

Shallow Gas Studies of the Gulf of Lion, Including the Rhone Delta and Cap De Creus Canyon Head

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LONG-TERM GOALS

To enhance and expand our understanding of the inter-relationship of shallow gas, seafloor morphology, and seafloor/shallow sub-surface acoustic properties. To continue our successful collaboration with our EuroSTRATAFORM colleagues through gas sampling during 2004 and 2005 Gulf of Lion (GoL) cruises, post-cruises analysis, interpretation, and integration with geophysical data sets. The main Institutions we have collaborated with are: CEREGE, France; U.S. Geological Survey, USA; ISMAR-CNR, Italy; Fugro Surveys Ltd., UK; and Univ. Laval, Canada.

We also would like to compare the GoL system with other areas worldwide and augment this dataset with an industry data set from the eastern Mediterranean we have been studying for the last 3 years. Our two main topics of interest are the origin and evolution of “crenulated seafloor” (wavy bedforms, slope failure features, or a combination of the two), and the distribution and effects of shallow gas on both the seafloor and the shallow sub-surface.

OBJECTIVES

To understand how the shallow gas and the flood events control are inter-related in the GoL system through the integration of mapping and coring. Previous ONR work in the Adriatic showed that the Po flood deposits resulted in a localized region of high organic matter deposition, and that the rapid accumulation of flood deposits removed the organic matter from the reach of physical and biological re-working, leading to high concentrations of shallow gas. Our goal in the GoL was to determine if this model would also hold for the Rhone system, which experienced a large flood in December, 2003.

Specific detailed sites of interest in the GoL include the Grand Rhône prodelta (inferred to be the main source for organic matter and therefore potential gas), along the western coast of the GoL (the circulation patterns, satellite and shuttle images as well as models indicate that this is the main pathway for flood-derived material) and in the Cap de Creus canyon, where flood sediments may be transported off the shelf (see Figure 1).

We were also interested in interpreting the available geophysical data that suggested anomalies due to gas-prone sediments, with follow-up coring to groundtruth that data through headspace analyses of gas. Our analyses of gas in the cores are combined with our colleague’s work on organic matter (ISMAR-CNR, Italy), sediment accumulation rates (CEREGE, U. Washington and TAMU), modeling (IFREMER, Duke U.) and current measurements and circulation (CSIC, Spain; U. Perpignan, France).

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14. ABSTRACT To enhance and expand our understanding of the inter-relationship of shallow gas, seafloor morphology, and seafloor/shallow sub-surface acoustic properties. To continue our successful collaboration with our EuroSTRATAFORM colleagues through gas sampling during 2004 and 2005 Gulf of Lion (GoL) cruises, post-cruises analysis, interpretation, and integration with geophysical data sets. The main Institutions we have collaborated with are: CEREGE, France; U.S. Geological Survey, USA; ISMAR-CNR, Italy; Fugro Surveys Ltd., UK; and Univ. Laval, Canada. We also would like to compare the GoL system with other areas worldwide and augment this dataset with an industry data set from the eastern Mediterranean we have been studying for the last 3 years. Our two main topics of interest are the origin and evolution of ?crenulated seafloor? (wavy bedforms, slope failure features, or a combination of the two), and the distribution and effects of shallow gas on both the seafloor and the shallow sub-surface.					
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In addition to our EuroSTRATAFORM work, we have continued our collaboration with Prof. Charles Holland (Penn State) in the analysis of possible gas at interpreted mud volcano sites in the Straits of Sicily (funded under a separate ONR program).

