration by calibration with water samples with different concentration of sediment, that have been sampled from the seabed (Fettweis, 2008). The particle size characteristics (size, shape) will be measured using a holographic camera (LISST-Holo), in order to estimate the flocculation capability and the settling velocity of the SPM (Fettweis et al., 2006, Lee et al., 2012). Knowledge of settling velocity is a key parameter for modelling the dispersion of fine-grained particles. The current profile will be measured with an Acoustic Doppler Current Profiler (ADCP). Furthermore, the acoustic backscatter from the ADCP will be converted to SPM mass concentration using the SPM concentration from the OBS. Acoustic backscatter is affected by sediment type, size and composition and are site specific.

The monitoring will consist of measurements with three small benthic frames, each equipped with an OBS and a CTD, during experiments where the seabed will be distorted. At the same time, vertical profiles of particle characteristics, SPM concentration and CTD will be carried out from the ship. Furthermore, long-term measurements will be executed by the German colleagues (BGR) involving long-term co-located OBS and ADCPmeasurements.

The data will deliver information on the natural sediment processes and on the behaviour of human induced turbid plumes in the deep sea. Data will serve as input for numerical models that will be set up by JPI-Ocean partners.

CONCLUSIONS

The RBINS-OD Nature has a vast experience in monitoring of SPM concentration, using different instruments and in analysing the data to get insight in sediment dynamics and in the impacts of anthropogenic activities. Numerical models are applied to assess the impacts of anthropogenic impacts and to perform predictions to improve management of the marine environment.

The RBINS-OD Nature will use this experience in providing equipment for a JPI-Oceans cruise with the RV Sonne to the CCZ area, to monitor the natural SPM concentration and to assess the impact of deep-sea mining related activities.

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Nd isotopic composition of present and Holocene water masses from the Gulf of Cadiz and the Alboran Sea

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Abstract: *Six depth-profiles of dissolved Nd concentrations and isotopic ratios (εNd) were obtained in the Gulf of Cadiz and the Alboran Sea to answer the lack of data in these areas. εNd are analyzed on a multi-collector inductively coupled plasma mass spectrometer. Seawater εNd will be compared with εNd values of deep-sea corals from Alboran Sea dated between 13.5-12.8ka, 11.2-9.8ka and 5.4-0.3ka. εNd from deep-sea corals remained unchanged during these periods and present a narrow range from -8.5 to -9.2 ± 0.2.*

Key words: *Nd isotopes, seawater, Gulf of Cadiz, Alboran Sea*

INTRODUCTION

Nd isotopic composition is expressed as $\varepsilon Nd = [(143Nd144Nd)_{Sample}/\ 143Nd144Nd)_{CHUR} - 1] \times 10,000$, where CHUR stands for chondritic uniform reservoir and represents the present-day average earth value; $(143Nd/144Nd)_{CHUR} = 0.512638$ (Jacobsen and Wasserburg, 1980). The residence time of Nd, recently re-assessed to about 800 yrs (Tachikawa et al., 1999), is shorter than the global turnover time of the ocean (about 1000 yrs. Consequently, through lithogenic inputs of material with various ages and boundary-exchange processes that occur at the continental margin (Lacan and Jeandel, 2005), intermediate- and deep-water masses acquire εNd from downwelling surface water (Goldstein and Jacobsen, 1988).

In the ocean, the only way to alter the initial isotopic composition of one water masse is to add Nd with a different isotopic composition through riverine or eolian inputs or by mixing with other water masses. In areas where the relative influence of exchange is small, Nd isotopes can be used as a tracer of water circulation. This proxy is used in paleo-oceanographic studies using the dispersed authigenic ferromanganese oxide precipitates in sediments, planktonic foraminifera or deep-sea corals to track changes in water mass provenance and mixing on a glacial/interglacial time scale.

The Mediterranean Sea communicates with the North-eastern Atlantic Ocean through the Strait of Gibraltar. At the surface, the Atlantic Inflow enters the Mediterranean Sea, while, at greater depth, the Mediterranean Outflow enters the Atlantic Ocean. Furthermore, the εNd value of the Mediterranean Outflow (εNd=-9.5; Henry et al., 1994) is higher than that of the Atlantic inflow (εNd=-11.8; Spivack and Wasserburg, 1988)

Despite being highly studied areas, εNd of the water masses from the western Mediterranean basin and the Gulf of Cadiz are poorly constrained. In this study, we present six new depth-profiles of Nd concentrations and seawater εNd collected in the Gulf of Cadiz and the Alboran Sea.

SAMPLES AND HYDROLOGICAL SETTINGS

Ten litters of filtered seawater samples were collected at six stations in the Gulf of Cadiz and the Alboran Sea (Fig. 1) during MD-194 EuroFLEETS-GATEWAY cruise in June 2013.

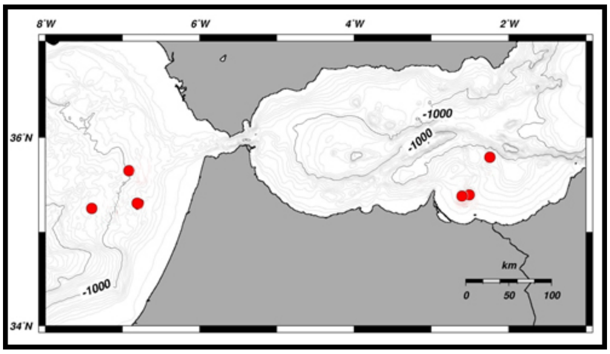

FIGURE 1. Sampling locations of seawaters (red dots).

Three CTD have been made in the Gulf of Cadiz (MD194-MOW1, 35°39.04'N 6°55.10'W, 988m; MD194-MOW2, 35°13.11'N 7°10.56'W, 1050m; MD194-BETA1, 35°17.80'N 6°47.31'W, 520m).

Five water masses are usually observed in the Gulf of Cadiz. The North Atlantic Central Water (NACW) is situated between 100 and 600m. The Antarctic Intermediate Water (AAIW) enters the gulf in the south-western part of the basin and spreads cyclonically at about 800-900m. The salty, dense Mediterranean Sea Water (MSW) flows out of the Mediterranean Sea between 800 and 1400m. In the lowest level lie the deep water masses of the North Atlantic: the Labrador Sea Water (LSW) and the Lower Deep Water (LDW).

Three CTD have been made in the Alboran Sea (MD194-OMS, 35°24.707'N 2°33.379'W, 340m; MD194-BR1, 35°26.075'N 2°30.822'W, 310m; MD194-CAB1, 35°47.736'N 2°15.669'W, 520m).

The Alboran Sea acts as transition area between the Atlantic Ocean and the Mediterranean Sea. Three water masses are identified in the Alboran Sea. In the upper ~150–200m, Modified Atlantic Water (MAW) flows through the Strait of Gibraltar eastward. In water depths of 200–600m, Levantine Intermediate Water (LIW), formed in the eastern Mediterranean Sea, flows westward towards the Atlantic. Below the LIW flows the Western Mediterranean Deep Water (WMDW) which is formed in the Gulf of Lions in the northern part of the western Mediterranean Sea.

METHODS AND RESULTS

Seawater samples were acidified to pH 2 and stored in precleaned plastic bottles for analysis on land. Dissolved Nd in seawater was preconcentrated using the C18 cartridge-HDEHP/H2MEHP complexation method (Shabani et al., 1992). Nd has been separated by using AG50X8 and Ln-Spec resins.

Nd isotopes were analysed on a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) at the Laboratoire du Climat et de l'Environnement (LSCE). Nd aliquots from column chemistry were dried and redissolved in 1N HNO_3 before aspiration using a nebulizer. All $^{143}Nd/^{144}Nd$ ratios were corrected for mass fractionation using $^{146}Nd/^{144}Nd=0.7219$.

Deep-sea corals from the Alboran Sea (Fink et al., 2013), collected between 280 and 440m, have been investigated in this study to establish past changes of the LIW. These deep-sea corals have been dated between 13.5 and 12.8ka, between 11.2 and 9.8ka and between 5.4 and 0.3ka permitting us to investigate past changes of the hydrology of the early and late Holocene and the Bølling-Allerød interstadial. εNd from deep-sea corals remained unchanged during these periods and present a narrow range from -8.5 to -9.2 ± 0.2. Such values are consistent with two εNd seawater profiles further west (between -8.9 and -9.6; Tachikawa et al., 2004). This suggests no major changes of the hydrology of the LIW during the late and early Holocene and the Bølling-Allerød which are characterized by rapid growth of the deep-sea corals in the Alboran Sea (Fink et al., 2013). Foraminifera of one core located close to this studied site will be investigated to complete the seawater εNd record of the Holocene in order to test if the beginning of the Holocene is associated with major reorganisation of the Mediterranean hydrology.

In addition, analyses of Nd isotopic composition in seawater are being acquired and will be presented in comparison with deep-sea corals preliminary results.

ACKNOWLEDGEMENTS

We thank François Thil for technical support regarding Nd isotope analyses on the MC-ICP-MS at the LSCE.

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Seawater density reconstruction of intermediate waters along the European continental margin

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Abstract: *The reconstruction of past ocean seawater densities can be helpful to understand benthic hydrodynamics and ecological processes important for ecosystems such as the cold-water coral (CWC) reefs along the European continental margin. DFG-project INWADE (Cold-Water Coral Mound Development Related to INtermediate WAter DEnsity Gradient) concentrates on the observation that the density of seawater is an important environmental factor for the Northeast Atlantic coral reefs. For three transects at 37°N, 51°N and 65°N across the European continental slope, the Recent distribution of temperature, salinity and seawater density is compared to modelled distribution during the Last Glacial Maximum. Geochemically reconstructed temperature and seawater density data from benthic foraminifera in sediment cores validate the modelled data (or vice versa) and raise the possibility to reconstruct seawater densities for the Pleistocene period.*

Key words: *cold-water coral reefs, carbonate mounds, environmental control, seawater density.*

INTRODUCTION

Recent studies underline the environmental control like temperature, salinity, current intensity, food supply, sedimentation rate, or substrate on the growth and development of cold-water coral (CWC) reefs along the European continental margin (e.g., Freiwald, 2002; Rüggeberg et al., 2007). The density of seawater, a function of temperature, salinity and pressure, is also reported to be an environmental prerequisite for the NE Atlantic CWC reefs (Dullo et al., 2008). At the density range of 27.35–27.65kg.m^{-3}, which is coherent with the position and stability of the thermocline for the Porcupine Seabight and Rockall Bank carbonate mounds (White and Dorschel, 2010), stable and favourable environmental conditions occur even over longer time scales. These conditions involve a constant food supply by continuous or tidally controlled currents allowing CWCs to create large reef ecosystems and to form giant carbonate mounds of up to 300m high.

DFG-project INWADE implements and utilises two different approaches: 1) the possibility to reconstruct palaeo-densities (Lynch-Stieglitz et al., 1999) and palaeo-temperatures (Marchitto et al., 2014) from stable oxygen isotope data of benthic foraminifera, and 2) using modelled temperature and salinity data from PMIP 2 HadCM3M2 to calculate seawater densities. Both approaches give us the opportunity to determine past environmental water mass characteristics, which we compare to the recent setting and interpret in relation to CWC growth and carbonate mound development.

RESULTS AND DISCUSSION

At three transects along 37°N, 51°N and 65°N (Fig. 1) intermediate water masses with warmer temperatures and higher salinities occur on the shelves and at the slopes compared to the open water settings (Fig. 2). The corresponding seawater density also shows a deepening structure towards the European continental margin, with values around 27.5kg.m^{-3} at depths where CWC are reported along the Norwegian (65°N) and Irish (51°N) margins.

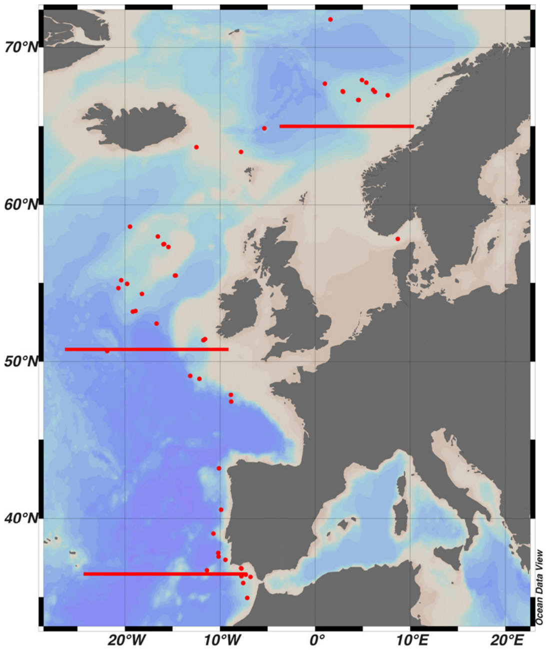

FIGURE 1. Location of oceanographic transects across the European continental margin and sediment core data collected for the data base.

The CWC carbonate mounds in the Gulf of Cadiz are situated at 500 to 700m water depth. Recently, a deeper chain of fossil CWC mounds at 800–900m water depth has been discovered (Henriet, pers. comm.). The mounds occur in less dense waters compared to their northern occurrences. AMS ^{14}C or U/Th dates of coral fragments indicate growth during glacial phases (Wienberg et al., 2010). For the Last Glacial Maximum the 27.5–pycnocline is located at 200m (65°N), < 500m (51°N) and 600–700m water depth for the Gulf of Cadiz region (37°N, see Fig. 2).

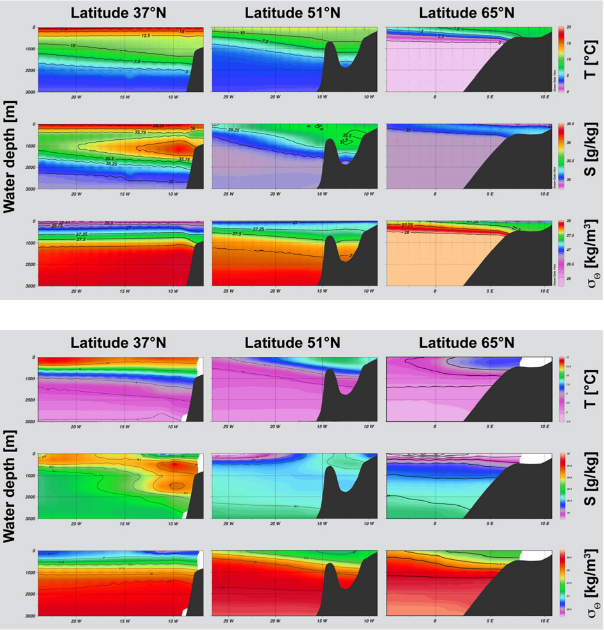

FIGURE 2. Recent (top) and LGM (bottom) temperature, salinity and density (σ_Θ) distribution along 37°N, 51°N, and 65°N (see Fig. 1). Annual mean data from World Ocean Atlas 2009 (Locarnini et al., 2010; Antonov et al., 2010) and from 21k-OAV-PMIP2 experiment using HadCM3M2 model (Braconnot et al., 2007).

