Deep Sea and Sub Seafloor Frontier (DS3F)

Workshop Report

Work Package 4

"Sediment Dynamics and Geohazards"

Can Barrina, Spain

February 21-24, 2011

Organizers:

Miquel Canals and Vasilis Lykousis

Section 1 (General information)

WP number: 4, Sediment Dynamics and Geohazards

Date: 21rst – 24th February 2011

Location: Can Barrina, Montseny, near Barcelona

Organiser(s): Miquel Canals, University of Barcelona

Local host: Miquel Canals, University of Barcelona

Section 2 (Logistics)

List of participants (by invitation only)

Canals, Miquel – GRC Geociències Marines, Universitat de Barcelona
Forsberg, Carl Fredrik - Norwegian Geotechnical Institute, Oslo
Gràcia, Eulàlia - Unitat de Tecnologia Marina, CSIC, Barcelona
Heussner, Serge – CEFREM, CNRS- Université de Perpignan Via Domitia
Laberg, Jan Sverre – University of Tromso
Lastras, Galderic - GRC Geociències Marines, Universitat de Barcelona
Likousis, Vasilis – Hellenic Centre for Marine Research, Athens
Puig, Pere – Institut de Ciències del Mar, CSIC, Barcelona
Pusceddu, Antonio – Dept. Marine Science, Polytechnic University of Marche, Ancona
Sultan, Nabil – IFREMER, Brest
Vanneste, Maarten - Norwegian Geotechnical Institute, Oslo
Vitorino, Joao – Instituto Hidrografico, Lisboa
Weaver, Phil - National Oceanography Centre, Southampton

Agenda

21rst of February 2011

Arrival of participants to Barcelona

22nd of February 2011
(timing is merely indicative)

Morning: Arrival of the rest of participants to Barcelona
Midday: Transfer to meeting place, Can Barrina, at Montseny, by car

- 13:45-14:45 – Lunch at Can Barrina
- 14:45-15:00 - Welcome and introduction of participants
- 15:00-17:00 – Presentations
  - 15:00-15:15 - Framing presentation: The Deep Sea & Sub-Seafloor Frontier (DS3F) by M.Canals
  - 15:15-16:45 - The 10 most pressing questions on SD&GH: first set of presentations by
    - A. Pusceddu (15:15-15:45): Every thing You Always Wanted to Know About Geosphere-Biosphere interactions along continental margins (and never asked, yet!)
    - P. Weaver (15:45-16:15): Some pressing questions on sediment dynamics and geohazards
    - J. Vitorino (16:15-16:45): Some questions related to sediment dynamics and GHZ
  - 16:45-17:00 - Discussion
- 17:00-17:15 – Coffee break
- 17:15-19:00 – The 10 most pressing questions on SD&GH: second set of presentations by
    - J.S. Laberg (17:15-17:45): Sedimentary processes on the continental slope - deep sea
    - M. Vanneste (17:45-18:15): Sediment Dynamics and Offshore Geohazards
    - E. Gracia (18:15-18:45): Searching the record of past earthquakes under water: Overview and questions in marine paleoseismology
  - 18:45-19:00 - Discussion
- 21:00: Dinner

23rd of February 2011
(timing is merely indicative)

- 08:00-08:45 – Breakfast
- 08:45-11:00 - The 10 most pressing questions on SD&GH: third set of presentations by
    - V. Likousis (08:45-09:15): Some remaining questions
    - M. Canals and G. Lastras (09:15-09:45): Our 10 most pressing questions on sediment dynamics and geohazards

P. Puig (09:45-10:15): Contributions to sediment dynamics & geohazards brainstorming workshop

S. Heussner (10:15-10:45): Sediment dynamics and geohazards

10:45-11:00 - Discussion

11:00-11:15 – Coffee break

11:15-13:45 - The 10 most pressing questions on SD&GH: fourth set of presentations by

N. Sultan (11:15-11:45): Submarine landslides and sediment deformations (pre-failure/failure): the 10 (most?) pressing questions

K.F. Forsberg (11:45-12:15): SD & GH brainstorminig

12:15-13:45 – Extended discussion

13:45-14:45 – Lunch at Can Barrina

14:45-15:30 – Summing up and closure of the Workshop

Afternoon: Transfer to Barcelona and to Barcelona airport by car. Departure of participants.