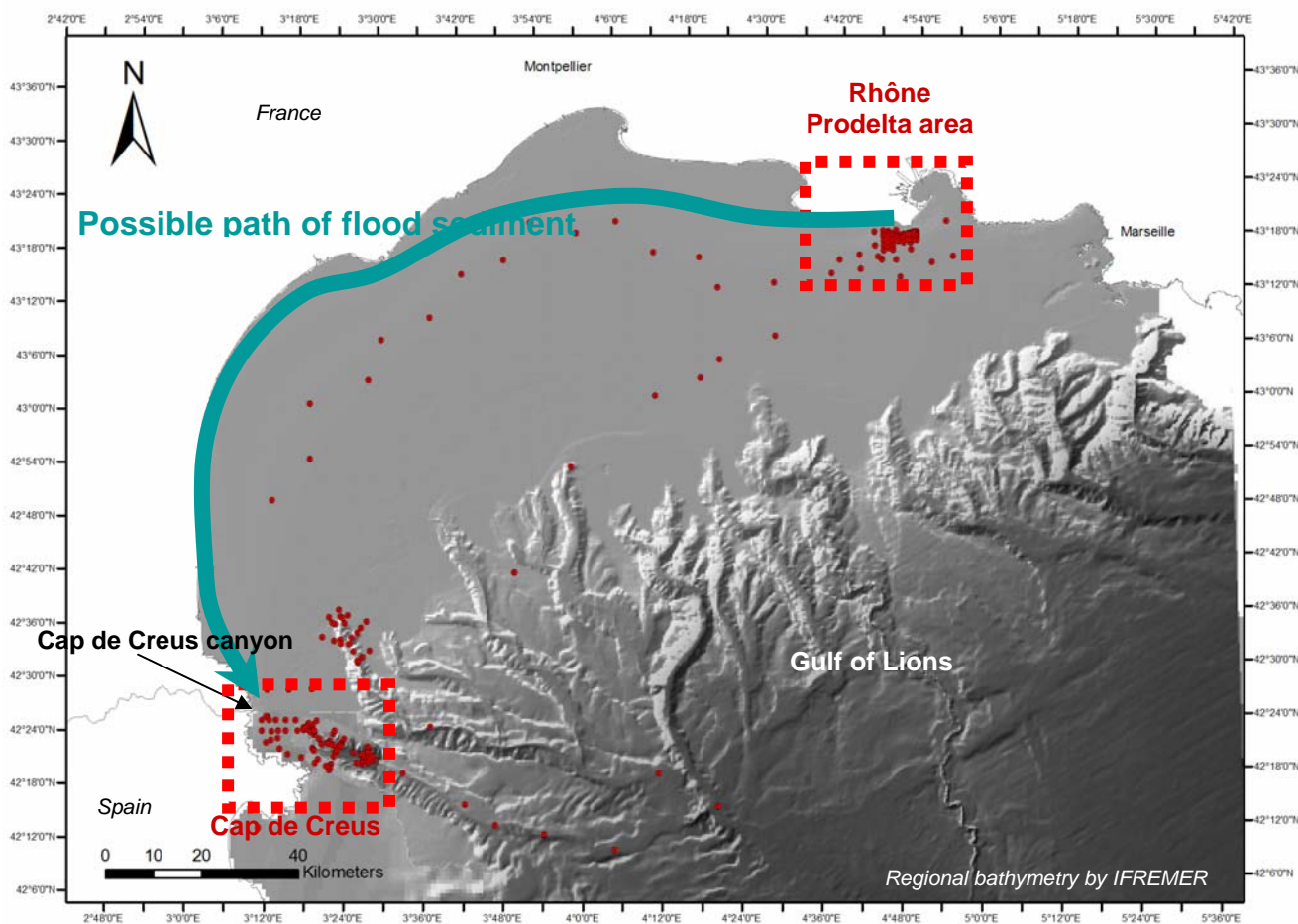


Figure 1. Cores taken for headspace gas analyses in several cruises during 2004 and 2005. Most of our work has been focused on the Rhône prodelta nad Cap de Creus areas. In the most recent cruise (May, 2005) we cored along the western coast to track the flood path.

APPROACH

Remote sensing and modeling suggested that from the Rhône area the flood sediment is carried southwest along the shelf, and that the canyons in the southwest GoL, including the Cap de Creus (CdC) canyon, act as primary escape routes for the flood sediment. To evaluate the link between flood sediment and shallow gas formation, we analyzed cores from the Rhône prodelta, and compared our results with the analyses of sediment accumulation related to the recent flood. Our gas analyses were also compared with other EuroSTRATAFORM workers who are studying the organic matter and floc fractions.