The distribution of living coral reef structures follows the hydrography of intermediate water masses with σ_Θ as an important parameter. Where σ_Θ of 27.5 ± 0.15 kg.m^{-3} hits the slope of the continental margin (Fig. 2) cold-water coral reefs may occur when substrates to settle and supply of nutrition is sufficiently available. This occurs not only in the Northeast Atlantic but is more and more reported from other areas in the Atlantic Ocean (e.g., Brazil, Argentina, Greenland).

During glacial times modelled data indicate a general freshening and cooling of water masses resulting in slightly heavier σ_Θ values. This is coherent with calculated σ_Θ values of benthic foraminifera $\delta^{18}O$ from off-mound or drift deposits around the carbonate mounds (Tab. 1).

OUTLOOK

Downcore records of environmental parameters like temperature and seawater density in carbonate mound and off-mound or drift deposit sequences will provide further evidence if seawater density can be reliably reconstructed through the Pleistocene and whether variations in this parameter controls coral reef and carbonate mound development.

		Recent / Holocene		Last Glacial Maximum	
		measured	calc.[1]	model	calc.[2]
65°N (300m)	T [°C]	7.24	7.6	6.5	5.63
	σ_Θ [kg.m^{-3}]	27.58	27.41	27.51	27.68
51°N (800m)	T [°C]	9.6	10.0	4.9	4.1
	σ_Θ [kg.m^{-3}]	27.43	27.37	27.85	28.07
37°N (600m)	T [°C]	10.9	10.2	10.1	9.96
	σ_Θ [kg.m^{-3}]	27.25	27.05	27.56	27.61

TABLE 1. Comparison of measured, modelled and calculated temperatures and seawater densities.

[1] *Calculations based on Recent $\delta^{18}O_C$ and $\delta^{18}O_{SW}$ values of 1.8 and 0.25 ‰ at 65°N, 1.5 and 0.5 ‰ at 51°N, and 1.4 and 0.42 ‰ at 37°N, respectively.*

[2] *Calculations based on LGM $\delta^{18}O_C$ and $\delta^{18}O_{SW}$ values of 3 and 1 ‰ at 65°N, 3.6 and 1.25 ‰ at 51°N, and 2.2 and 1.17 ‰ at 37°N, respectively.*

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A Physical Oceanography contribution to understand the processes affecting El-Arraiche Mud Volcano field (NW Moroccan Margin)

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Abstract: *The EL-Arraiche mud volcano field is located in the NW of the Morrocan margin and consists of 8 mud volcanoes in water depths between 200 and 700m (Van Rensbergen et al, 2005). These are geologic features where sub bottom fluids can emerge and contribute to specific marine ecosystems. The physical oceanography of the geographic region where the mud volcano field is included is largely unknown due to lack of dedicated observational studies. Some efforts towards the hydrographical characterization have been taken in the last years by several teams. Here are presented some of the results of the dedicated physical oceanographic campaign in the scope of the European project Hermione together with an opportunity collection of hydrographic data during a seismic survey focused on the sedimentary history of drift deposits.*

Key words: *Physical Oceanography of NW Moroccan Margin***,** *El-Arraiche mud volcano field.*

INTRODUCTION

The Atlantic margin of Morocco is an exciting yet poorly known oceanic area. The discovery in 2002 (Van Rensbergen et al., 2005) of giant mud volcanoes and the associated biological communities (cold water corals) galvanized the scientific community and lead to increased efforts to study this geographical area. Examples of these efforts were the European projects HERMES and HERMIONE which gathered in the Moroccan margin some of the leading European institutions in the study of these subjects. As partner in both these projects Instituto Hidrográfico (IH) proposed to complement the geological and biological studies of the Moroccan fluid escape structures with the understanding of the physical oceanography of the area. A first multidisciplinary cruise (IHPT2009-HERM2) was conducted by Instituto Hidrográfico (IH) in June 2009 for the observation of the oceanographic conditions on the NW Moroccan margin, with particular emphasis on the El-Arraiche mud volcano (EA MV) field. These observations included short-term (10 days) currentmeter mooring measurements at 3 positions along the slope (one located over the EA MV field) and CTD/LADCP coverage of the global area complemented with VMADCP measurements (Fig. 1). In 2013 the opportunity was taken for IH to participate in the COMIC2013/16 mission conducted by the University of Ghent in the same area. This participation served the proposed to extend the data set of physical oceanography measurements (Fig. 1) available for this area, improving our understanding of the processes playing a role in the EA MV field and to evaluated the add value of some of the observation methods that IH presently uses (Lowered ADCP and Vessel Mounted ADCP) in a framework of a mission not dedicated to the physical oceanography component.

The present contribution aims to describe the ongoing work of analysis of the 2009 data set and the new insight that is provided by the 2013 data set.

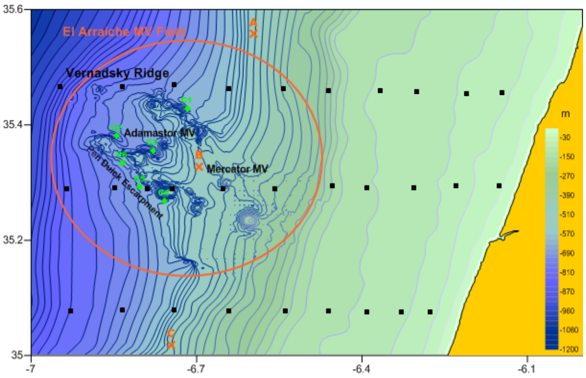

FIGURE 1. El-Arraiche and Moroccan margin bathymetry. Hermione CTD/LADCP stations (•), Hermione moorings (✕) and CTD/LADCP station of the COMIC survey (◆).

RESULTS AND DISCUSSION

The general circulation and water mass distribution observed in June 2009 in the NW Moroccan margin is being analysed in Vitorino et al (in prep) through the combined use of CTD data and a numerical model for the area. At surface levels (upper 100 m) they show details of the recirculation towards south of the eastward directed Azores Current, feeding the upwelling southward flow along the Morocco shelf and upper slope. At deeper levels the data/model results reveal the occurrence of a poleward slope current down to depths of about 700m. At the deeper levels this slope current advects to the EA area, water with a contribution of Antarctic Intermediate Water (AAIW), relatively fresher. This can be seen here from the θ-S diagrams that were draw with the CTD data collected on the EA area during the IHPT2009-HERM2 and COMIC2013/16 cruises (Fig. 2). Below the levels of influence of North Atlantic Central Water (subtropical component in orange and sub polar component in green), both diagrams show evidences for the presence of high salinity Mediterranean Overflow Water (MOW, in dark red/gold) in the oceanic area offshore and of a salinity minimum at depths of 600-800m in the stations along the slope, which reflect the influence of AAIW (in blue/dark blue).

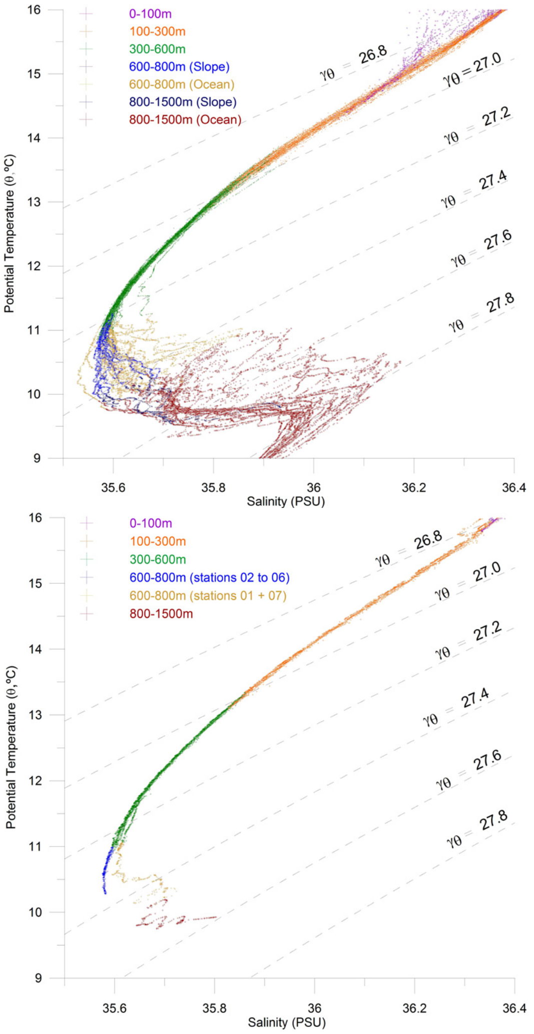

FIGURE 2. θ-S diagrams of the Hermione 2009 CTD stations (above) and COMIC 2013 CTD stations (below).

The data collected during the COMIC2013/16 cruise add details on this picture, showing that the water with AAIW contribution is found along the Pen Duick Escarpment (PDE) and along the Renard Ridge in the direction to Adamastor MV. Details on the physical processes affecting the EA MV field in June 2009 are being analysed in Martins & Vitorino (in prep) from the CTD/model results and direct current measurements. One of the aspects focussed in this study is the impact of high frequency motions over the seafloor of EA. The currentmeter data revealed important internal tidal motions, which are bottom intensified at 500m, in the moorings North and South of the MV field. Inside the MV field, however, this intensification was not so clear, which may indicate that some of the internal tide energy was blocked by the eastern flank of the Mercator MV. This data also shows that the poleward slope current extends over the interior of MV field. The high resolution model provides details on the circulation in this area of complex topography. Further insight on the deep slope circulation around the PDE and EA MV field is provided by the LADCP data collected during the COMIC2013/16 cruise. Figure 3 shows the along topography current measured by the LADCP following a section that extends along the PDE and Renard Ridge bases. The along slope current is positive when flowing in the direction that leaves shallower topography to the left. A bottom current seems to flow along PDE in roughly the NW direction. This flow seems to turn around the PDE Northern tip and to progress along Renard Ridge in direction towards the Adamastor MV, extending inside the EA MV field. Only at station 5 we observed a reverse in the bottom circulation. This can be associated with an overshoot of the current in this area of bottom curvature, which leads to a recirculation there.

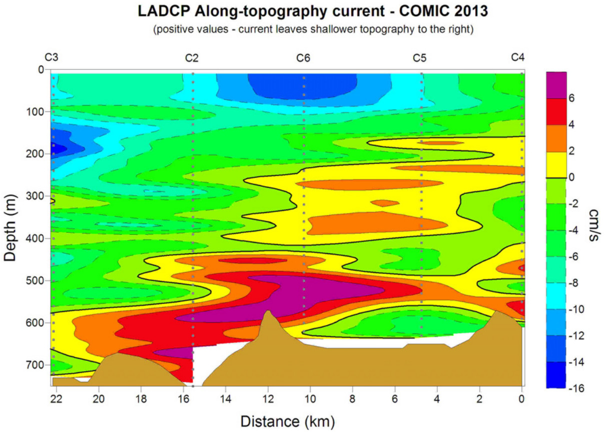

FIGURE 3. LADCP current section along topography of COMIC 2013 stations 4, 5, 6, 2 and 3.

CONCLUSIONS

Physical observations collected during IH cruise in June 2009 and during the UGhent cruise in May/June 2013 provided consistent views of the dynamics and hydrography in the EA area. One of the main aspects that rise from these studies is the presence of a poleward slope current. At depths from 200 to 500m this flow penetrates inside the EA MV field. At deeper levels the flow advects water with AAIW contribution and follows northward along the PDE, turning at its northward tip and continuing along Renard Ridge towards the inner part of EA MV field. This dynamical pattern will most likely have an important impact on the MV field.

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Preliminary results of a sedimentological study of carbonate mounds and cold-water corals from Brittlestar Ridge I and Cabliers site (Moroccan Alboran margin)

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Abstract: *Five box-corers deployed during Eurofleets Cruise MD 194 Gateway on the eastern Melilla carbonate mound at the Alboran Moroccan margin were studied in order to understand the sedimentological processes and the sources of the sediments. Preliminary results of this study showed that sediment associated to cold-water corals and carbonate mounds are supplied by two main sources: an intrabasinal biogenic source and a land source, the Bou Areg plain in the Nador region. The area off the Brittlestar Ridge I was alimented by terrigenous source, the Cabliers site was supplied by biogenic source and the top of the Brittlestar Ridge I was alimented by both sources.*

Key words: *Carbonate mound, Melilla, Alboran Moroccan margin.*

INTRODUCTION

The Melilla carbonate mounds were discovered in the Alboran Moroccan margin during the R/V Hesperides cruise (Comas and Pinheiro, 2007). Later during the TTR-17/ MARSIBAL cruise with R/V Logachev in 2008, cold-water corals were discovered on these carbonate mounds (Comas et al., 2009). The next scientific cruise POS 385 cruise with R/V Poseidon in 2009 allowed the mapping of Eastern Melilla site and ground truthing using box-corer and ROV (Hebbeln et al., 2009). The study of the age of the cold-water corals recovered near the seabed surface (0-30cm) during this cruise reveal relatively young ages corresponding to the Late Holocene (< 5,400yrs) (Fink et al., 2013).

During Eurofleets Cruise MD 194 Gateway (10-21 June 2013) box-corers were deployed in Eastern Melilla side from Brittlestar Ridge I (4 box-cores) and Cabliers carbonate mound (1 box-core) (Fig. 1). The sediments of these box-cores were investigated to precise the sediment sources and factors that control sedimentation on carbonate mounds that developed in an active tectonic context. The objective of this work is to present the preliminary results of XRD analyses of the total rock, calcimetry and geochemistry of major elements.

DATA AND RESULTS

The box-core description made on board (Van Rooij et al. 2013) showed that:

1) The nature of sediment varies from silty sand at the surface to silty clay at the base of the box-cores;
2) Coral association is mostly composed by *Lophelia pertusa, Madrepora oculata, Dendrophyllia cornigera, Dendrophyllia cornucopia,* and some solitary corals (*Desmophyllum dianthus, Caryophyllia calveri, Javania cailleti, Stenocyathus vermiformis)*;
3) The frequency of corals decrease from the surface to the bottom; and
4) All scleractinian corals are dead except from a small broken colony of *Dendrophyllia cornigera* and tiny *Desmophyllum dianthus* found at the surface of MD13-3471.

The XRD analyses of the total rock, indicate two mineralogical assemblages: 1) calcite, quartz, halite and clay minerals in the box cores located at the off of the Brittlestar Ridge I and Cabliers site and 2) quartz, calcite, dolomite, halite and clay mineral in the top of the Brittlestar Ridge I. These mineralogical assemblages are similar to those recognized in the Plain of Bou-Areg, Moroccan hinterland (Mahjoubi, 2001;Bloundi, 2005)

The percentage of total carbonate content varies between 16% and 19%, except of the box-cores from Brittlestar Ridge I where the carbonate content of surface sediment of MD13-3465 and MD13-3468 may reach 21% and the carbonate content of the base of MD13-3456 decrease to 11%.

The result of geochemical study based on major elements processed by the PCA (principal component analysis) method, indicate sediment supplies from two main sources: a land terrigenous source and an intrabasinal biogenic source. The area off the Brittlestar Ridge I was alimented by terrigenous source, the Cabliers site was supplied by biogenic source and the top of the Brittlestar Ridge I was alimented by both sources.