24th of February 2011

Morning: Departure of latest participants from Barcelona airport.

Section 3 (Scientific wrap-up)

Abstract

Invited experts from France, Greece, Italy, Norway, Portugal, Spain and the United Kingdom attended the workshop on Sediment Dynamics and Geohazards. The main topics presented and discussed, with no strict time limitation, were the following: i) Sediment transport processes along continental margins, and the significance of onshore-offshore links at specific settings; ii) Physical oceanography processes and their interactions with sediment dynamics and geohazards along continental slopes; iii) Dense water flows and their sediment transport and seafloor shaping potential; iv) Geotechnical properties and sediment destabilization mechanisms and processes; v) Role of fluid flow, gas hydrates and weak layers on sediment destabilisation; vi) Tsunamigenic faults and landslides; vii) Marine paleoseismology and the use of mass-transport deposits to characterize past earthquakes; viii) Dating of events, multiplicity of time and space scales to be addressed and natural variability vs. anthropogenic influences on sediment dynamics and geohazards. ix) Climate and anthropogenic influences on sediment transport and geohazards; x) Sediment dynamics and geohazard interactions with the biosphere along continental margins; xi) Observation of events, sampling needs and technological developments required for the near future; and xi) Topics of interest to the offshore industry (oil industry an others): to route towards reliable predictions

Background and Objectives

Sedimentary processes transfer matter and energy from the atmosphere and the continent to ocean margins and basins. The study of sedimentary processes has profound implications for the deep-sea ecosystem, the climatic evolution of our planet, natural resources and geohazards. Therefore, their study represents a centrepiece within the frame of the Coordination Action on "The Deep Sea & Sub-Seafloor Frontier".

(1) Sedimentary processes involve water column, near-bottom, seabed and subseafloor processes that occur at variable time scales, from minutes to millennia. Sedimentary processes have the ability to **shape the seafloor** as illustrated by the development of submarine canyons, valleys, gullies, mounds or deltas and deep-sea fans. Sedimentary processes synthesise the **physical abiotic factors controlling the deep-sea ecosystems** and, therefore, are key to understand their current status and future evolution. Sediments are porous and permeable, so that **prokaryotes and, at shallow burial depth, eukaryotes** become habitants and exchanges genetic information within and along them.

(2) The climatic evolution of Earth is closely related to specific sedimentary processes, to sediment volumes and accumulation sites as determined by climatically controlled sediment erosion and transport, and sea level changes. Recent findings on the capability of **cascading sediment-laden dense shelf waters** to capture large amounts of C and transfer it rapidly to the deep ocean where it could be stored in the sediment and therefore removed from the CO_2 ocean-atmosphere exchange. On a longer time perspective, **marine sedimentary archives** contain the best, longest and most continuous record of past global environmental changes. Understanding the **present day sedimentary processes** is essential to better assess the significance of the past climatic and paleo-environmental signals preserved in the sediment and how the **climatic evolution of Earth** has determined modern deep-sea ecosystems.

(3) Sedimentary processes in the ocean determine the formation of **mineral and energy resources**. Oil and gas resources result from the maturation of **organic matter** trapped in ancient marine sedimentary rocks leading to the formation of hydrocarbons that, after migration, accumulated in porous sediment layers and structures from where they are currently exploited. Furthermore, the last two decades have seen the **move of the hydrocarbon industry to the deep ocean** where energy resources are being increasingly exploited. The deep ocean is, also for the hydrocarbon industry, one of the very last frontiers on Earth targeted to ensure future energy supplies to our society. Exploiting deep ocean resources has various environmental implications concerning the **deep-sea ecosystems** that so far have been poorly investigated by independent research consortia. **Gas hydrates** trapped in marine sediments constitute the largest fossil C accumulation on Earth, are a potential future energy source and could lead to the catastrophic landsliding of ocean margins would the on-going near-bottom water temperature rising trend trespass the hydrate destabilization threshold.