Continuing our collaboration with Dr. Stefano Misserocchi at ISMAR-CNR, Bologna, Italy. ISMAR provides organic matter datasets where our samples for gas are being taken. We also continue our

collaboration with Dr. Chuck Nittrouer at U. Washington and Dr. Beth Mullenbach at TAMU whose studies in sedimentary rates help to understand how the GoL system works. In the Rhône prodelta area, Dr. Olivier Radakovitch at CEREGE provides sedimentary rates and Dr. Serge Berne at IFREMER provides models for the flood and geophysical background, both important studies to compare with our gas samples. In the Cap de Creus area, after mapping in high-resolution the head of the canyon in 2004, we knew where to core for gas and test our hypothesis.

All gas composition and isotope analyses have been, and will continue to be, carried at the U.S. Geological Survey under the direction of Dr. Tom Lorenson at no charge to ONR.

WORK COMPLETED

Grand-Rhône prodelta:

Working with our EuroSTRATAFORM colleagues, we identified a large number of coring sites on the Rhône prodelta, which were cored in March and October 2004. A total of 77 sites were analyzed for gas content (methane through hexane, C1-C6), CO₂, and H₂S by gas chromatography. Sites included areas of interpreted sediment accumulation related to the recent flooding, as well as sites where ADCP data suggested gas seepage out of the seafloor (Dr. Patrick Friend, SOC, UK). A subsequent analysis of the change in bathymetry related to the flood deposit was carried out by Dr. Serge Berne, IFREMER, France, and compared to the sampled sites. An additional 12 sites were analyzed during two additional cruises to the Rhône prodelta in February and May, 2005. The results of the analyses for the 2005 cores are still pending.

The Cap de Creus canyon head:

In March, 2004 AOA Geophysics Inc. and Fugro Survey Ltd. acquired a high-resolution map of the Cap de Creuse canyon head at no charge to ONR. These data, which include multibeam bathymetry, multibeam backscatter, and sub-bottom profiler data in a GIS environment (plus Fledermaus fly-throughs) have been circulated on a DVD to colleagues. These DVDs have been made available to all EuroSTRATAFORM scientists, and serve as a basemap for anyone working in the CdC area. We have distributed an additional 50 DVDs to the scientific community so far.

Again, working with our EuroSTRATAFORM colleagues, we identified a large number of coring sites in the Cap de Creus canyon, which were cored in October 2004. A total of 56 sites were analyzed for gas content (methane through hexane, C1-C6), CO₂, and H₂S by gas chromatography. Sites include transects both across canyon and down-canyon. An additional 88 sites were analyzed during two additional cruises to the Cap de Creus canyon in February and May, 2005. The results of the analyses for the 2005 cores are still pending. Sites were selected to target morphological regions identified on the bathymetric data, as well as sites where the sub-bottom profiler data suggested potential gas.

RESULTS

Grand-Rhône prodelta:

Many of the Rhône cores show anomalous concentrations of methane (up to 87440 ppm; see Figure 2a). Compositional and isotopic analyses of the gas support a microbial origin although there are a few sites that show relatively heavy $\delta^{13}\text{C}$ values (-53 per mil) suggesting a mixed source for the gas. Anomalous methane concentrations have been evaluated and integrated with organic carbon data, sedimentary rates and ADCP profiles. All of the highest gas concentrations of gas were found directly

off the river mouth where the models and mapping indicate the thickest accumulation (> 2 m) of sediment related to the flood event. Sampled sites include locations where previous surveys identified acoustic anomalies in high-resolution seismic profiles which may be related to the presence of gas (see Figure 2b). With the interpretation of the collected data we will be able to discuss the nature of shallow gas off the Rhône delta and its association with shallow and seafloor acoustic properties and recent sedimentary dynamics.