CONCLUSION

These preliminary results allow to precise the mineralogical and chemical composition of the sediments associated to the carbonate mounds of Brittlestar Ridge I and Cabliers site. They also enable to identify two main sediment sources: an intrabasinal biogenic source and a land source, the Bou Areg plain in the Nador region.

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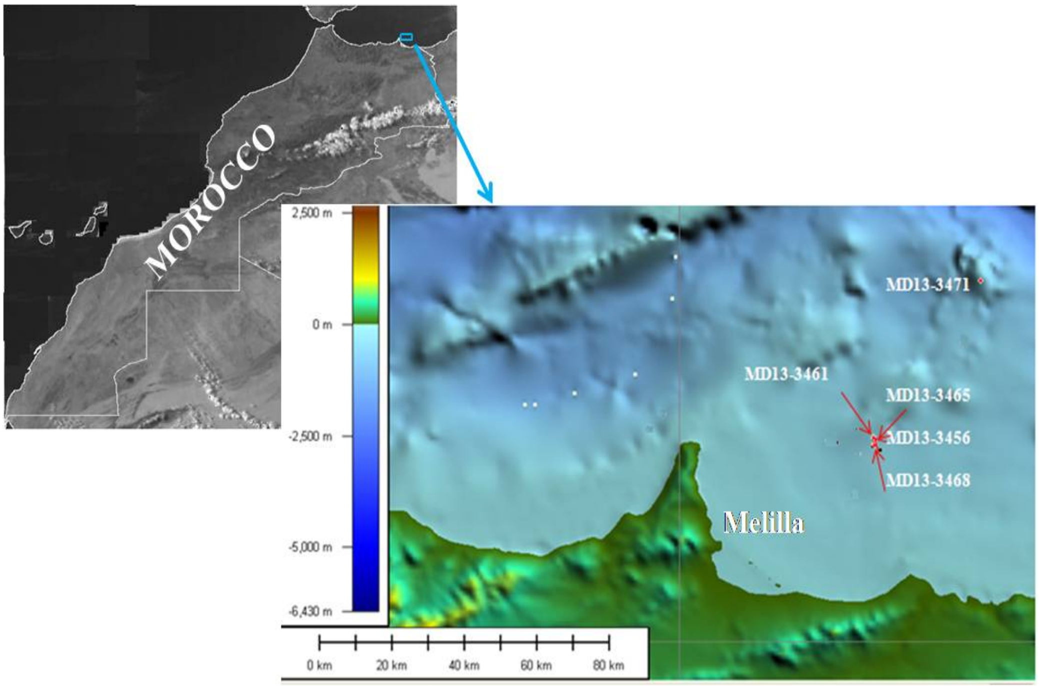

FIGURE 1. Location of studied box cores from Brittlestar Ridge I and Cabliers carbonate mound, Eastern Melilla.

Morphology and shallow stratigraphy of the West Melilla and Cabliers CWC Mounds (Alborán Sea). Preliminary insights from the GATEWAYS MD194 Cruise

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Abstract: *In this study we present the main morphological characteristics of the West Melilla and Cabliers CWC Mounds (Eastern Alboran Sea) and include the preliminary results from the analysis of four gravity cores collected in the area during the GATEWAY MD194 Cruise. The West Melilla Mound field is composed of two different clusters which may have different ages. The Cabliers Mound is a 15km long CWC ridge, where large living CWC reefs, almost unique for the Mediterranean Sea, have been observed on its summit through ROV videos, thriving under moderate current regimes and intense sediment transport. High density of CWC frameworks and strong variability of CWC species suggest that the Cabliers Mound corresponds to a peculiar feature compared to the other mounds of this region. The acquired data represent a step forward in understanding the evolution of the Alboran Giant CWC Mounds in their sedimentary environment.*

Key words: *Cold-Water Coral Mounds, Eastern Alboran Sea, Geomorphology, Gravity Cores.*

INTRODUCTION

Two different Cold-Water Coral (CCW) Mound provinces have recently been unveiled through high-resolution bathymetric mapping in the Eastern Alboran Sea (Western Mediterranean) during the MELCOR Cruise in 2011: the West Melilla Mounds, 9km west of Cape Tres Forcas (Moroccan Margin) and the Cabliers Mound, 80km northeast Cape Tres Forcas (Fig. 1). Oceanographic data clearly display the interaction of the Modified Atlantic Water (MAW) and the Levantine Intermediate Water (LIW) at a depth of around 200m. The mound fields were eventually re-visited and sampled through 4 gravity cores, from 5 to 11m long, during the GATEWAYS MD194 Cruise in 2012. The main morpho-sedimentary characteristics and preliminary results from the gravity core analyses will be presented in this study.

RESULTS AND DISCUSSION

The West Melilla Mounds:

Up to 103 mounds organized in two main clusters have been recognized within a depth range of 299–590 m, displaying a high density of 5 mounds.km^{-2} (Lo Iacono et al., 2014). Mounds, 260m wide on average and 1–48m high, show a skewed distribution, with most of them less than 10m tall while only a few reach heights of up to 48m. The main central cluster, where 81 small mounds have been mapped, consists of slightly asymmetrical to circular mounds. The lobe shape of the main cluster suggests that a landslide functioned as hard substrate for the settling of CWC communities, contrasting with the surrounding fine grained seafloor (Lo Iacono et al., 2014). According to the seismic records crossing the CWC mound field, most of these mounds appear partly draped by a transparent fine sediment layer. This is confirmed by the video images of an ROV dive, showing highly bioturbated fine sediment covers, and by the Van Veen sediment samples consisting of stiff and consolidated clays. The absence of bottom currents in ADCP data acquired in the area also confirms a prevailing depositional environment. A second cluster composed of nine mounds was mapped in the eastern portion of the study area, in a depth range of 347–430m. These mounds are the tallest and largest mapped in the West Melilla area, displaying a mean height of 28m. They develop for almost 1.5km along a NNW–SSW direction until a depth of 500m. The deepest sections of the mounds are buried under fine-grained sediments, which according to the seismic records can vary from 1 to 12m. The mounds of the second cluster are rooted on a single unconformity which suggests a common start-up phase. The depth of this unconformity (35m), the average dimensions of the mounds and the thickness of the overlaying sediments suggest that the mounds of the second cluster are older than the mounds of the first main cluster. Two gravity cores were collected on the West Melilla mounds. Core MD52G, collected on a 10m tall and 305m deep mound of the first cluster, is 5.58m long and displays silty bands (grain size mode ca. 7µm) alternating with dense CWC frameworks, which are more frequent and almost constant from the depth of 224cm to the bottom of the core (558cm). More frequent coral species are *Lophelia pertusa* and *Madrepora oculata*, with the latter dominating the shallower part of the core. Core MD51G, collected on a 35m tall and 370m deep mound of the second cluster, is 5.22m long and displays a continuous silty band (grain size mode ca. 10µm) until the depth of 168cm. Below 168cm, scattered CWCs, mainly *Lophelia pertusa*, occur along the core, increasing in density and dimensions from around 430cm to the bottom of the core (522cm). However, no dense CWC frameworks were observed in the core. The preliminary insights from the core analysis confirm the different ages of the two clusters in the West Melilla Mound field (Lo Iacono et al., 2014), with the mounds of the second cluster being older and buried under at least 4m of fine sediments. Similar sediment textures have been described for the East Melilla Mounds by Fink et al., 2013. The drastic changes in sedimentary dynamics during the last sea-level rise, due to stronger interactions between Cape Tres Forcas and across shelf currents, could have increased the local sedimentation rates, favouring the burying of the mound clusters.

The Cabliers Mound:

The Cabliers Mound consists of a 15km long NNE-SSW oriented linear to sinuous mound/ridge system, from 60 to 100m tall and with the summit from 295 to 620m deep. However, this CWC ridge developed linearly above the edge of a large tectonic feature, suggesting a strong control of contour currents in its orientation, as also suggested by a deep erosive moat along its western flank. ROV videos recorded in the northern portion of the Cabliers Mound, show an extremely thriving CWC reef under a moderate to strong current regime, with large colonies of *Lophelia pertusa*, *Madrepora oculata*, cup sponges, gorgonians and antipatarians. These observations are also confirmed by the infauna and epifauna collected in Rauchert grab samples, revealing an uncommonly increased biodiversity for this region. The thriving conditions of the CWC communities and their associated species make this portion of the Cabliers Mound a unique example of a “living and active giant CWC mound” for the Alboran Sea and likely for the whole Mediterranean. Two gravity cores were collected along the Cabliers Mound. Core MD69G, collected at a depth of 437m along the southern summit of the 60m tall mound, is 10.55m long and displays a rather high variability, with silty bands (grain size mode ca. 8µm) alternating with dense *M. oculata* and *L. pertusa* frameworks, large bands dominated by *Dendrophyllia cornigera,* solitary corals (presumably *Desmophyllum sp.*) or gastropods. Core MD70G was collected at a depth of 313m along the northern summit, where the mound is 88m tall. This core, 8.84m long, was collected where the thriving CWC reefs were observed in the ROV videos. The core shows an extremely dense and constant *M. oculata* and *L. pertusa* CWC framework almost along its whole extension, sporadically interrupted by thin fine sediment layers. Preliminary results from the high-resolution CT scans support this observation, with highest values of CWC density up to 28%. ROV videos and core analysis confirms that the Cabliers Mound is a peculiar feature both in the present day, with thriving large CWC communities on its summit, and in the past, with almost constant and very dense CWC communities and unusual occurrence of *D. coringera* reefs and large solitary corals.

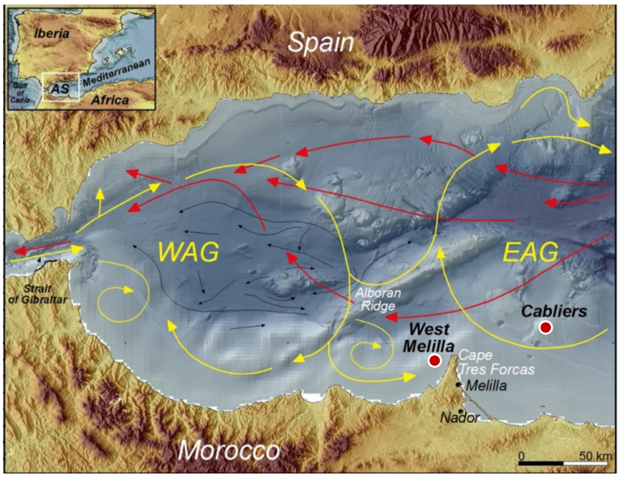

FIGURE 1. Topographic and bathymetric map of the Alboran Sea and location of West Melilla and Cabliers Mounds (red dots). The yellow lines indicate the MAW. The red lines indicate the LIW. The black lines indicate the deep Mediterranean Water. WAG: Western Alboran Gyre, EAG: Eastern Alboran Gyre. Inset: location of the Alboran Sea (AS).

CONCLUSIONS

The recently mapped West Melilla Mounds and Cabliers Mound gave new insights in the distribution of CWC mounds in the Western Mediterranean and can help in better highlighting their large scale bio-geographic patterns in the Mediterranean. The preliminarily insights from the four gravity cores collected on the two mound fields suggest important differences between the studied areas, which show variable CWC compositions, density and cyclicity. The core MD70G suggests that the Cabliers Mound likely grew under exceptional permanent thriving environmental conditions, at least during the latest stages of its evolution, as suggested by the greater occurrence of dense CWC frameworks within the whole core.

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Using cold-water coral mini-mounds as analogue for giant mound growth: assessment of environmental drivers and anthropogenic impact

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Abstract: *The FWO MINIMOUND project (2013-2016) aims to investigate small fossil cold-water coral (CWC) mounds within the Bay of Biscay in order to determine the impact of: (1) palaeoceanographic changes related to glacial-interglacial climate change in the last 15ka, (2) hydrocarbon related processes (seepage) and (3) anthropogenic fishing activities on CWC habitats. A better understanding of these mini-mounds will provide insight in the mechanisms of mound initiation and build up to large CWC mounds (e.g. Challenger Mound). The project will target three mini-mound provinces: the Explorer and Dangeard Canyons on the Celtic Margin, the Guilvinec Canyon on the Armorican Margin and the Upper Ferrol Canyon on the Cantabrian Margin. In these provinces USBL guided cores will be acquired to allow for sedimentological, palaeoceanographic and biogeochemical analyses throughout the mini-mounds. In addition, video dropframe acquisition will allow for habitat mapping and predictive modelling of the CWC habitats.*

Key words: *Cold-water coral mounds, Lophelia pertusa, palaeoceanography, habitat mapping.*

INTRODUCTION

Cold-water corals (CWC) are found along the entire north-eastern Atlantic Margin from Norway to the Gulf of Cadiz. These coral reefs are mainly formed by framework building scleratinians *Lophelia pertusa* and *Madrepora oculata* that baffle sediment and over time, have the potential to develop into large coral carbonate mounds of up to 300m high (Roberts *et al.*, 2006). These large mounds (e.g. Challenger mound in the Porcupine Seabight) have been well studied over the past two decades (Wheeler *et al.*, 2007). The detailed mechanisms of initiation and build-up of such large CWC mounds are however not yet fully understood (Huvenne *et al.*, 2009). It is therefore essential to study smaller mounds (often termed "mini-mounds") that can be interpreted as earlier growth stages that haven't had the time to coalesce and develop into larger mounds (De Mol et al., 2005).

The FWO MINIMOUND project (2013-2016) aims to investigate the initiation, growth and demise of these small CWC mounds and to determine the role of climatic and hydrocarbon-seepage related processes as well as anthropogenic impact. This high-resolution multidisciplinary study will focus on three mini-mound provinces along the Biscay continental margin (Fig. 1): (1) the Explorer and Dangeard Canyons on the Celtic Margin (Stewart et al., 2013), (2) the Guilvinec Canyon on the Armorican Margin (De Mol et al., 2011) and (3) the Upper Ferrol Canyon on the Cantabrian Margin.

These mini-mounds are fossil (9.7ka BP) and occur at relative shallow depth on the interface between the Eastern North Atlantic Central Water (ENACW) and the Mediterranean Outflow Water (MOW). Contrastingly, most present-day living CWC reef habitats dwell in the deeper MOW depth range, relying on the density and dynamics of this water mass for their food supply.

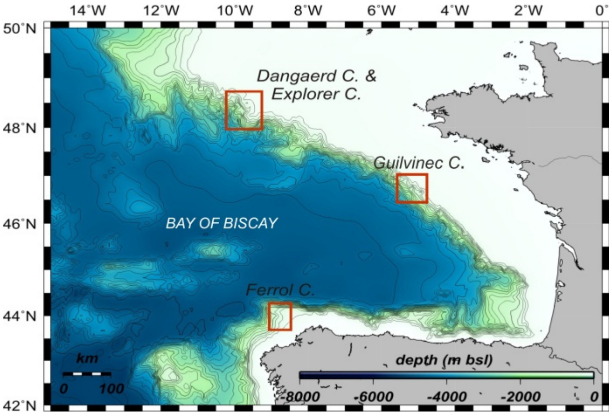

FIGURE 1. Bathymetry map (GEBCO) of the Bay of Biscay with indication of the three study areas of the FWO Minimound project.

