Proposal 101

The Rhone delta submarine canyons: Geomorphological, stratigraphical and sedimentological evolution

Stéphanie Girardclos, Pablo Corella: Dept Geology and Paleontology and Institut des Sciences de l'Environnement, Université de Genève, 1205 Genève, Switzerland; stephanie.girardclos@unige.ch; Pablo.Corella@unige.ch

Flavio S. Anselmetti and colleagues: Eawag, Department of Surface Waters, 8600 Dübendorf, Switzerland; flavio.anselmetti@eawag.ch

Description: 'The canyons of the Rhone delta' is a research workpackage of the Elemo scientific program (http://www.elemo.ch). This research project is focussing on the proximal Rhone delta area, characterized by a complex underwater morphology with a slope deeply incised by submarine canyons (Sastre et al., 2010; Fig. 1). The proximal Rhone delta area constitutes an excellent laboratory to: i) understand the triggering mechanisms controlling the location, shape and stability of the canyon walls; ii) establish an age model for the aggradation and migration patterns of the different Rhone delta lobes; iii) characterize the sedimentary and geochemical evolution of the canyon beds/levees sedimentary sequences; iv) evaluate the role of anthropogenic activities and climate affecting sedimentation of the Rhone river during the last centuries.

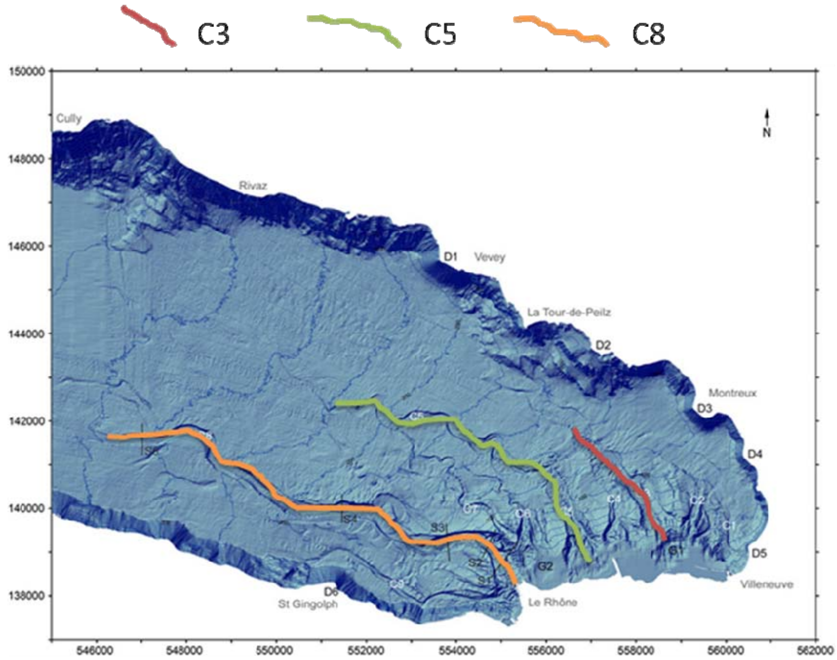

***Fig 1**: Multibeam bathymetric map (modified from Sastre et al., 2010) and location of the studied canyons. C8 (modern, active canyon) ; C5 (modern, active before Vieux-Rhone river correction); C3 (older, non-active canyon)*

The research strategy consist of a multiproxy approach - including geomorphological, sedimentological and geochemical analyses - to investigate the sedimentary dynamics and geomorphological and stratigraphical evolution of both, modern (C8, active) and older canyons (C3 and C5, non-active; Fig. 1). Submarine surveys in these sub-environments, complemented by regular sediment-coring campaigns from research vessels, will provide a wide range of valuable data:

- In-situ observations of sediment structures such as ripples, dunes, scars, furrows, etc, superficial sediment sampling and high-resolution multibeam bathymetric data will enable to carry out a detailed geomorphological and sedimentological mapping of the submarine canyons.
- Sub-horizontal sediment coring along different vertical profiles in the canyon walls, and regular sediment cores in the canyon beds and levee structures (Fig. 2), will be crucial to achieve an adequate dating and characterization of the deltaic sequence and to compare sedimentation rates in modern

and older canyons. The chronology will be based on AMS ^{14}C dating and $^{210}Pb/^{137}Cs$ activity. In addition, 3D optical imaging in the canyon walls will also provide a link between the coring sites and the wall stratigraphy. Subsequent detailed lithological and geochemical analyses will be performed in sediment cores to characterize sedimentation in the canyon beds/levee structures. CTD measurements will complement these data recording limnological changes in the water column.

The expected results from this research project will offer a remarkable opportunity to characterize the sedimentological and geomorphological evolution of the Rhone delta submarine canyons. Furthermore, this study will contribute to i) acquire a better comprehension of the Rhone delta stratigraphical architecture and ii) understand the sedimentary processes affecting this complex deltaic system.

Reference:

Sastre, V. et al., 2010. Morphology and recent history of the Rhone River Delta in Lake Geneva (Switzerland). Swiss Journal of Geosciences, 103: 33-42.