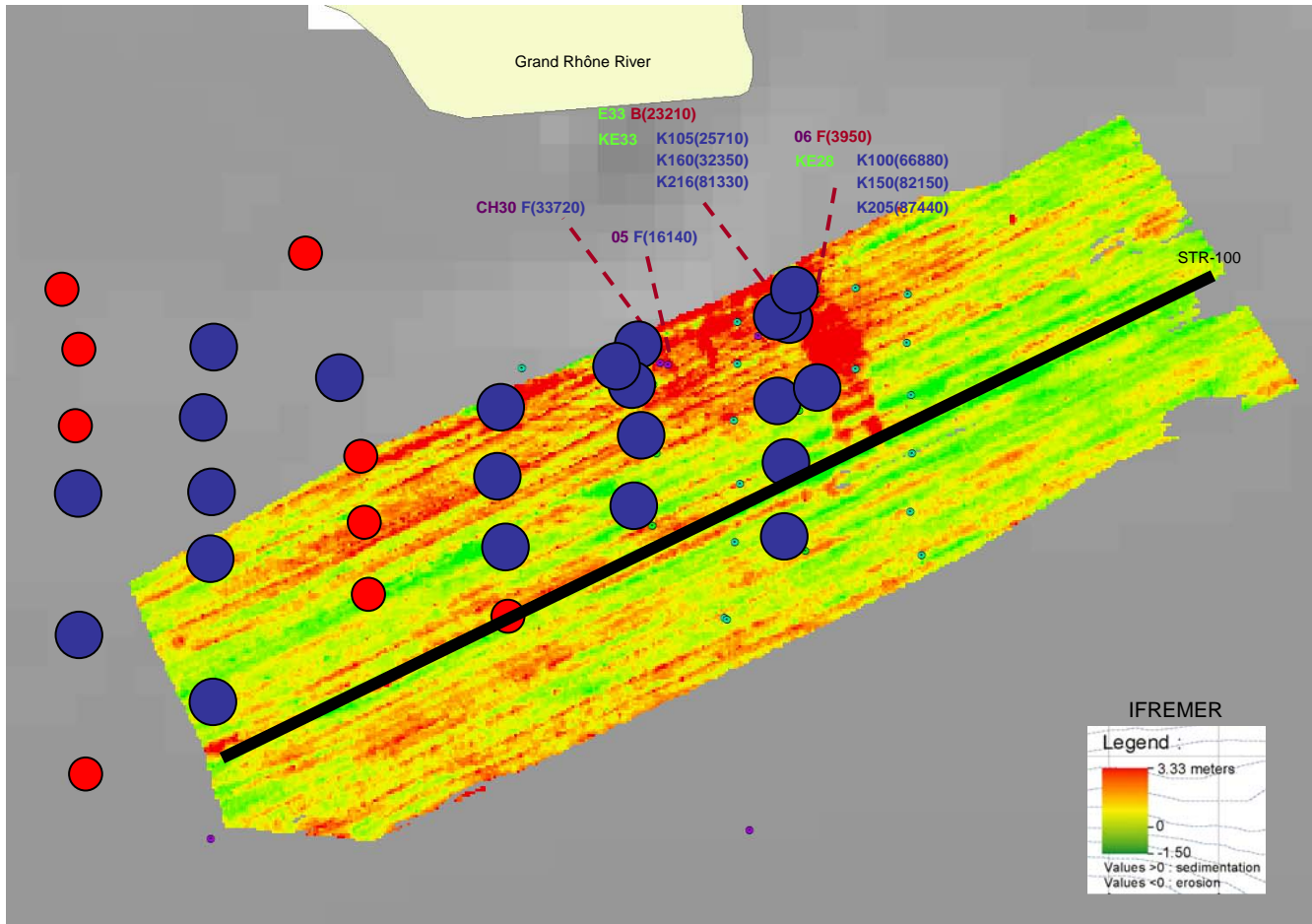


Figure 2a. Cores taken for headspace gas analyses off the Rhône prodelta. Sites with methane content between 100-1000 ppm are shown as red dots, sites with more than 1000 ppm (up to 87440 ppm) in blue. Notice the highest contents are related to the highest sediment accumulation rates due to the flood (shown in red in the IFREMER mapping). High-resolution seismic line STR-100 shows acoustic anomalies due to gas within the sediments (Figure 2b).