OBJECTIVES

The objectives of the project are threefold: (1) the establishment of a chronostratigraphic framework and the reconstruction of palaeoceanographic changes over the last 15,000 years in order to determine the impact of glacial to interglacial climate change on the ENACW-MOW interface and the CWC habitats (Frank et al., 2011); (2) the mini-mound province at the Upper Ferrol Canyon shows a close association with hydrocarbon-seepage (pockmarks) which allows to assess the role of hydrocarbon related processes in CWC mound formation; (3) the potential impact of anthropogenic fisheries activities will be investigated.

PROJECT OUTLINE

These objectives will be tackled through a coupled geophysical, sedimentological and integrative approach, including the palaeoceanographic and biogeochemical core study in cooperation with the BGS (UK), LSCE (Gif-sur-Yvette, France), IFREMER (France), IGME (Spain) and IEO (Spain). Two sampling campaigns with the R/V Belgica will be undertaken of which the first is planned for June 2014. This campaign will target the mini-mounds, pockmarks and off mound sites on the upper slopes of the Ferrol Canyon and the Explorer and Dangeard Interfluves. The targets were selected based on the analyses of multibeam bathymetry maps, high resolution seismic and groundtruthing of the CWC mounds using ROV (Fig. 2). Cores will be acquired with a USBL guided vibrocorer supplied by the BGS (UK). In addition to core collection, drop frame images will be acquired to allow habitat mapping and predictive modelling of the CWC habitats in cooperation with the Marine Institute of Plymouth University (UK). During the 2nd Deep Water Circulation Congress, the first preliminary results of the core analysis will be presented.

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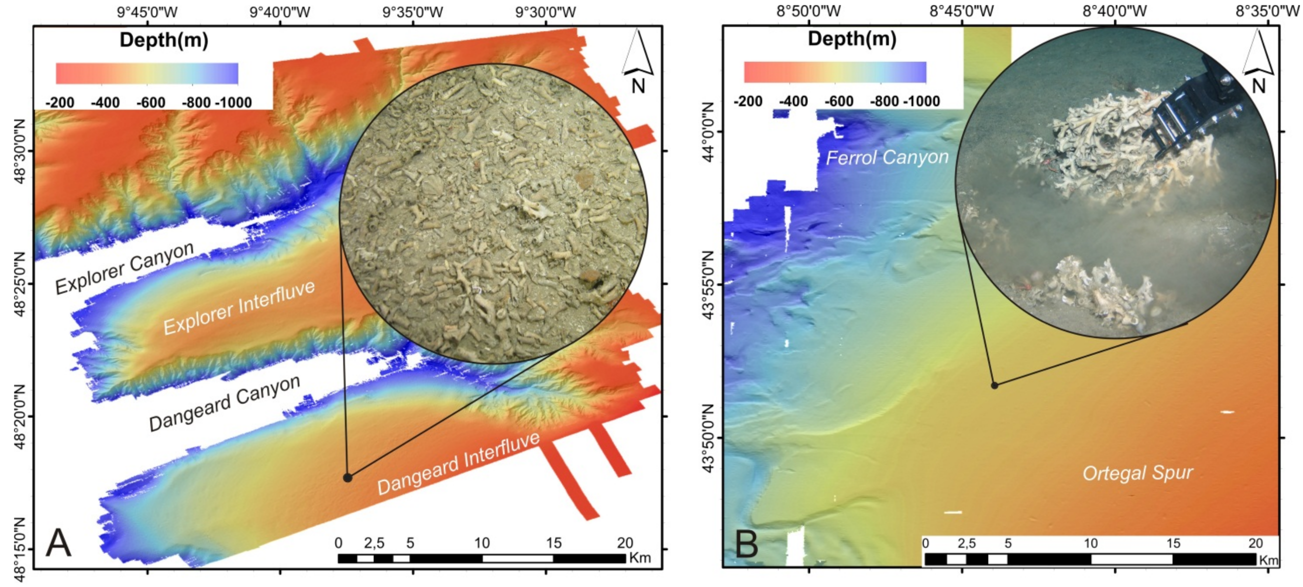

FIGURE 2. Bathymetry maps and ROV footage of the study areas targeted by the 2014 R/V Belgica campaign. A: The Explorer and Dangeard Canyons (data collected by MESH canyons cruise with the R/V Celtic Explorer, 2007). B: The upper Ferrol Canyon (data collected by the R/V Belgica GENESIS cruise, 2009).

Seabed morphology and bottom water masses related to benthic habitats at the Cristóbal Colón diapir (NW of the Guadalquivir ridge, Gulf of Cádiz)

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Abstract: *The seabed morphology and the sub-superficial characteristics of the Cristóbal Colón diapir located on the continental slope of the Gulf of Cadiz have been analysed from data obtained in the framework of the LIFE+INDEMARES/CHICA project. The aim of this study is to recognize the morphological features and the geological processes generated by the bottom water masses and their influence on the habitats and associated benthic communities. The NACW affects the generation of morphological features on the summit, revealing that different oceanographic conditions favoured the carbonate mound growth in the past. The interface between the NACW and the MOW sweeps the bottom from the SE to the NW and the presence of benthic communities dominated by filter feeders on the contouritic drift indicates that this current is strong enough to favour the availability of nutrients and organic particles and to develop both the contouritic deposits on the SE flank and the moats on the N and W flanks.*

Key words: *carbonate mounds, contourite drift, benthic habitats, hydrodynamics, Gulf of Cadiz.*

INTRODUCTION

Diapirs are characterized by a surface bulging that results from a slow uplift of massive plastic materials from the deep layers to the surface due to density differences. In the uplift process, diapir ridges deform the middle continental slope of the Gulf of Cadiz and can reach the surface (Fernández-Puga et al., 2007). Diapir outcrops interact with the water masses changing the water circulation pathways and velocities, and also affecting the sedimentary processes in their vicinity (Davies and Laughton, 1972). This situation provokes a local circulation pattern that can support different habitats and associated benthic communities if both nutrient supply and substrate are adequate. Changes in the oceanographic conditions can give rise to changes in the seabed morphology and the habitats.

The study area is located in the channels and ridges sector in the middle slope of the continental margin of the Gulf of Cádiz (Hernández-Molina et al., 2006). The Cristóbal Colón diapir is placed on the northeasternmost outcrop of the Guadalquivir Diapiric Ridge, at the north of the Gusano contouritic channel.

The aims of this communication are to study (1) the seafloor morphology and the sub-superficial characteristics of the Cristóbal Colón diapir, (2) their relation with the hydrodynamic of the water masses and (3) their influence on the benthic habitats.

DATA AND RESULTS

The data set obtained during oceanographic cruises carried out in the LIFE+INDEMARES/CHICA project comprised: bathymetric information from a Kongsberg Simrad EM-710 multibeam echosounder; very high resolution acoustic profiles from the system TOPAS PS018; one box corer surface sample; and ROV images and videos.

The zone is characterized by different water masses: the North Atlantic Central Water (NACW) flowing in different directions from the surface to 450m depth; the Mediterranean Outflow Water (MOW) flowing to the north and west between 550-700m water depth; the interface between the NACW and the MOW that flows between 450-550m water depth (Fernández-Salas et al., 2012).

Cristóbal Colón diapir is located between 389m and 525m water depth and displays a tabular plan view, slightly elongated toward NE-SW direction (Figure 1). The major and the minor semiaxes are 5.5 and 2.5km long, respectively. At the summit, the slope is not very sharp but with a flat tendency interrupted by small linear depressions and mounds. Mounds have an average height of 10m with higher backscatter values than the adjacent seafloor. The main mound, named Isabel de Castilla, is 35m high and 300m wide and is located at the east of the summit (Figure 1). ROV videos and samples collected on the mound display abundant coral rubble (mainly *Madrepora oculata*, with scarce *Lophelia pertusa*) that is colonized by a wide variety of small gorgonians (*Bebryce*, *Switia*, *Placogorgia*), but no living corals were found here although they could occur on other unexplored mounds. The northern and western base of the diapir is bound by depressions of 15m depth and two ridges of 20m average height, 0.15km and 0.2km wide, and between 1.2km and 2km long, respectively. In contrast, the southern flank of the main diapiric structure is characterized by a plastered contouritic deposit that ascends the diapir flank and is colonized by sea-pens (mainly *Funiculina quadrangularis, Pennatula aculeata* and *Kophobelemnon stelliferum*).

DISCUSSION

Mounds on the summit have been interpreted as relict carbonate mounds, containing hard substrates made of coral fragments and benthic fauna within a matrix of hemipelagic sediments that could provide the high backscatter values. Ridges on the northern and western base of the diapir are related to tectonics scarps that could have been colonized by corals in the past. The NACW has more influence on the diapir summit, at 380-420m water depth (Fernández-Salas et al., 2012) and this current may not be strong enough to support living corals. The hemipelagic sedimentation could bury the coral mounds. The large amount of coral rubble suggests different oceanographic conditions in the past that favoured the carbonate mound growth, and allowed the water mass to provide enough nutrients and the correct current speed to support cold-water coral reefs.

The interface between the NACW and the MOW flows from the SE to the NW affecting the seafloor sediments. This current generates the plastered contourite drift observed on the SE flank giving rise to a low slope surface. In the high resolution profiles there are no evidences of these deposits on the top of the diapir. In this zone, sea-pens favour the muddy sediments and the flow. The interaction of this current with the diapir generates an increase of the flow speed and triggers the erosion on the lee side of the diapir producing elongated depressions (moats). The strong current is also evidenced by the erosion of the surface of the faulted scarps.

CONCLUSIONS

The interaction of two water masses with a diapiric structure has been interpreted as the main controlling factor for relict morphology and habitats developing. The NACW affected the summit and could favour the carbonate mound growth as coral reef patches that declined in subsequent periods. Below this water mass, the interface between NACW and MOW swept the seafloor to the NW supporting the contouritic deposits on the SE flank of the diapir favouring sea-pen communities and the moats on the N and W flanks.

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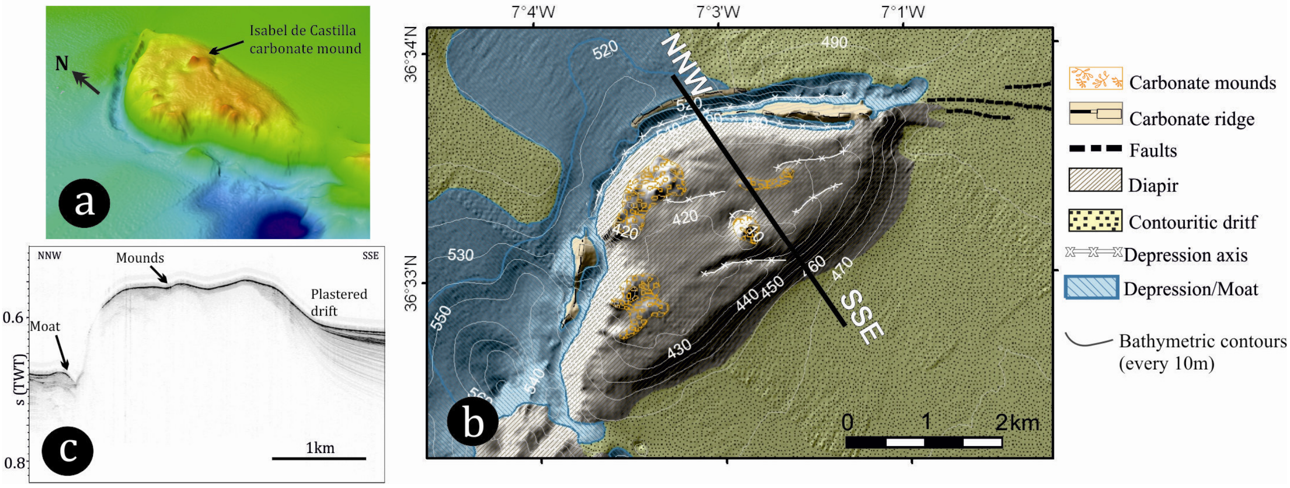

FIGURE 1. a) 3D model with illumination source azimut 315° and 15m resolution, b) Geomorphological interpretation draped over a hillshade map, c) Very high resolution acoustic profile crossing the Cristóbal Colón diapir.

Late Cenozoic fossil cold-water coral concentrations and mounds on the Argentine continental margin, Southwest South Atlantic

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***Abstract**: Fossil (Late Pleistocene) assemblages of cold-water corals (Scleractinia) were collected in the northern sector of the Argentine continental margin. After discussing its characteristics and setting it is considered that they were controlled by the influence of the high-energy interface between water-masses at the base of the Antarctic Intermediate Water on a hard substrate at the head of Mar del Plata canyon.*

***Key words:** Cold-water corals, Argentine margin, AAIW, Mar del Plata canyon, contourites.*

Cold-water coral (CWC) ecosystems are among the richest biodiversity hotspots in the deep sea, providing shelter and food for hundreds of associated species. Recent investigations have shown that extensive CWC ecosystems exist along the Argentine continental margin (ACM). A common point of discussion concerns the driving forces regarding the initiation of these complex systems. Both oceanographic boundary conditions (salinity, temperature, nutrient availability, current speed) and geological (i.e. hardground availability) processes have been proposed to play a significant role in the CWC nucleation, growth and decline. An intriguing question is to what extent the occurrence of CWC reefs along the Southwestern Atlantic margin (SWAM) is related to the pathway of the Antarctic Intermediate Water (AAIW).

Records of fossil Cenozoic CWC are extremely scarce in the SWAM. However, in the last few years CWC fossil concentrations of Late Pleistocene age were found in deep sea cores from the northern sector of the ACM (Fig. 1). Based on acoustic (multibeam images), sampling (deep-sea cores) and oceanographic data, a morphosedimentary characterization as well as water masses definition have been carried out in order to analyze the main factors controlling the growth and distribution of fossil CWC. We intent to determine: (i) the spatial distribution of the fossil CWC concentrations in the northern sector of ACM; (ii) the influence of the Antarctic Intermediate Water (AAIW) on the distribution of the CWC; and (iii) the role of the hydrodynamic pattern generated flow impinging the slope topography in the spatial distribution of the fossil CWC concentrations.

The northern sector of the ACM includes a huge contouritic depositional system (CDS) which potentially is a relevant indicator for the interaction between ocean dynamics and the sea floor (Hernández Molina *et al*., 2009). The CDS (including terraces, drifts and channels) was generated by long-lasting contour-parallel currents whose strengths and boundaries were forced by variations in climate and sea level since the Miocene.

In the middle slope of the northern sector of the ACM two major terraces result in a step-like slope morphology: La Plata Terrace -T1- and Ewing Terrace -T2- (Fig. 2).