Submarine landslides could behave as tsunamigenic sources or could add to tsunamigenic potential if combined with earthquakes best illustrate the contribution of sedimentary processes to **geohazards**. Several studies have shown that tsunamigenic submarine and coastal earthquakes often have a contribution by landslides triggered by the earthquake. Amongst many others, this was the case for the destructive Lisbon tsunami of 1755, the Amorgos 1956 and Gulf of Corinth 1963 tsunamis in the Mediterranean Sea, and also for the most recent Boumerdes earthquake of May 2003 that not only generated a tsunami impacting the Baleares where hundreds of boats sank, but also numerous submarine cables offshore Algeria were cut by landsliding sediment masses. Such catastrophic events are often harmful to marine ecosystems on the continental slopes and shelves; however, their immediate consequences are rarely assessed. Geohazards are notoriously **difficult to predict** because of their episodicity and wealth of potential triggers, so that viable **risk assessment and hazard mitigation** depend on a clearer understanding of the causes, distributions, and consequences of such natural events.

The objectives of the Sediment Dynamics & Geohazards theme and, therefore, of this workshop, are (1) evaluating the state-of-the-art of current scientific knowledge on sedimentary processes and geohazards, with the focus on Europe's ocean margins and basins; (2) identifying the most relevant sedimentary processes in terms of impact on the deep-sea ecosystem, climatic relevance, interest for activities related to the exploitation of deep-sea resources, and risks they may pose; (3) to formulate technological needs and propose best research strategies on sedimentary processes and geohazards with the focus on subseafloor sampling potential contributions; and (4) contributing to the definition of an European scientific research strategy on deep-sea ecosystems including subseafloor sampling for the next decade.

The aims announced above will be achieved by (1) identifying scientifically outstanding individuals from Europe and abroad with recognized skills and vision on sedimentary processes and geohazards to form a "task force"; (2) to organize up to two devoted workshops by the "task force" members to address and reach consensus on the keys points covered by objectives 1 to 3 above; (3) to implement a devoted session as part of the international conference addressing objective 4 above; and (4) to contribute to the position paper resulting from that conference.

Results and Discussion (workshop minutes)

22nd February

15:20 **Introduction and tour of the table presentations**
15:28 **Nomination of G. Lastras as rapporteur of the workshop**

15:30 **Framing presentation by M.Canals**
Reminder of the DS3F background and history. Workpackage (WP) organization. Theme objectives of WP4 on Sediment Dynamics and Geohazards. Work to be done within the WP. What is expected from this workshop.

15:47 **A. Pusceddu**
Everything you always wanted to know about geosphere-biosphere interactions along continental margins. **1.** Climate-driven effects on deep-sea ecosystems. Primary production, vertical fluxes, and other relevant aspects vs. alteration of ecosystems after Dense Shelf Water Cascading (DSWC). Interruption of DSWC occurrence could mean stop of exportation of C to the deep-sea. Could bring changes in faunal abundance, biomass, biodiversity, but also to ecosystem

functioning. **2.** Impact of changes in frequency of episodic events in microbial foodwebs and associated biogeochemical fluxes. **3.** Shifts in deep-sea ecosystem due to reiterative or increased episodic events. **4.** Increase of hypoxia due to climate-related changes occurs in shallow water. Does canyon morphology control or mitigate changes in oxygen and food to the deep-sea? **5.** Canyons are places where biodiversity is different, host peculiar communities. Why? Link limitation versus open slope? Do canyon ecological connections exist? Do they produce biodiversity, or accumulate it? Do they regulate the diversity of a region? **6.** Heterogeneity. Presence of microhabitats can produce different communities in a scale of hundreds of metres. Each of some particular deep-sea geomorphological features host totally different species. What characteristics explain this changes? **7.** Slide versus stable slopes, they have a similar biodiversity (number of species) but totally different species composition. Why does this occur in sediments slided thousands of years ago? **8.** Ecosystem function vs. biodiversity has an exponential relation. If biodiversity decreases, will ecosystem function collapse? Does vulnerability change with sediment dynamics, morphology, etc? **9.** Canyons are more vulnerable, but if you decrease the scale of observation, this does not happen. **10.** Ocean acidification has reached the deep-sea. Sudden shift in environment for organisms. Interference with primary production? What will be the effect?