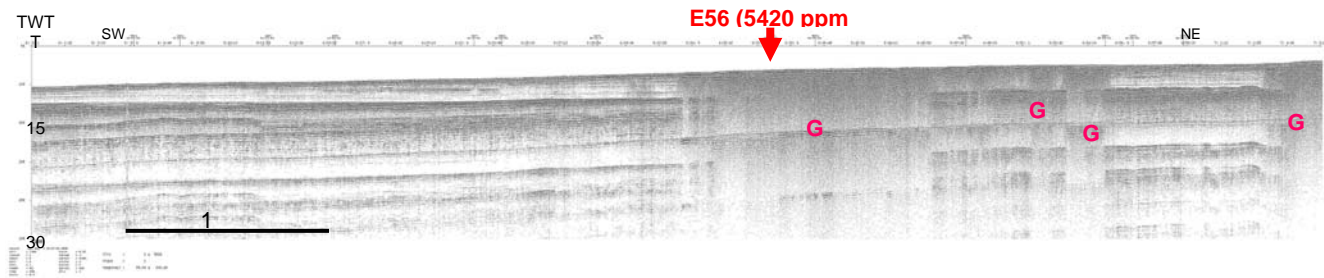


Figure 2b. Seismic line STR-100 off the Rhône outlet (data courtesy IFREMER). Acoustic anomalies, suggestive of shallow gas, are indicated with a 'G'. Site E56 was sampled with a box core, and yielded 5420 ppm of methane. Location of line shown in figure 2a.

The Cap de Creus canyon head:

Seafloor bathymetric data (Figure 3) show distinct morphologic domains in the canyon that we infer to be due to the different geologic processes that have shaped the canyon. Seafloor backscatter data show significant variations throughout the field area and appear to be related to changes in seafloor sediment type. Laterally restricted high backscatter zones are related to seafloor outcrops of over-consolidated sediment and to possible gas seeps. The analysis of the different echo characters in sub-bottom profiler data (distinct, indistinct, sharp, in step, chaotic, mounds and wavy echoes) provides a detailed understanding of the present seafloor and the recent processes that have shaped it.

The preliminary analyses of cores acquired in the canyon show relatively little shallow gas in the core samples (Figure 3). Samples with anomalous gas (up to 715 ppm of methane) are limited to the northern flank of the canyon, where the samples also show higher amounts of organic matter and the seafloor suggests recent sediment drape. The southern flank and the canyon thalweg show no anomalous gas in any of the samples taken so far (all < 90 ppm of methane) although sediment accumulation rate studies indicate relatively high (but spatially variable) rates of accumulation in the canyon axis. Our working hypothesis is that away from the flood-related sediments off the Rhône delta (where methane content is up to 87440 ppm) the organic matter is being reworked and remineralized on its way along the western coast of the Gulf of Lions, so that the recent deposits in the canyon contain little reactive carbon. The anomalous samples on the northern flank may be related to methanogenesis of older sidewall canyon infill.