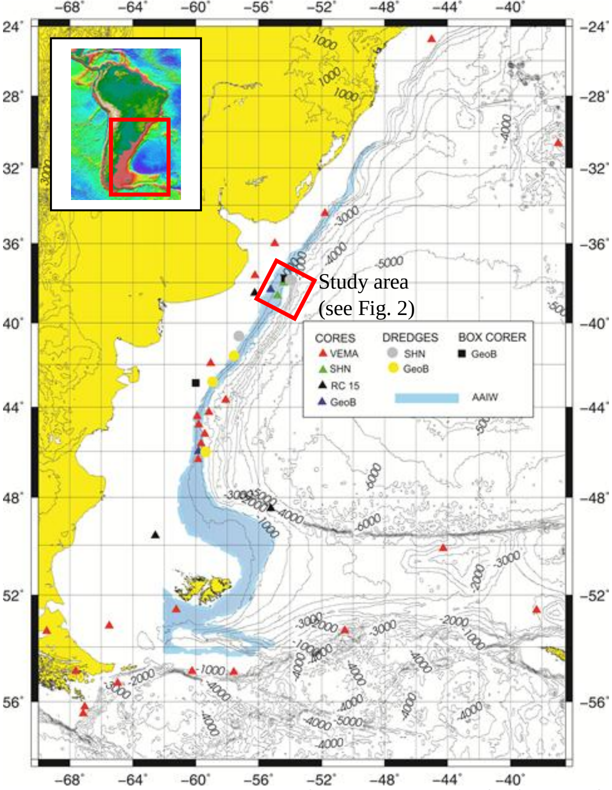

FIGURE 1. General bathymetry of the ACM, depths of influence of the AAIW (light blue area) and location of samples containing corals.

Especially the latter encompasses significant sediment accumulation. The Mar del Plata Canyon (MPC) intersects the Ewing Terrace. This canyon originates at ~1000m water depth cutting transversally into the middle slope and reaching the foot of the lower slope. The canyon´s head ends upslope at the foot of an erosive steep slope that marks the transition between both terraces. The intermediate circulation in this sector is conditioned by the northward flowing of the Antarctic Intermediate Water (AAIW) and of the two

Circumpolar Deep Water (CDW) fractions: the Upper (UCDW) and the Lower (LCDW). Several geological-geophysical cruises on board the R/V Puerto Deseado (Ministry of Defense - CONICET) have been carried out since 2002. A suite of piston cores and dredges were obtained at the northern sector of the ACM containing modern and fossil isolated scleractinians, but in two cores at the outer border of the Ewing Terrace, near the head of the MPC (Fig. 2), scleractinians form fossil concentrations: core SHN-T300 (219cm long; 37°48.4´S - 54°20.1´W, 1300m water depth) and core SHN-T372 (115cm long, 38°00.3´S - 54°24.9´W, 1208m water depth).

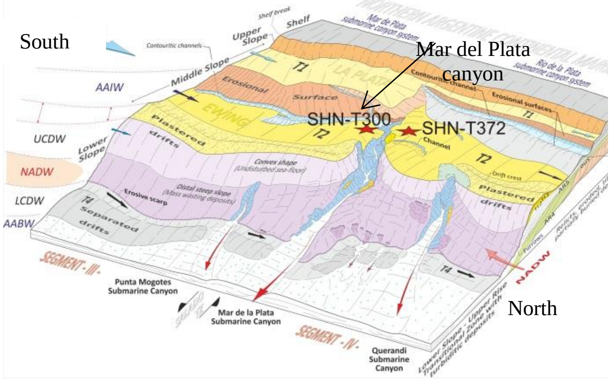

FIGURE 2. 3-D map of combined morphosedimentary and hydrographic features around Mar del Plata canyon in the northern sector of the Argentine continental margin (after Preu et al., 2013).

Besides, the search of other references to available samples (cores, dredges and box-corers) in the ACM led to the finding of 41 sites (Fig. 1) containing corals, sampled during cruises from Lamont-Doherty Earth Observatory and Bremen University. However, only cores SHN-T300 and SHN-T372 contain fossil CWC concentrations. Scleractinian belong to *Bathelia candida* Moseley, 1881. A matrix-supported fossil concentration was found in the uppermost 23cm of core SHN-T372 in olive-grey massive mud. In core SHN-T300 eight discrete levels of corals were observed in the upper 90cm. In this core, echinoderm spines, benthic and planktonic foraminifera, ostracods, radiolarians and sponge spicules were found accompanying corals between 55 and 68cm. Micropaleontological (planktic foraminiferal) analyses of coral-bearing levels indicate a typical upper Pleistocene assemblage dominated by transitional species in a bathyal context.

Bathelia candida is considered as a species needing hard substrate to settle. Nowadays it is distributed from southern Brazil to southernmost Argentine margin where it usually forms small aggregates or “coral gardens”. Bathymetric distribution (500 to 1600m depth) roughly coincides with the location of the AAIW on the ACM. Fossil concentrations were found only on the Ewing terrace around the head of the MPC. The sampling location is presently near the transition between the AAIW and the underlying UCDW. Probable semi-buried mounds were recognized with multibeam images near the canyon flank. In this sector, contourite channels were recognized related to the turbulent boundary between AAIW and the UCDW (Fig. 3). Considering age and bathymetry of the fossil CWC concentrations and hydrographic and geomorphologic context, based in the position of the AAIW during LGM according to Preu *et al*. (2012), we conclude that development, growth and distribution of CWC mounds in the northern sector of the ACM were probably controlled by the following environmental factors: (i) the exposure of hard substrates necessary for the initial settling of cold-water coral larvae around the head of the Mar del Plata canyon, possibly related to stronger bottom water currents during LGM times; (ii) the turbulent boundary between the AAIW and the UCDW water masses that control the transport of coral larvae along the SW Atlantic continental margin; (iii) the turbulences created by the interface AAIW/UCDW impinging the surface of the Ewing Terrace, creating suitable currents and substrate that favor intrusion of the nutrient afflux from Patagonian margin and allowing coral colonies to growth.

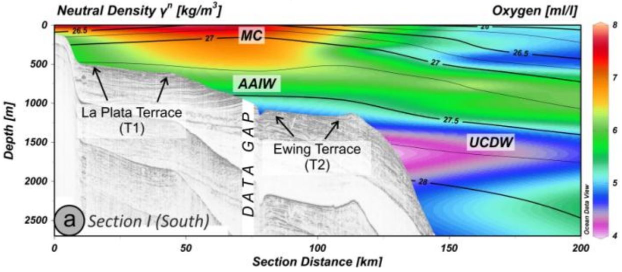

FIGURE 3. Seismic–hydrographic section close to the southern flank of Mar del Plata canyon, showing the influence of the water-masses on the terraces morphology (after Preu et al., 2013).

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Trace Element Characteristics and Sedimentary Environmental Significance of the Lower Ordovician Contourites in Northern Hunan, China

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Abstract: *In order to figure out the sedimentary environments of contourites of two areas in northern Hunan, we test trace elements in all the 43 samples taken from them. The results show that during the Early Ordovician, Jiuxi area was a platform slope zone which was in a hot, dry, high-salinity and reducing environment. Yuanguping area was a transition zone between the slope (the slope was in a hot, humid, ungated and weak-reducing environment) and the basin.*

Key words: *trace elements; sedimentary environments; northern Hunan; the Lower Ordovician; contourite sequences.*

GEOLOGICAL BACKGROUND

The study area is within the distribution range of the Lower Ordovician contourite drifts in Jiuxi, northern Hunan (the south of the Middle Yangtze Craton). The area was in the environment of a deep-water slope in the Early Ordovician. In the northwest, there existed vast shallow-water carbonate platforms (Duan et al., 1993). The sedimentary province of the basin was in the southwest, which mainly developed the Panjiazui Formation, Madaoyu Formation, Taohuashi Formation, Jiuxi Formation and Sherenwan Formation. This paper mainly studies the Panjiazui Formation, which developed contourites well. Through studying and measuring two geological sections (Jiuxi section and Yuanguping section) we divide the contourites of the study area into 5 types (Faugeres and Stow, 1993), namely, calcilutitic contourite, calcisihitic contourite, calcarenitic contourite, bioclastic contourite and calcisiltitic contourite. Calcilutitic contourite is well developed in the Yuanguping area, while other types are less developed. We also identify three types of sequences, namely, a single calcilutitic contourite sequence, an incomplete contourite sequence and a complete contourite sequence (Rebesco and Camerlenghi, 2009). The single calcilutitic contourite sequence, which is firstly discovered in the study area, mainly exists in Yuangupin area.

DATA AND RESULTS

In order to figure out the causes and the sedimentary environments of contourites of the two sections, we test trace elements in all the 43 samples taken from them. The results show that K, Na, Al and other trace elements, which mainly exist in terrigenous mud, are of high contents in contourites. And terrigenous mud mostly accumulates in continental shelf and slope where the flow is relatively slow. Therefore, the contourites were mainly developed in the platform slope zone (Luo et al., 2002). The contents of Cr, Ni, V and other elements in contourites are higher than that of autochthonous deposits, showing that the contourites were formed in relatively deep water. Since the variation of water depth is positively correlated with contourite sequences, this means that the water depth varied from shallow to deep and to shallow again during the formation of the contourite sequences. Meanwhile, Ti, Zr/Al and other elements also indicate water depth. When Ti content is low and the value of Zr/Al is above 20, the water is relatively shallow. The values of Zr/Al of Jiux section are all above 20, while the values of Yuanguping section are all below 20. It means that the sedimentary water of Yuanguping area was deeper on the plane and the contour currents near the basin were relatively weak (Luo, 2002). So the single calcilutitic contourite sequence is relatively developed. In the whole study area, Rb/K is above 2 and V/(V+Ni) is ≥ 0.46, showing that the area was in a relatively ungated, high-salinity and reducing environment. Resistant minerals containing Nb and La are easy to decompose in a hot and humid environment. Nb and La are relatively rich in Yuanguping area, showing the climate of Yuangping area was hot and humid at that time. But the climate of Jiuxi area was mainly hot and dry.

CONCLUSIONS

In conclusion, during the Early Ordovician, Jiuxi area was a platform slope zone which was in a hot, dry, high-salinity and reducing environment. Yuanguping area was a transition zone between the slope (the slope was in a hot, humid, ungated and weak-reducing environment) and the basin. Thus, the contour currents of Jiuxi area were active and of high energy, which formed a complete contourite sequence. The contour currents of Yuanguping were weak, which formed a single calcilutitic contourite sequence.

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Seafloor geomorphology of the Passage of Lanzarote (West Africa Margin): Influences of the oceanographic processes

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Abstract: *The seafloor morphology of the Passage of Lanzarote has been analysed with the aim to know the active processes on the bottom surface related to the oceanographic context. Multibeam bathymetric data and high and very high resolution seismic profiles obtained in the SUBVENT2 cruise have been used. Five main morphological groups have been analysed: (a) Volcanic or diapiric submarine hills; (b) Tectonic features on the continental slope (linear scarps and a rhombohedral depression) related to normal faults; (c) Submarine venting at top of diapirs initially triggered circular depressions; (d) Sedimentary instabilities (gullies, canyons, mass transport deposits) are present specially on the Fuerteventura-Lanzarote ridge; and (e) Contouritic bottom features both erosive (central valley, marginal valleys) and depositional (plastered drifts) are on the central part of the passage, and are generated by the interaction of MW and the interface MW-AAIW with seafloor.*

Key words: *Seafloor morphology, bottom-current interaction, West Africa Margin, Canary Islands.*

INTRODUCTION

Islands and seamounts constitute barriers to water mass flows and control deep-sea sedimentation systems. One example is the Passage of Lanzarote (PoL) which corresponds to the Atlantic Ocean region extended between the West Africa continental margin and the NE-SW volcanic ridge of Fuerteventura-Lanzarote (FLR) (Fig. 1). On the sea-surface the PoL has 100km width to the south, but increases northwards up to 250km. The PoL results from the elevation of the volcanic FLR culminated with the formation of Lanzarote and Fuerteventura volcanic islands, dated at 15.5 and 20.6My respectively. The FLR constitutes a wall of 350km length, 8-20km width, 1200m height respect to the PoL seafloor and 8º of average gradient (up to 40º). The continental margin has arc geometry, from S to N, its orientation changes from NE-SW to ENE-WSW, simultaneously increasing their width (from 45 to 170km) and reducing their gradients (from 7º to 1-2º). The margin corresponds to the Tarfaya basin offshore, that is characterized by salt mobility (Tari et al., 2012). The central seafloor surface of the PoL extends between 1240 and 1460m water depth, its width varies between 20 and 50km, and it shows a smooth longitudinal profile (0.2-0.5°) although locally the gradients increase until 15° in relation to local reliefs.

There are three water masses through the PoL: The upper thermocline North Atlantic Central Water (NACW), which spans from the surface to the approximate neutral density ($\square_n$) value of 27.3kg.m^{-3} (roughly 600m depth). NACW shows a mean southward transport of -0.81Sv, except in autumn that flows northwards. At intermediate levels, two water masses interleave in the PoL: Antarctic Intermediate Water (AAIW) and Mediterranean Water (MW). AAIW is found below the NACW, mainly between the layers 27.3 and 27.7kg.m^{-3} (roughly 600–1100m depth) with its core centred at 27.6 kg.m^{-3} (roughly 900m depth). AAIW flows basically northwards with a mean mass transport of +0.09Sv. The MW reaches deeper than AAIW, roughly from 900m to the bottom of the PoL ($\square_n > 27.45$kg.m^{-3}) with a mean southward transport of -0.05Sv and a similar seasonal pattern of the NACW (Fraile-Nuez et al., 2010).

The main aim of this work is to define the PoL seabed morphology in relation to oceanographic and geologic processes. A data set has been obtained in the SUBVENT2 expedition aboard the R/V Sarmiento de Gamboa (March-April, 2014): multibeam bathymetry (ATLAS Hydroacustic-DS), very high (parametric ATLAS Parasound) and high (airguns) resolution seismic profiles. A previous multibeam bathymetric grid (90x90m) from the Instituto Hidrográfico de la Marina (MDEF, Spain) has been also used.

MORPHOLOGY

It has been identified 10 morphological types on the seafloor: *i)* 15 *submarine hills* that show cylindrical or subrounded shapes (2-10.5km diameter) and elongated and flat at top (1.2-8.5km length). Their bases range between 1225 and 1530m and their tops between 828 and 1336m water depth. At the top, they show cones, ridges, slides, and terrace levels around 915-930m and 1130-1150m water depth. Some minor individual cones or ridges have also been observed in the area. *ii) Gullies* are located in the eastern flank of FLR. They show E-W to NE-SW trends and 1-5km length. *iii)* Two *canyons* have been located, one to the northeast of the FLR with an E-W to NE-SW trace, 33km length, width between 37km in the headwall and 2.5km in the slope, and 50m of incision. The second is located on the continental margin, with a NW-SE direction, 13km length, 2km width and 180m of incision. *iv) Mass transport deposits* are present along the FLR lower slope as foot of slope fans. *v) Linear normal fault scarps* with 10km length and up to 20m deep have been located on the continental slope. *vi)* A *rhombohedral depression* present at 960m depth on the continental slope, with 5km length and 0.8km width, related to normal faults. *vii) Circular depressions,* with a diameter of 2.5km and 90-130m deep, are located on the continental slope at water depths of 1170-1210m. They have asymmetrical profiles and present erosive features (truncated reflectors) on seismic profiles. *viii)* The *central valley* of the PoL has 100km length in a NE-SW direction, and is located at the foot of the slope. From 1290m water depth, the valley deepens toward the NE down to 1460m and toward the SW down to 1320m water depth. It shows erosive features on seismic profiles. *ix) Elongated depressions* are located around the submarine hills and could be classified as contouritic marginal valleys. They have so different lengths (1-17km) and widths (0.5-2km), the larger ones correspond to the coalescence of smaller. They are best developed to the east and south of the submarine hills, but their bases (1270-1530m water depth) are shallower than the central valley westwards. They show 180m of incision distributed in successive levels and clear erosive features on seismic profiles. In some cases a terrace level has been located at a depth (~1150m) similar to described on submarine hills. *x)* Some minor contouritic deposits (thickness around 50ms) are distributed along the area, they are *plastered* drifts NE-SW oriented, located between the submarine hills (6-10km of length) and related to the central valley, the three most important are situated around 1360-1385m, 1345-1355m and 1325-1315m water depth. The former have associated a contouritic channel with 10m deep.