Most of the points were discussed at the relevant time during the presentation.

16.47 **P. Weaver**
1. Climate change/anthropogenic activity vs. landslides. Will they increase? Flows triggered by extreme flood events (typhoon). Flows triggered by hydrate dissociation. **2.** Are giant landslide scars really stable? Saharan slide scar reactivated 2 ka ago. What would be the outcome of Storegga scar reactivating? Why retrogression stops at a given point? **3.** Travel distance of turbidity currents along low slope gradients. How does this occur? Also, vs. long run-out of landslides. How does the transformation process occur between a landslide and a turbidity current? **4.** Modelling tsunamis from retrogressing landslides? Cores indicate significant time interval between subunits deposited during retrogressing slides in the Canary Islands.

Most of the points were discussed at the relevant time during the presentation, including a long lasting discussion about weak layers. It was also discussed for how long a turbidity cloud stays in the water column and how does this affect the deep-sea ecosystem.

17.28 Break.

17.55 **M. Canals and G. Lastras**[1]
1. Significance of DSWC and other dense near-bottom flows in shaping the seafloor? **2.** Why do canyons develop and evolve into both sediment fed and starved margins? **3.** What is the meaning of gullies? **4.** Recycling of fossil organic matter due to erosion of older strata? **5.** How to be there when things happen? **6.** Physical oceanography vs. slope instability. **7.** Fluid flow vs. seafloor destabilisation. **8.** What is the paper of weak layers? **9.** Is there a memory in the sediment? **10.** Unsourced megaturbidites. **11.** Seafloor heterogeneity.

[1] Since Vitorino, who was just disembarked, asked for his talk to be re-scheduled for the next day, the talk by Canals and Lastras was re-located in the schedule and offered the first day instead of the second.

Various points were discussed during the presentation, in particular the ability of dense water flows of different nature to carve erosive channels at various depths.

19:00 **J.S. Laberg**
1. Frequency of submarine landslides affecting the Norwegian margin. How to identify the number of landslides? There are more records observed in turbidite deposits in the deep sea than scars in the continental margin. Also, problem related to extrapolation of sedimentation rates to date deposits older than the limit of 14C dating. Also, tsunamis dated to periods when no known submarine landslides have occurred. **2.** How do the sediments move? Also, how movement starts, what is the velocity, why some are tsunamigenic and others are not? **3.** What is the origin and properties of weak layers?

Amongst the points were discussed during the presentation the dating problems of paleo-landslides and paleo-tsunamis received particular attention.

19:41 **M. Vanneste**
Link between fluid flow / oil industry / slope stability. More data reveal more geohazards. Presentation of C-Dog project, study of areas showing sediment instability, at different water depths. Geohazards in fjords. Onshore-offshore relationships. Modeling of landslides, variety of models for a complex environment. Parameters needed for a good modeling, and then as input for tsunami modeling. Impact of landslides on infrastructures. How to infer, detect and quantify excess pore pressure? Gas hydrate vs. reservoirs and vs. slope failures.

The onshore-offshore relationships, especially in settings such as fjords, and the excess pore pressure issue received particular attention during the discussion.

20:20 **E. Gràcia**
1. Marine paleoseismology. **2.** Overview: On- & Off-fault paleoseismic evidence in the South Iberian Margin. **3.** Pressing questions and topics: **3.1.** Identification of earthquake ruptures of the seafloor. **3.2.** Obtention of vertical and horizontal slip per EQ event (co-seismic slip). **3.3.** Linking offshore earthquakes with submarine faults. **3.4.** Using mass-transport deposits (MTDs) to characterize earthquakes. **3.5.** Tsunamigenic potential of seismogenic faults and related slides. **3.6.** Contribution to Seismic and Tsunami Hazard Models. **3.7.** Fluid escape and benthic habitats related to active fault areas

The discussion on the relevance of paleo-seismology studies and how their results could be utilized in practice for present-day risk assessment, specially at places where recurrence periods are long to very long.