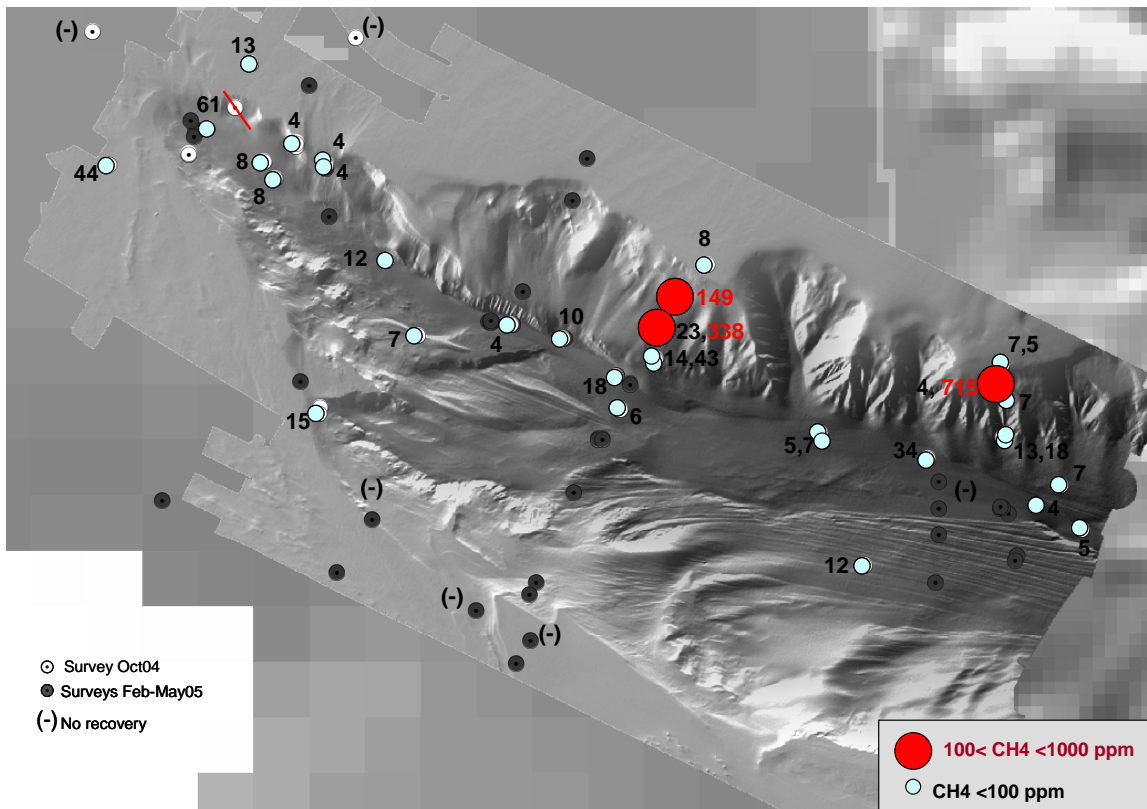


Figure 3. Cores taken for headspace gas analyses in Cap de Creus, with the values of methane shown in ppm. Sites with anomalous methane content (>90 ppm) are shown in red. Analyses of sites sampled in 2005 (dark dots) are still in process. Note the highest gas samples are located on the northern flank of the canyon, but that even these samples are low when compared to the Rhône prodelta.

IMPACT/APPLICATIONS

The Rhône mapping and sampling program provide data consistent with the model developed as part of our earlier EuroSTRATAFORM work off the Po in the Adriatic. We propose that in the Rhône prodelta, flood deposits deliver significant amounts of terrigenous organic matter that can be rapidly buried, effectively removing this organic matter from aerobic oxidation and biological uptake, and leading to potential methanogenesis with burial. In areas unaffected by this high flux of organic matter and rapid/thick flood deposition, or in between flood events, the conditions for methanogenesis and gas accumulation have not been met. In these areas, the physical and biological reworking of the surficial sediment may effectively oxidize and mineralize organic matter and limit bacterial methanogenesis in the subsurface (see Figure 4). Now that we have shown this model to be consistent for the Po and the Rhône, we suggest that the model can be extrapolated to other flood-related shallow environments worldwide to explain and understand the occurrence and distribution of shallow gas. This model, and its implications for methanogenesis, may provide an important baseline for understanding seafloor acoustic and geotechnical properties, and the potential for gas-related failure of near-surface sediments. This model also has implications for carbon cycling and climate change.

Our mapping program in 2004 in the Cap de Creus area (conducted with AOA Geophysics and Fugro Survey Ltd.; Figure 5) was key to understanding the recent processes in the Cap de Creus canyon, and provided a detailed base map for all of the subsequent EuroSTRATAFORM coring and mapping in the

canyon. This image appeared on the cover and back of the special issue of *Oceanography* in December 2004 (Figure 5). This special issue highlighted the EuroSTRATAFORM program.