DISCUSSION

The mapped features can be grouped into five main groups based on their distinct origin: (a) Submarine hills that have volcanic or diapiric origin, which are the most significant features of the central part of the PoL together with marginal valleys. (b) Tectonic features, such as the linear scarps and a rhombohedral depression which are related to normal faults at top of diapirs on the continental slope. (c) Circular depressions on the continental slope must be initially related to venting from diapirs, however must be reworked by bottom current dynamics. (d) Features related to sedimentary instabilities as canyons, gullies and mass-transport deposits at the FLR. (e) Bottom features related to contourite processes have been differentiated mainly produced by erosion processes such as the central valley and the marginal valleys around submarine hills, but also minor scale plastered drift deposits are present.

The shallower depth of seafloor in the PoL respect to the northern and southern adjacent regions favours the interaction of MW and the AAIW-MW interface with seabed. The central valley works a contouritic channel with structural control that favours the funnelling and acceleration of the MW eroding the seafloor. This process is focused in the base of the slope. Similarly, the marginal valleys must be related to the intensification of MW but also of the AAIW-MW interface with seafloor (down 900-1100m water depth) and their interaction surrounding the submarine hills that produce successive incisions with some characteristic terrace level. Locally this interface and the core of AAIW eroded the top of the hills around 900m water depth.

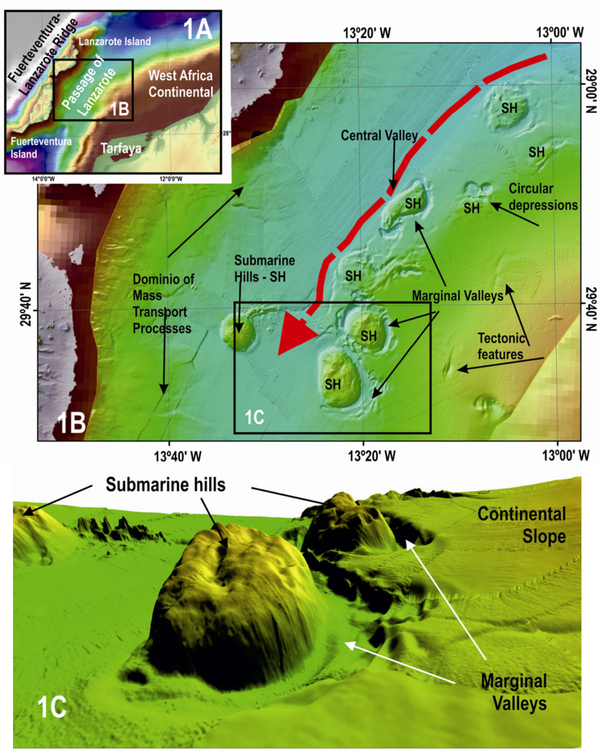

FIGURE 1. A) Situation Map; B) Compilation bathymetric map of the Lanzarote Passage; C) 3D scheme of a submarine hill and the associated marginal valley, view from SSE.

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New findings of contourite-related structures and their implications on oceanographic and sedimentary conditions on the Demerara Plateau (French Guiana and Surinam)

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Abstract: *We report preliminary data for a multidisciplinary investigation of the eastern Demerara Plateau conducted in 2013 during the IGUANES cruise (seismic and bathymetric data, sediment cores, and mooring). Our first observations show the presence of a vast field of longitudinal bed forms and comet marks between 2000 and 2800m water depth, with a NW-SE orientation, which indicate strong bottom water currents in this area. Preliminary analyses of the sediment cores and the mooring data (positioned 3064m depth) support the occurrence of active winnowing and contourite deposition, most probably related to the southward flow of the North Atlantic Deep Water (NADW).*

Key words: *Contourites, Demerara Plateau, Western Equatorial Atlantic, Guyana.*

INTRODUCTION

Several sedimentary units made of contourite deposits have been identified in South America, essentially along the Brazilian margin and described by Viana (1998). The Iguanes cruise in May 2013 focused on the Demerara Plateau (DP), as part of collaboration between the CEFREM, IFREMER and Shell. The main target was to elucidate the sedimentary processes at the origin of deposits along the Guiana Margin, and one the most significant result obtained during this cruise is the presence of thick contourite deposits along the Demerara Plateau (DP). The DP forms a 380km long and 220km wide promontory at water depth ranging between 1000m and 4500m. It is separated from the Guinean Plateau during the Albian transform-dominated opening of the equatorial Atlantic Ocean (Basile et al., 2013). The North boundary is a passive transform margin characterized by a steep slope and marked by instability and mass transport deposits (Loncke et al., 2009; Pattier et al., 2013). These MTD are associated with fluid escape structures on the seafloor (Pattier et al., 2013). #

BED FORMS

Two types of bed forms were identified on the DP between 2000 m and 3500m (Fig. 1). (1) Depressions show a peculiar morphology that might be roughly defined as "*comet tail*" and comet scour around obstacles. The position of depressions with respect to obstacles, the triangular shape of these depressions indicate a NW toward SE direction of sediment transport, that is confirmed by *in situ* current velocity measurements near the bed. This direction corresponds to the North Atlantic Deep Water circulation (NADW). (2) Chirp seismic profiles and bathymetric map display sedimentary structures very similar to sediment waves described throughout various continental margins (Lee et al., 2002). The upslope position of successive crests, as well as the thickening of their lee side compared to their stoss side, suggests an upslope migration of these bed forms. This result is in apparent contradiction with sea-floor morphologies and current velocity measurements, indicative of an along slope sediment transport. We propose that these bed forms are in fact longitudinal features with their crest slightly parallel to the main axis of the NADW. In that case, helicoidal flows generated by bed roughness (for instance at the position of comet marks) promote the formation of these longitudinal structures (Flood, 1981). The elongation of the comet structures clearly suggests the existence of a south-eastwards flowing deep-sea current.

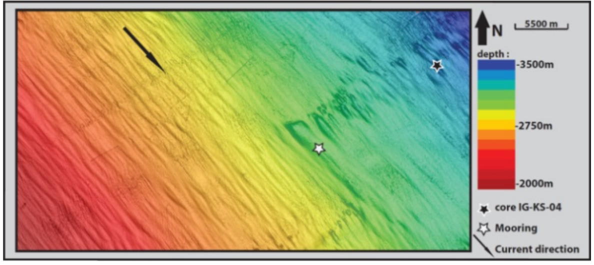

FIGURE 1. This bathymetry map illustrates comet features and longitudinal bed forms on the seafloor.

LITHOFACIES

20 Cores, collected on the DP between 1200m and 4200m water depth, are studied to characterize the different facies. The recovered sediment varies between 3 and 10m in core length, according to the encountered lithology. The bottom of 5 cores was dated by radiocarbon measured on planktonic foraminifera tests. The oldest recovered sediment is dated at 52.000 ± 3000 years BP. This allows a preliminary estimation of sedimentation rate with should be around 5.9cm.kyr^{-1}, even though more radiocarbon dates will be necessary for refining the age model.

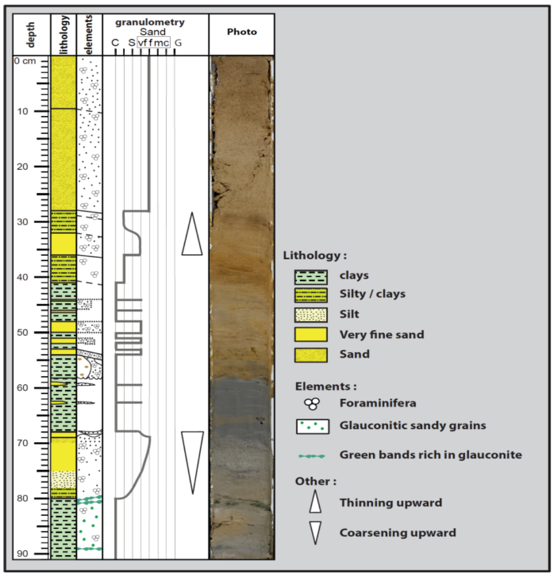

FIGURE 2. Sedimentary log of IG-KS-04 section 1: This section illustrates the lithology variations between sand and mud intervals.

On the whole, main lithological facies can be synthesized as follow: on the top, a layer of variable thickness made of brownish sediments, rich in planktonic foraminifera (Fig. 2). Below, the sediments are made of grey/greenish clays mottled by bioturbations and by glauconite-rich greenish lenses and beds (Fig. 2). These sediments contain sparse bioclasts in the silty matrix: foraminifera, pteropods, others gastropods, urchins, sponges. Occasionally, coarse-grained sands beds rich in foraminifera and glauconite are found. Shells and tests found in these levels are very fragmented. Glauconite is thought to be formed *in situ* by clays minerals transformation at the sea-sediment interface (Giresse, 2008). The maturity of glauconitic grains is related with the residence time of sediments along this interface and also the rate of sedimentation (Giresse, 2008). The winnowing caused by a bottom current can slow down or prevent the accumulation of fine sediments and then can promote the formation and the maturation of glauconite. The winnowing is linked to high energy hydrodynamic conditions which prevents the deposit of fine-grained particles and promotes the coarser deposit setting. The variation of the bottom current velocity controls the construction of more or less sandy sequences as illustrated in the Fig. 2 (Gonthier et al., 1984). Sedimentary structures are poorly preserved, probably because of the strong bioturbation.

Evidence of MTD including massive debrites is found in some of the collected cores. These are blocks composed by white indurated sediments rich in planktonic foraminifera. They are systematically observed under the comet scours observed on the seafloor suggesting that they form hard reliefs that boost the development of those structures. On the sea floor, some comet structures may initiate along pockmarks as stated by Pattier et al., 2013.

OCEANOGRAPHY

According to the measurements acquired on the sea bottom over a year time-laps, the comet-area is the place of a SE oriented current. Its mean velocity is 9.5cm.s^{-1} with some peaks reaching 32.5cm.s^{-1} recorded in December 2013. The current is connected to the NADW located between 1200m and 4000m (Viana, 1998).

CONCLUSION

We present recently acquired data (i.e. comet structures, longitudinal bed forms, winnowing illustrated by glauconite concentration and sand beds, and current meter measurements) which indicate the presence of contourites along the DP. The presence of contourites around this Plateau could be promoted by the morphology and by the steep slope related to the transform margin. Future work should aim to better understand the links between contourites and slope instability on the DP.

ACKNOWLEDGEMENTS

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Medical CT-images of contourite cores: An onset to processing and data interpretation

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Abstract: *Although CT scans are being used in scientific research since the late 1970's, they are only recently being used in contourite research. Mostly a vertical slice through or an X-radiograph of the sediment core is shown, not displaying the three-dimensional variations within the sediment core. These can be very important however. This research attempts to discern components within the entire core based on their radio-density values, using the 3D analysis software "Morpho+", developed by the UGCT (Ghent University Centre for X-Ray Tomography). The abundance of each component is displayed throughout the sediment core and will be compared to MSCL, XRF and grainsize data in order to derive what information is held within CT scans. By scanning muddy, silty and sandy contourite cores (both compacted and not), a non-exhaustive reference set of CT scans for contourite cores will be created.*

Key words: *CT scanning, contourites, Gulf of Cádiz, MSCL, XRF.*

INTRODUCTION

X-ray computed tomography (CT) is a non-destructive technique enabling researchers to obtain information of the internal structure of an object (Brabant et al. 2011). CT-images in sediment core sections may display features not visible with the naked eye or on core-pictures, such as distinct layers, bioturbation, cracks, and weathering effects (e.g. Dewanckele et al. 2014) and as such it is a tool which has been used to further improve core interpretations. CT imagery in contourite research is scarce so far. Some authors (e.g. Rebesco et al. 2012 and Voigt et al. 2013) use X-radiographs, which do not take into account the full 3D variations within a core. Lateral variations are of high importance and should be taken into account. This research focusses on several contourite cores from the Alboran Sea and the Gulf of Cádiz containing muddy, silty and sandy intervals in order to assess what extra information can be obtained from CT scans and to generate a preliminary reference set of CT scans against which future cores can be compared.

MATERIAL AND METHODS

Over 5 meters of sediment core GC01 (northern Gulf of Cadíz) were scanned with the SOMATON definition flash scanner of the Ghent University hospital. A 120kV step and rotation time of 1 second were set by which a x and y-resolution of 0.2mm and z-resolution of 0.6mm was obtained. The images were reconstructed using the "J37s medium smooth" algorithm. The analytical software package Morpho+ (Brabant et al., 2011) from the Centre for X-ray Tomography of the Ghent University was used in order to discern different components based on the radio-density values histogram (Fig. 1), a measure for changes in density and average atomic number. These components are isolated and quantified in comparison to the total volume of interest.

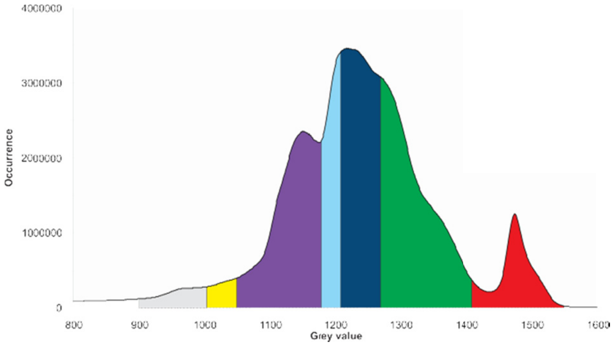

FIGURE 1. Histogram of the radio-density values in core GC01 (Gulf of Cádiz). The colours in this histogram correspond to those in Fig.2.

INITIAL RESULTS

The colours within the vertical section (Fig. 2) generally only show the component which has the highest percentage in that interval. However other components are not fully absent within those zones, e.g. between 2150 and 2550 cm the dominant component is the purple one while the light blue component is not absent (up to 20%). There is as well an important amount of the yellow (up to 7.5%) component present (Fig. 2). Also although never really visible in the core image, the red component is never totally absent and has sometimes percentages up to 5% (e.g. 900m, Fig. 2).