23rd February
08:56. **V. Likousis**
1. Shallow-coastal submarine failures. Recurrence and frequency? **2.** Impact of retrogression in coastal zones. Tsunamis. Historical changes in the coastline of the Gulf of Corinth. Sand layers (tsunamites) in cores obtained in the deep basin. Small individual events but big when estimated over specific periods of time. Proposed “failure activity” in continental margins by total volume failure over period and slope area. **3.** DSWC, sediment dynamics, ecosystem functioning and benthic biodiversity.

The discussion focused on very active continental margins and on the evidence provided by historical records and observations, in view of the excellent examples included in the talk (mostly from Greek margins).

09:35 **J. Vitorino**[2]
Slope circulation processes. **1.** What is the role of slope-intensified currents in sediment transport? **2.** Impact on bottom conditions of slope currents (either on sediments or gas hydrates)? **3.** Which is the level of connection of slope circulation (e.g. North African Atlantic towards the Iberian margin)? **4.** Is canyon dynamics building areas of poor slope stability? **5.** Which are the links between flushing events and atmospheric patters and global change? **6.** How canyons modulate sediment transport in nearby shelves? **7.** Role of internal waves on the sediment erosion at the continental rise and abyssal plain? **8.** Potential classification of canyons depending of upslope/downslope movements, cascading and other hydrodynamical processes.

The discussion turned around the influence of deep margin circulation and hydrodynamics on deep-sea sedimentation, and on the effect of the seafloor topography over the near-bottom circulation.

10:25. **P. Puig**
1. Interaction of internal waves with the continental slope. Intermediate nepheloid layer detachments due to impinging internal waves in the slope, and their relation to deep-sea populations. **2.** Storm-induced gravity flows in submarine canyons. Moderate storms and cascading combine to export particles along the canyon. **3.** Liquefaction by excess pore pressure, preparing sediment for transport. Wave-supported sediment gravity flows (see Rogers and Goodbred, 2010). **4.** Deep-sea trawling activities in canyon rims vs. resuspension and sediment gravity flows. Daily gravity flows! Signal observed in sediment cores. **5.** Which processes trigger benthic storms in the deep environment? **6.** Which processes generate and maintain nepheloid layers in the deep environment? Not only by resuspension. **7.** Links between DSWC and deep-sea populations? e.g. collapse of deep-sea shrimps during major dense water cascading effects. Does DSWC promote demersal fisheries worldwide?

The influence of extreme events, such as storms and DSWC, on gravity flows in submarine canyons, the role of excess pore pressure in liquefying sediments this easing their transport by bottom currents, and the anthropogenic impacts on deep-sea sedimentations and slope stability received particular attention during the discussion.

11:55 **S. Heussner**
Understand (processes) and quantify (fluxes). **1.** Cross sediment dynamics with space and time: questions can be identified that need answers in multiple cells of this 3d plot. Overarching questions have to be identified governing natural variability from seconds to millennia. Upscaling? Priority need for interdisciplinary integration. Small-scale spatial variability hides temporal variability. **2.** Cross sediment dynamics with habitat/biodiversity and ecosystem functioning. **3.** Cross sediment dynamics and man: societal implications. e.g. impact on sediment delivery via river discharge.

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[2] See note 1.

The discussion focused on the various time and space scales to be integrated for a more complete understanding of the relationships of the physical processes and their impacts on the ecosystem, particularly in view of the strong natural variability and man-induced forcings.

12:45 **N. Sultan**
1. What is triggering slope failures on the European Continental Margin? **2.** What is the variability from one site to the next? **3.** Why will one region of seafloor fail while neighbouring regions remain undisturbed? **4.** What are the factors that determine where a slope failure will occur? **5.** What determines the location of the slip planes? **6.** What is the role of gas hydrates in slope stability?