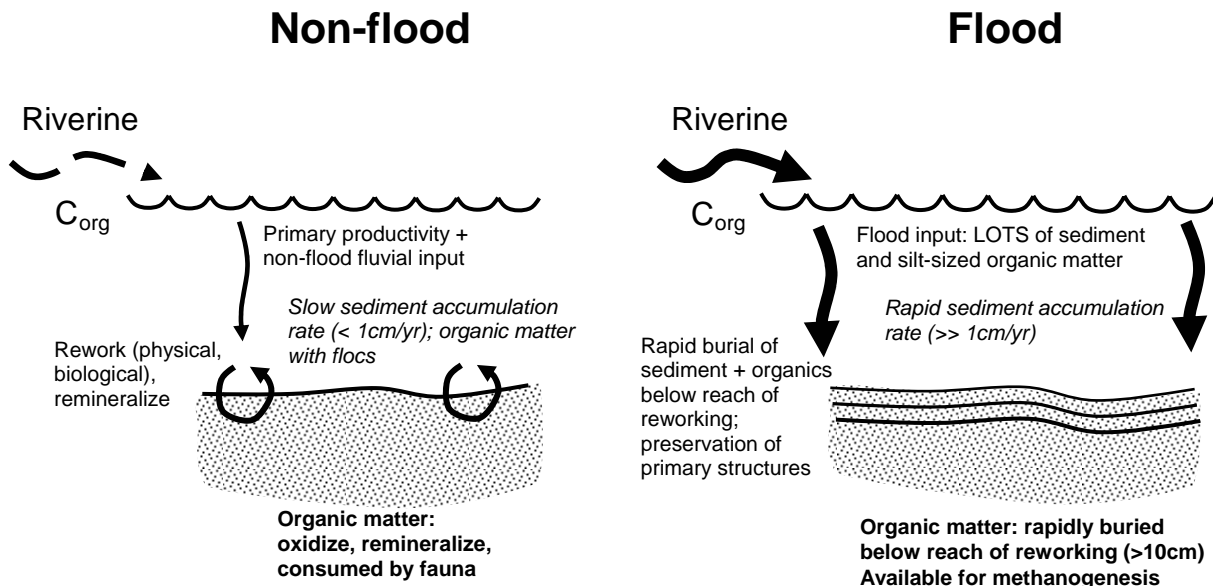


Figure 4. Schematic diagram showing the relationship between sediment delivery, reworking, organic matter burial, and methanogenesis. During non-flood times, organic matter may be delivered by both fluvial processes and primary productivity. Organic matter may settle to seafloor as flocculated material. The relatively low sediment accumulation rate allows physical and biological reworking processes to consume or oxidize the organic matter, leading to relatively little organic matter availability for biogenic methanogenesis. During flood events, in contrast, rapid and thick accumulation of particulate organic matter and sediment may effectively isolate organic carbon from physical or biological reworking, leading to enhanced methanogenesis in the actively accreting foreset / topset portion of the delta.

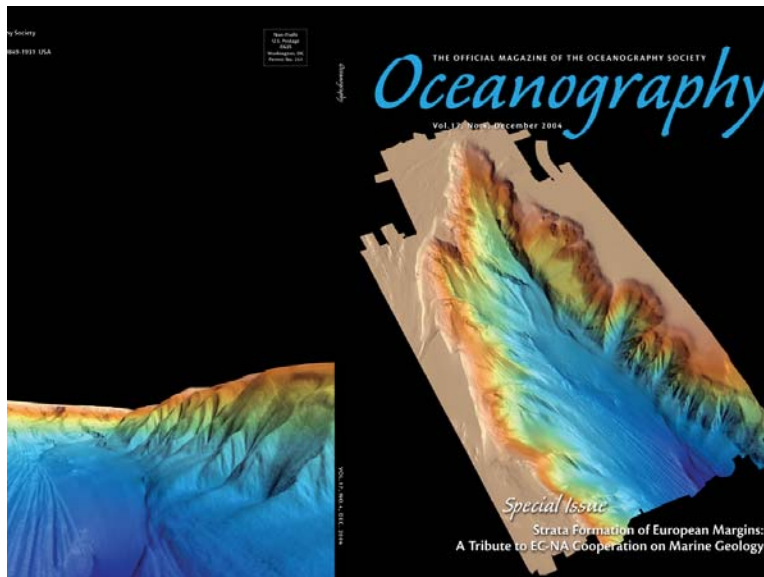


Figure 5. The cover of *Oceanography* (December, 2004) showing high-resolution multibeam images of the CdC. This 2004 survey, conducted by AOA Geophysics and Fugro Survey Ltd. was of great help for further scientific plans and was key to deciding where to core for all subsequent cruises.

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