Based on the abundance of the different components, at least 14 units can be distinguished (Fig. 2). These units almost exactly match XRF-defined zones (cfr. Fe/Ca and Si/Al curves in Fig. 2). Zone 2 (green box in Fig. 2) consists mostly of the green component and correlates with Si/Al values. The variation of the other CT-components can however still be used in order to derive intra-zone variations. In this case the red component, indicating very high radio-density values still shows a lot of variation. It has to be noted that XRF measures the chemical composition of the top millimetre of a split core, which may not be the same throughout the entire horizontal slice of the core this measuring point represents. A CT scan measures the radio density of that entire horizontal slice and may as a result potentially reveal more information on the core.

FUTURE RESEARCH

Further comparisons to XRF, MSCL and grain-size data will be carried out to find out what the different components represent and how they can be used to further interpret contourite cores. To achieve this goal, contourite sections from various settings will be scanned in order to compile an initial reference set against which future scans can be compared.

ACKNOWLEDGEMENTS

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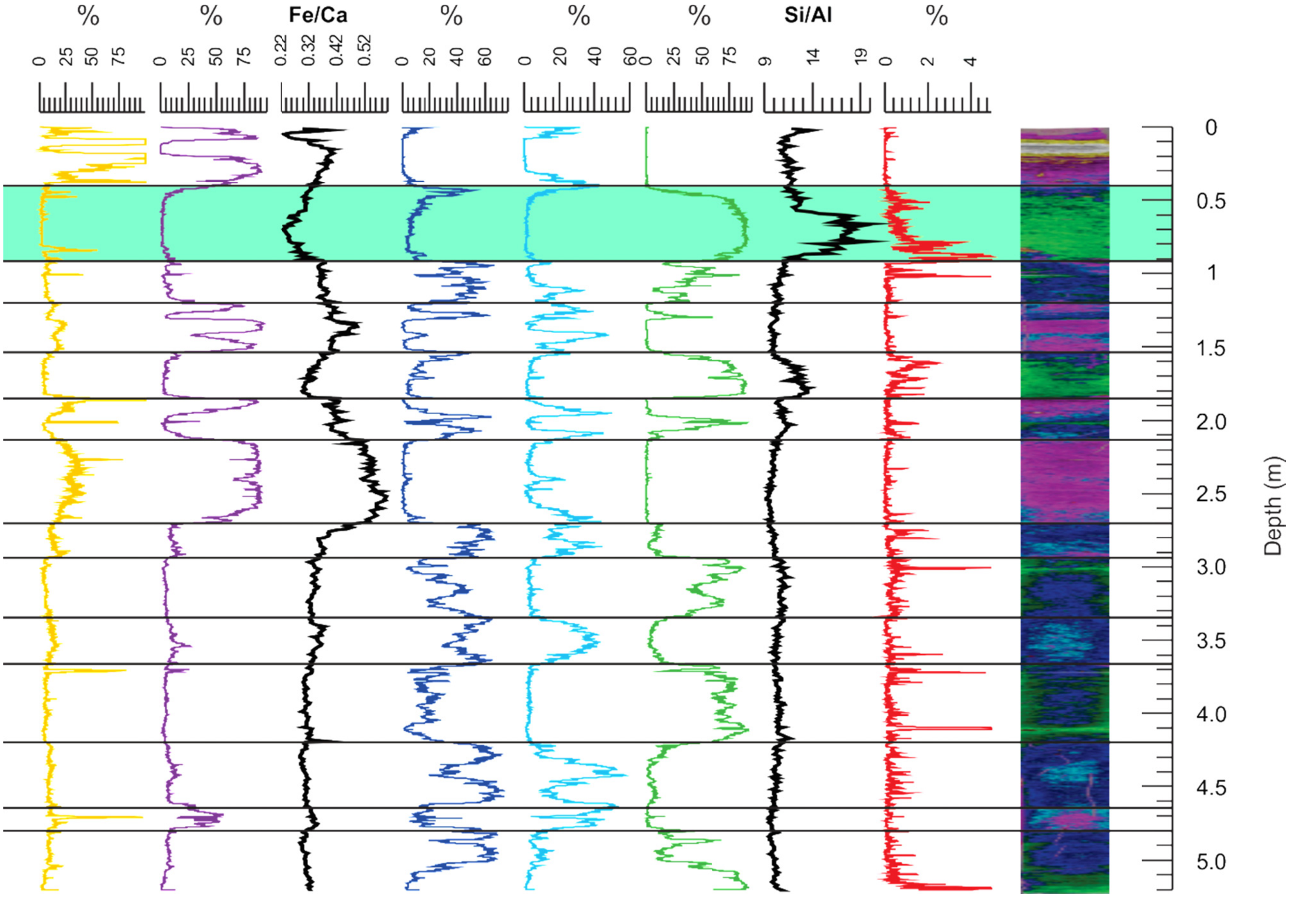

FIGURE 2. Variation of the components (percentages) and XRF-measured Fe/Ca and Si/Al throughout sediment core GC01. The grey component is not displayed in the graphs. A vertical section through the core is given on the right. The black horizontal lines delineate 14 zones based on the CT data. Zone 2 is indicated in green because it shows a good correlation between the green component and the Si/Al data. Also the purple component and the Fe/Ca data display the same trends.

Sediment drifts in Lago Castor (Chilean Patagonia) reflect changes in the strength of the Southern Hemisphere Westerly winds since the Last Glacial Maximum

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Abstract: *Lago Castor (45.6°S; 71.8°W) is located within the postglacial pathway of the core of the Southern Hemisphere Westerly winds, which migrated from~42°S during the LGM to ~52°S at present. During two field expeditions (2009-2011) a network of high-resolution reflection-seismic profiles of the lake infill was acquired and a 15 m long composite sediment core was retrieved. The combination of the seismic stratigraphy and the sediment core lithology shows that the lower units were deposited in a proglacial environment, while the upper units (younger than 18.3 kyr BP) were influenced by bottom currents counteracting currents of surface waters driven by the Southern Hemisphere Westerlies. We conclude that sediment drifts constitute a good and relatively poorly investigated proxy for Westerly wind strength reconstructions.*

Key words: *lake sediments, Southern Hemisphere, Westerlies, Chile, Holocene*

INTRODUCTION

Variations in the latitudinal position and strength of the Southern Hemisphere Westerly Wind Belt (SWWB) have strongly determined climate fluctuations in Patagonia since the Last Glacial Maximum (LGM). Reconstructing variations in the strength and/or latitude of the SWWB, however, requires an array of paleoclimate records located along a north-south transect. Lago Castor (45.6°S; 71.8°W) is located within the postglacial pathway of the core of the Westerlies, which migrated from~42°S during the LGM to ~52°S at present. Lago Castor is a glacigenic lake on the eastern side of the Andes mountain range in Chilean Patagonia, and it contains a sedimentary record encompassing the entire Holocene and deglaciation.

METHODS

During a first expedition in 2009, a dense network of high-resolution reflection-seismic profiles (3.5 kHz and sparker) of the lake infill was acquired. The seismic profiles were analysed using IHS Kingdom software. In the austral summer of 2011, a 15 m long composite sediment core was retrieved using a UWITEC piston coring system. After opening and description, pictures were taken and magnetic susceptibility was measured at 2.5 mm intervals (Bartington MS2E point sensor), organic matter content has been estimated using loss–on-ignition, and grain-size analyses of the terrigenous fraction (pre-treatment with H_2O_2, HCl and NaOH; Malvern Mastersizer 3000) were performed every ~10 cm. The core chronology was is based on nineteen ^{14}C dates.

RESULTS

The sediment core penetrates into the lower units (E and F) of the sedimentary infill of the lake, which is characterized by a ponding, semi-transparent seismic facies (FIGURE 1). The sedimentary facies consists of layered to laminated clays to fine silts with a very low organic matter content. The top of unit E was dated to ~18.3 kyr BP.

The upper part of the lake infill (units A-D) consists of draped to mounded sediment packages, with fluctuations between both end-members (FIGURE 1). This unit corresponds to the upper nine meters of the sediment core. The green-brown laminated sediments are richer in organic matter and are composed of fine to coarse silts. They are also frequently interrupted by coarser grained volcanic-ash layers characterized by high magnetic-susceptibility values.

DISCUSSION

The combination of the seismic stratigraphy and the sediment core lithology shows strong changes in sedimentary processes (FIGURE 1). When the laminated sediments of units E and F were deposited, Lago Castor was a proglacial lake. The lake received high amounts of fine-grained sediments form the Patagonian Ice Sheet outlet glaciers, resulting in typical glacial varves.

On the contrary, the draped sediments from units A-D can be attributed to hemipelagic sedimentation under calm conditions. The mounded packages are interpreted as sediment drifts in which sedimentation is strongly influenced by bottom currents. In lakes Cardiel, Potrok Aike (Argentinean Patagonia; Anselmetti et al., 2009;

Gilli et al., 2005) and Lac d'Armor (Kerguelen Archipelago; Heirman et al., 2012), similar sediment drifts have been attributed to an intensification of the SWWB. Westerly winds blow surface waters to the Eastern extremities of the lakes, a process which is counteracted by bottom currents from East to West. In the Argentinian lakes the onset of wind-driven sediment drifting has been dated to 6.8 kyr BP (49°S) and 6.0 kyr BP (52°S). In the more northerly situated Lago Castor (45.6°S), this process started much earlier, i.e., shortly after the start of the deglaciation around 18.0 kyr BP. Since then, wind strength has gradually increased, interrupted only by a decrease around the time of the Antarctic Cold Reversal (~13–14 kyr BP; end of unit D). Although some of the sediment-drift-architecture changes during the Holocene may also be influenced by variations in sediment supply (by, for example, high input of volcanic ashes, e.g. unit B), there appears to be an increase in sediment drifts during the last 3000 yrs (unit A), which we interpret as an increase in the strength of the SWWB.

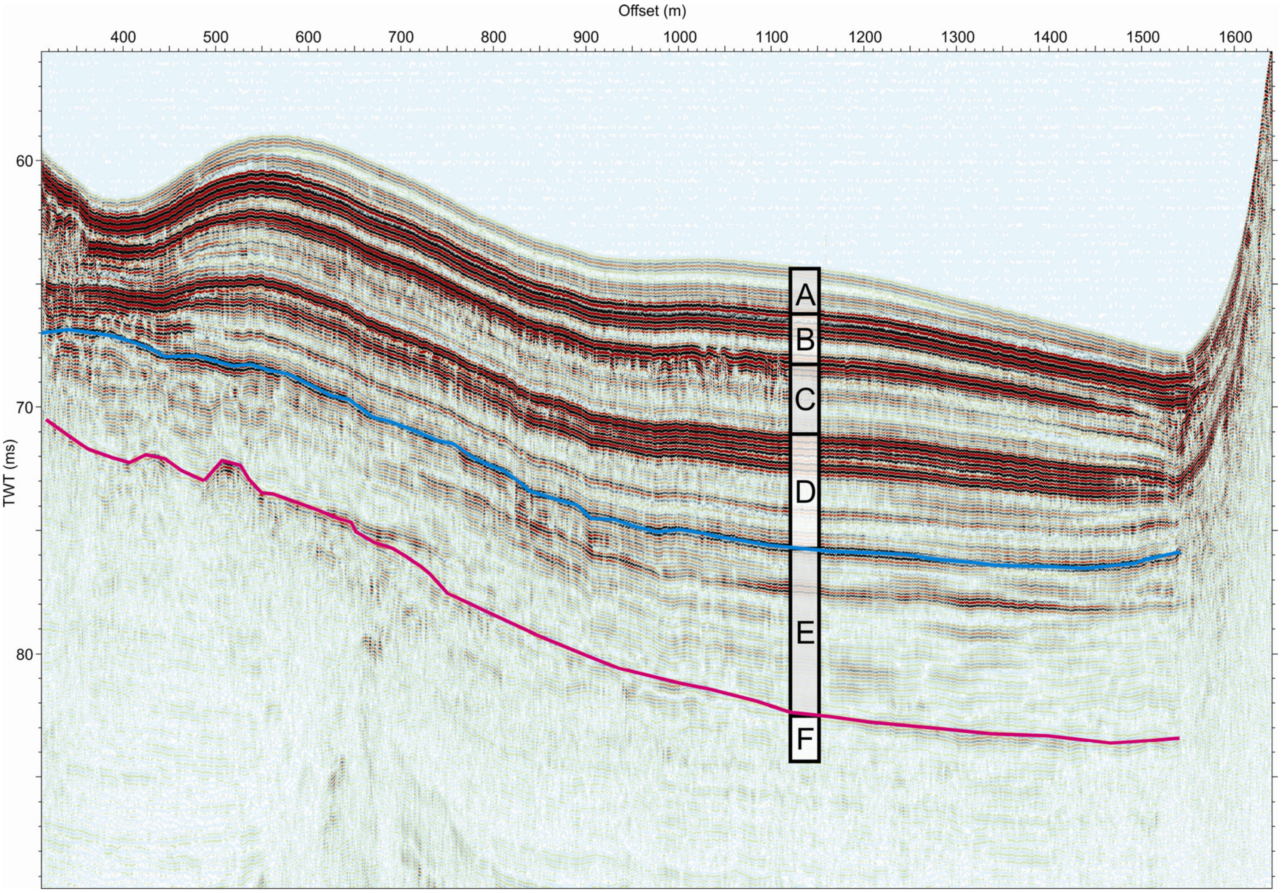

FIGURE 1. 3.5 kHz profile showing the different units of lacustrine infill of Lago Castor. The 15-m-long sediment core is projected on the profile.

CONCLUSIONS

The Lago Castor sediment drifts allow the reconstruction of changes in the intensity of the Westerlies since the LGM. Sediment drifts constitute a good and relatively poorly investigated proxy for Westerly wind strength reconstructions, which is independent from other sedimentological or biological proxies.

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Evidence for Holocene bottom-currents erosion in the Western Gulf of Corinth, Greece

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Abstract: *The Gulf of Corinth, Greece, is connected to the Ionian Sea through a 62m deep sill. Strong tidal currents have been measured above this sill, what could potentially induce bottom-current erosion in the Gulf. Seismic reflection data allowed us to identify this present-day expected seafloor erosion in a wide area, as well as erosional unconformities and a wide channel between 100 and 300m below sea level. These features highlight the possible occurrence of strong bottom-currents since the last sea level rise.*

Key words: *bottom-currents, seafloor erosion, Holocene transgression.*

INTRODUCTION

The Gulf of Corinth is a 860 m deep basin in central Greece, connected to the Ionian Sea to the west through the 62 m deep Rio sill. Because of the presence of the sill, the Gulf was disconnected from the World Ocean during Quaternary lowstands (Collier et al., 2000). Consequently, hydrodynamic circulation should have changed dramatically between lowstand and highstand conditions, and these changes could have been recorded in the offshore sedimentation. Periodic changes in the sediments properties in relation with the eustatic level have been highlighted in the deep Gulf by seismic data, but the processes responsible for these changes are still unknown (Bell et al., 2009; Taylor et al., 2011). Measurements of present-day sea currents are scarce. Strong, up to $2 m.s^{-1}$, tidal currents occur at the Rio Strait (Hadjitheodorou et al., 1992), but the influence of these currents on the deep gulf water circulation is unknown.