Following the talk's contents the discussion focused on some of the most basic questions that require a better understanding to make further progress on slope stability assessment and prediction including current hazard analysis schemes and danger characterization procedures and methods.

13:30 **K.F. Forsberg**
1. Submarine slides. **1.1**.High-quality geotechnical samples/measurements. **1.2.** Pore pressure measurements. **1.3.** Slide runout: model calibration. **1.4.** How are slides on low angle slopes triggered? **2.** Overpressure: understanding the plumbing. **2.1.** Fluid flow predictions, e.g. fracturing vs. intergranular flow. **2.2**. Relationship between hydrate/BSR and fluid flow? **3.** Gassey sediments. **3.1.** Behaviour of sediments containing gas. **4.** Future changes. **4.1.** Climate change: influence of sea level rise on sedimentary dynamics. How good is our ability to predict the consequences e.g.: access to erodable sediments, increased canyon activity, increased slide activity.

The significance of meaningful in situ measurements and subsequent modelling to assess slope stability was particularly stressed during the discussion, which also covered the role of fluids on sediment destabilisation and the likely impacts of the on-going climate change.

14:25 **Extended discussion, summing-up and closure of the Workshop**
It was agreed by the participants that since long and to the point discussions had already taken place during and after each presentation, and also in view of the late hour[3], it was not necessary to re-open a long discussion. Instead, a summing-up of the presentations and a review of the main questions raised during the workshop were made by the organizer (M. Canals), which was followed by specific comments by some of the participants.

The general appreciation was very positive and all participants considered the workshop worth, timely and extremely beneficial as it covered a broad range of related frontier topics on Sediment Dynamics and Geohazards that are very uncommonly addressed altogether in a single meeting, so that the workshop was also considered a learning experience by all participants.

The workshop was subsequently closed at 14:45 hours, local time

[3] Some of the participants had their flights back home leaving from Barcelona airport at about 60 km distance in the late afternoon / evening.

Areas where European scientists are strong

1. In situ observation of on-going sediment transport processes and their effects on the seafloor, from sediment-laden currents to landslides (further development would highly convenient as well).

2. Acoustic imaging of the seafloor and the subseafloor, and subsequent integration with drilling, coring and in situ testing data.

3. Shallow in situ measurements of sediment stability parameters further development would highly convenient as well, in particular to reach greater subseafloor depths).

4. Assessment of the role of gas hydrates and fluid flow on slope stability.
5. Geosphere-biosphere links along continental margins, as related to sediment transport events and processes that may lead to the generation of seafloor heterogeneity and, eventually, trigger geohazards

6. Role of climate change and anthropogenic activities on sediment transport events, sediment destabilisation and, ultimately, seafloor shaping (further development would highly convenient as well).

Section 4 (link to WP7 and WP8)

Technological requirements for sub-seafloor sampling and measurements identified

1. Drilling and coring tools providing large volume, high quality samples for geotechnical and other purposes.

2. Long-lived, resistant in situ observation tools providing key parameters on large-scale sediment transport events from dense flows to landslides, including pre- and post-event situations. These observatories may range from moorings to benthic stations to OBSs to seafloor deformation, fluid flow and seepage, and hydro-mechanical behaviour sensors.

3. VHR mid to deep-penetrating 3D and 4D acoustic imaging techniques.

4. Long-term borehole instrumentation to better understand the basic mechanisms behind marine geohazards and, in general, shallow Earth processes.

5. Quick event response instrumental packages, easy to mobilise, to be rapidly deployed during or after a major events has occurred.

Emerging infrastructure needs identified

1. Long-term in situ observatories serving to the assessment of massive sediment transport events and geohazard-triggering events at faults and unstable slopes.

2. Observatory networks at various spatial scales (e.g. European scale but also at specific slope segments).

3. Usage of opportunity vessels (e.g. fishing vessels, cargo vessels, ferries) for continuous monitoring of the water column and the seafloor at key areas (e.g. straits, active submarine canyon systems, unstable slopes).