Here we investigated the western extremity of the Gulf of Corinth, i.e. the Nafpaktos Basin. In this area located just East of the sill, we look for evidence for bottom-currents morphologies associated with the known tidal currents. Because of the disconnection of the Gulf during Quaternary lowstands, occurrence of bottom-current-related morphologies could be a reliable stratigraphic marker for highstand or transgressive conditions.

METHODS

To test this hypothesis, seismic reflexion lines have been acquired with RCMG's “Centipede” multi-electrode sparker. They allowed us to image at least 130ka of sedimentation according to a previously developed chronostratigraphic model (Bell et al., 2009). Isopach map for the Holocene has been built and morphological features and deposits associated with bottom-currents have been mapped.

RESULTS AND DISCUSSION

Present-day seafloor erosion is observed in the whole Nafpaktos Basin, between 40 and 100 m water depth, indicating widespread action of bottom-currents coming from the Rion sill. In the center of this basin, a 10 m deep, 400 m wide channel is eroded into what we interpreted as early Holocene deposits. This feature is reminiscent, at a smaller scale, to mega-flood channels described in the English Channel (Gupta et al., 2007) and could indicate that a similar flood event occurred in the Gulf of Corinth during the Holocene transgression, 11.5ka ago. However, improving the Nafpaktos Basin stratigraphy is needed to better date this erosional event.

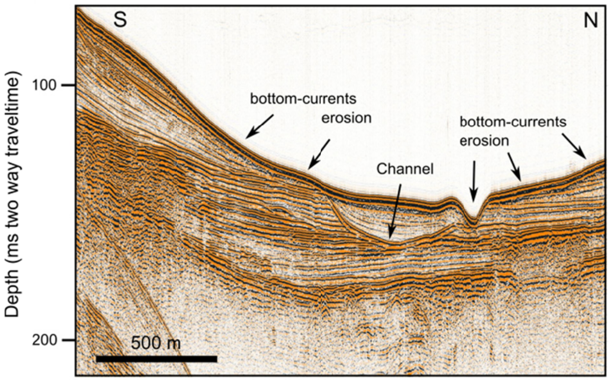

FIGURE 1. Seismic profile showing present seafloor erosion and Holocene mega-flood (?) channel in the centre of the Nafpaktos Basin, Gulf of Corinth, Greece.

More to the east, no seafloor erosion is observed, indicating that today, bottom-currents erosion stops around 12km east of the sill. Instead, depositional reliefs develop on the flanks of the basin floor. These morphologies could be formed by bottom-currents (“contourites”) or could result from the cloud settling of turbidity currents originating from the surrounding deltas.

In the northern depositional relief, 200 to 300 m below sea level, an erosional unconformity is observed below 30m of Holocene sediments. It may indicate in this area the occurrence of erosive bottom-currents occurring only during the post-glacial rapid sea level rise in this gulf. Identification of erosional unconformities associated with older Quaternary highstands and associated transgressions, e.g. the marine isotopic stage 5, is in progress.

CONCLUSION

As expected by the strong tidal currents measured at the outlet of the Gulf of Corinth, seafloor erosion is highlighted in a wide area at the western tip of the Gulf. This erosion stops around 12km east of the sill where large depositional relief develop. Two older phases of bottom-currents erosion are observed. The first one is associated to the post-glacial sea level rise, and the second one occurred during the early Holocene.

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Geological resource management of the future: Drilling down the possibilities

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Abstract: *Management of geological resources is based, ideally, on information on the quality and quantity of surface and subsurface litho-stratigraphical properties. Increasingly, these data become available for the offshore realm, though the integration into manageable and user-friendly applications is still at its infancy. Building on expertise from on-land data mining, we are now in the phase of creating 3D voxel models allowing for multi-criteria resource volume calculations. The underlying data will be subdued to uncertainty modelling, a necessary step to produce data products with confidence limits. Anticipating on the dynamic nature of the marine environment, we aim at coupling the voxel model to environmental impact models to calculate resource depletion and regeneration, based on geological boundary conditions. In combination with anticipated impacts on fauna and flora, mining thresholds will be defined. All of the information is integrated into a decision support system for easy querying and on-line visualizations . The main aim is to provide long-term predictions on resource quantities to ensure future developments for the benefit of society and our future generations.*

Key words: *Sustainable Exploitation, Mining thresholds, 3D Geological Models, 4D Decision Support System, Uncertainty modelling.*

INTRODUCTION

Mineral and geological resources can be considered to be non-renewable on time scales relevant for decision makers. Once exhausted by humans, they are not replenished rapidly enough by nature, meaning that truly sustainable resource management is not possible. Comprehensive knowledge on the distribution, composition and dynamics of geological resources therefore is critical for developing long-term strategies for resource use (e.g., Van Lancker et al., 2010). For the marine realm, resource management is often hampered by sparse data availability, though increasing exploitation demands call for innovative approaches that include uncertainty as a primary asset. This is the scope of the TILES project (2013-2017), set-up for managing marine aggregate exploitation in the southern North Sea, but generically designed for a broader range of resources and environments.

The ambition of TILES is to:

(1) Develop a decision support system (DSS), containing tools that link 3D geological models, knowledge and concepts, providing information on present-day resource quantities and distribution, to numerical models of extraction-related environmental impact through time. Together they quantify natural and man-made boundary conditions and changes to define exploitation thresholds that safeguard sustainability on a multi-decadal time scale.

(2) Provide long-term adaptive management strategies that have generic value and can be used for all non-hydrocarbon geological resources in the marine environment.

(3)Propose legally binding measures to optimize and maximize long-term exploitation of aggregate resources within sustainable environmental limits. These proposed measures feed into policy and associated monitoring plans that are periodically evaluated and adapted.

WORKFLOW

The project objectives will be achieved through interdisciplinary and transnational research on the nature and dynamics of geological resources and on the environmental impact of extraction (FIGURE 1). State-of-the-art 3D geological models will be developed by transforming a layer model, defining stratigraphic unit boundaries, into a so-called voxel model (consisting of '*tiles*' or volume blocks) and assigning to each voxel lithological or other characteristics (e.g., Stafleu et al. 2011). The primary voxel information will be based on a combination of point and line data, respectively from coring and seismic investigations. These data, and additional environmental datasets, that are added to the voxels will be subjected to uncertainty analyses, a necessary step to produce data products with confidence limits. Uncertainties relate to data- and interpolation issues (van Heteren and Van Lancker, in press); their propagation will be assessed through the data products. The geological models will feed into 4D numerical impact models that quantify the environmental impact of extraction. Here, there is scope to define mining thresholds, based on the nature and dynamics of geological resources and on the impact of their removal. The 3 and 4D model results will be incorporated into scenario analyses and forecasts, using a newly developed multi-criteria decision support system (DSS) (e.g., De Tré et al., 2010). The DSS, based on an object-oriented database structure and resource suitability modelling, will allow specifying flexible criteria for geological, environmental and socio-economical parameters. Information will be visualized in series of tailor-made suitability maps that assist in resource assessments.

Using a dedicated subsurface viewer, a suite of data products will be viewable online. They can be extracted on demand from the underlying voxel (3D pixel) model. The flexible 3D interaction and querying will be invaluable for professionals, but also for the public at large and for students in particular.

CONCLUSIONS

To anticipate on actual and future resource supplies and needs, long-term adaptive management strategies for the exploitation of geological resources are urgent requests (e.g., marine spatial planning, EU's Marine Strategy Framework Directive). They comply ideally with EU recommendations on 'Efficient use of resources' (EC COM2011_571) and ICES Guidelines for the management of Marine Sediment Extraction (ICES, 2003). The scope of the latter corresponds well with the recommendations provided by the International Seabed Authority (ISA) regarding deep-sea mining.

It needs emphasis that setting-up transnational, harmonized geological knowledge bases can function as a critical platform for the exchange of data, information and knowledge. It will herald a new age in resource management, locally and transnationally.

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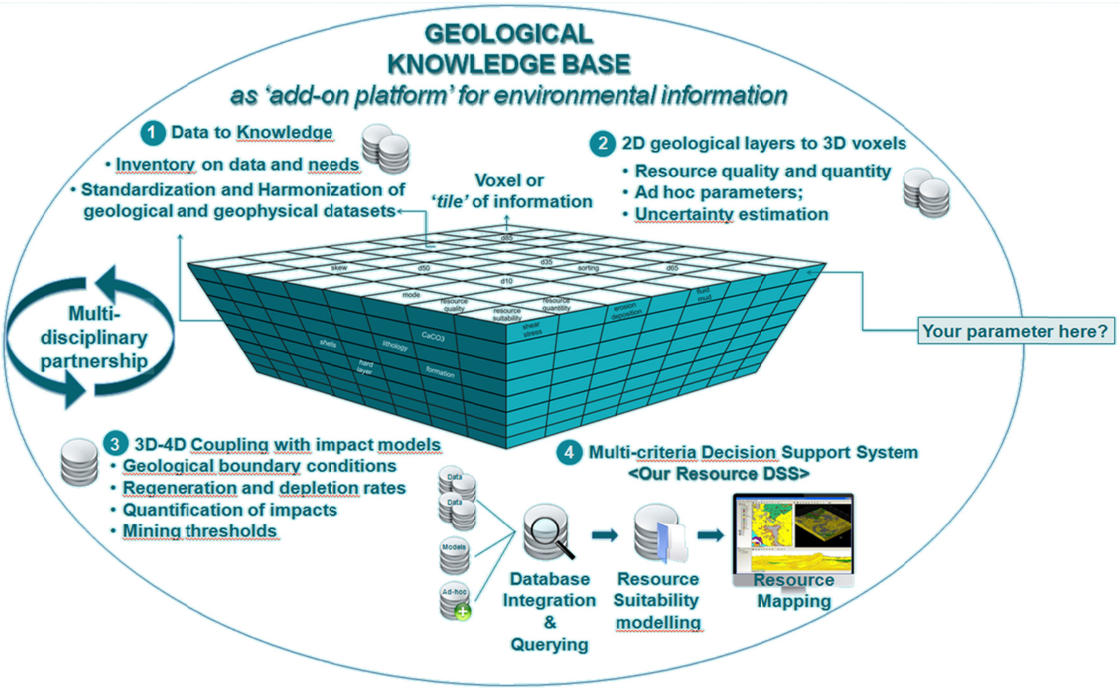

FIGURE 1. TILES workflow. The set-up of a Geological Knowledge Base is promoted to advance and innovate, structurally, on collaborative research and management related to resources, in casu non-living, but with ample opportunities to link with the living environment.

RV BELGICA II: THE NEW BELGIAN RESEARCH VESSEL TO REPLACE THE EXISTING RV A962 BELGICA

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Abstract: *For 30 years RV Belgica has been the marine infrastructure for Belgian marine scientists working on the Belgian Part of the North Sea and in the marine realm stretching from Norway, over Ireland to Morocco. Even if the ship is still performing research activities for more than 180 days per year, the increasing number of technical breakdowns and the rising maintenance cost associated with her age makes the replacement by a new RV Belgica II a necessity for the Belgian marine science community.*

Key words: *RV A962 Belgica, RV Belgica II, research vessel.*

INTRODUCTION

The present-day Belgian oceanographic research vessel A962 Belgica is a thirty-year-old research platform. Although the RV Belgica continuous to perform scientific activities for ca. 180 days per year, the renewal of the vessel should be anticipated. The lifetime of a research vessel is approximately 30 years (Binot et al., 2007).

FIGURE 1. The current RV A962 Belgica.

FEASIBILITY STUDY

In 2009 a feasibility study (BELSPO & Techmar International, 2009) was ordered by the Belgian Science Policy Office (BELSPO) to assess the best future options for the A962 Belgica, i.e. replacement by a new oceanographic research vessel or modernizing the existing vessel. The main conclusions of this study are:

i) RV Belgica is overall in good working order but obsolescence of certain equipment together with (hidden) corrosion and the lack of space and comfort are troublesome for a modern oceanographic research vessel;

ii) The ship time demand in terms of researcher units (8 hours) expressed by the Belgian scientific community (questionnaire 2008) would lead to a total of 10.000 units compared with the current 4.000/5.000 units. The current vessel operated by 1 crew can certainly not accommodate for this demand;

iii) The scientific community insists that the new ship should be a multipurpose research vessel (for hydrography, geology, biology, oceanography, fisheries, environmental sampling, etc.) with dynamic positioning capabilities, with an autonomy of 4 weeks, with more space and ideal for large-scale equipment (AUV, ROV, coring, etc.) and with a minimal ice class;

iv) Multipurpose oceanographic research vessels belonging to the regional/ocean class will be lacking in Europe in the near future. Therefore a pan-European approach regarding transnational access, design, pooling of equipment etc. should be fostered (cfr. EC-FP-7 EUROFLEETS project);

v) Regarding the financial, technical, statutory aspects modernizing the existing vessel can be abandoned as a feasible option; acquiring a new oceanographic research vessel is the only option.

FINANCING STUDY

In 2013-2014 a financing study was performed by BELSPO and RBINS-OD Nature to get an update of the building and operating costs of a new Belgian research vessel. This study was based on the scientific needs as were expressed by the Belgian scientific community in the feasibility study (BELSPO & Techmar International, 2009). Furthermore, several management options and a collaboration with neighboring countries for the build and exploitation of the new research vessel were investigated. The main conclusions of the financing study are:

i) As stated in the feasibility study, the modernization of the current RV A962 Belgica is financially, technically and scientifically not a solution.

ii) The expected build and delivery cost of RV Belgica II is 54.45 M€, including VAT.

iii) The expected exploitation cost of RV Belgica II for 300 days at sea is 4.3 M€ per year. To sail 300 days per year, 2 crews are needed.

iv) Over the 30 year life span of a research vessel, financially the best option is for the Belgian federal government to foresee in the build and the operational aspect of the new research vessel, as is the case for the current vessel. A continuation of the collaboration between the Belgian Science Policy Office and Belgian Defence – Naval Component to operate the vessel can be expected and will be further explored.

Besides these financial and operational results the financing study also resulted in several letters of support in favor of the RV Belgica II project; support comes from different Belgian national and regional institutes and universities, government bodies and private companies expressing their need for a larger Belgian research vessel to sustain the growing demand for marine research, training and education.

It is still unclear what the future will be for the current RV A962 Belgica if the much-awaited RV Belgica II will be taken into service. In any case, from the moment the budget for the new vessel will be foreseen by the Belgian federal government, it will still take 3.5 years for the ship to be delivered and to be made operational.

RV BELGICA II & RV SIMON STEVIN

The new research vessel Belgica II will be completely complementary to the Flemish research vessel Simon Stevin. As the present day RV Belgica, the new RV Belgica II will perform multiple day (5-20 days) expeditions whereas the RV Simon Stevin generally performs daily expeditions. The new RV Belgica II will be a larger ship (overall length ca. 65m, breadth ca. 15m, draught max. 4.8m) and will perform scientific tasks in Belgian and European waters whereas the RV Simon Stevin is much smaller (36m by 9m by 3.5m) and is mainly operated in Belgian coastal waters. The difference in working area and in expedition duration shows that both research vessels are indeed complementary. The two research vessels, RV Belgica II and RV Simon Stevin, will accommodate for the growing demand in marine research and knowledge.

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FIGURE 2. An artist impression of a possible design of the RV Belgica II.

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