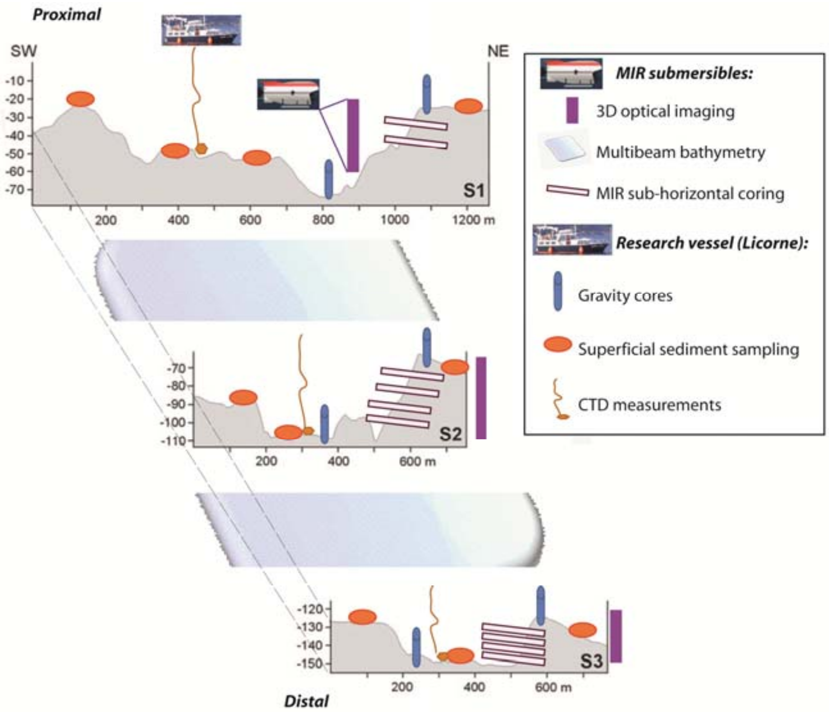

Fig 2: *Schematic diagram of the multiproxy sampling strategy during the « Elemo-MIR » survey (canyon C8)*

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Involved scientists: Stéphanie Girardclos[1] (PI), Flavio S. Anselmetti[2], Pablo Corella[1], Jean-Luc Loizeau[3], Michael Sturm[2]

1 Dept Geology and Paleontology and Institut des Sciences de l'Environnement, Université de Genève, 1205 Genève, Switzerland
2 Eawag, Department of Surface Waters, 8600 Dübendorf, Switzerland
3 Institut F.-A. Forel, Université deGenève 10 route de Suisse, Case Postale 416, 1290 Versoix, Switzerland

E-mails:stephanie.girardclos@unige.ch ; flavio.anselmetti@eawag.ch; Pablo.Corella@unige.ch; Jean-Luc.Loizeau@unige.ch; mike.sturm@eawag.ch

More information under :
http://www.unige.ch/sciences/terre/geologie/people/persoPages/Girardclos_en.html
http://www.eawag.ch/organisation/abteilungen/surf/schwerpunkte/sedi/index_EN

Proposal 102

Tracer release experiment for studying intrusions from the mixed boundary layer into the interior over sloping bottoms

Alfred Wüest and colleagues, Eawag (Alfred.wueest@eawag.ch); Eawag, Surface Waters - Research and Management, Seestrasse 79, CH-6047 Kastanienbaum, Switzerland
Phone Office: +41 (0)41 349 21 81

Scientific question / hypothesis / objectives: For understanding and modeling the vertical (diapycnal) mixing of water constituents on a basin-scale, it is fundamental to know the communication pathway between the well-mixed bottom boundary layer (BBL) and the stratified interior. In this project, by using dye tracer, the question will be addressed, whether this exchange between BBL and interior occurs by “intrusions” or by “turbulent entrainment”. We will investigate the question on how a substance, residing in the BBL, is exchanged with the interior of a stratified water body. Is the substance turbulently diffused into the interior or does the BBL water form blobs of different densities, which form intrusions? The very different efficiency of these two processes will allow much more realistic modeling of vertical fluxes on a basin-scale. Such experiments are extremely difficult to perform, as by “fishing” from the surface (boat) controlling the position relative to the sediment is not feasible.

Although we have performed numerous measurements in BBLs using tracers, microstructure probes and acoustic current meters, which are documented in at least 20 peer-reviewed papers, we have only once been able to follow, partly, tracer originating from the BBL. Therefore, the above stated scientific question is still unanswered. Using a submarine is the perfect opportunity to explore the feasibility of such an approach.

Proposal 202

Degradation of organic material in Rhone delta related lake sediments

Carsten Schubert & Bernhard Wehrli, Eawag (carsten.schubert@eawag.ch)

Whereas countless studies on the transformation of organic material were performed in the marine environment (Hartnett et al. 1998) studies in lakes on the same topic are rather rare (Sobek et al. 2010). Understanding the preservation of organic material and the associated transfer of CO_2 into sediment deposits is crucial for correct budgets of carbon dioxide in the atmosphere (Cole et al. 2007). The here proposed study focuses on important research questions regarding the degradation or preservation of organic compounds like lipids, lignin, sugars, amino sugars and amino acids in the delta of the Rhone river in Lac Leman. The study will address the currently open question of how the patterns of formation and degradation of organic compounds are changing in the sediment of the lake when travelling from the coast (river inflow) to the more central part (no river influence). The fate of all these organic compounds in lacustrine systems is particularly poorly studied, and we will answer questions about the sources, turnover, and ultimate fate of these quantitatively highly important compounds. To answer these questions we will combine state of the art organic geochemistry and isotope geochemistry techniques with pore-water analysis of inorganic carbon and its isotopic signature using dialysis plates. Variations in concentration and isotopic signature will help to reveal sources, transformation, and preservation/ degradation behaviour of these compounds in sediments deposited throughout the delta from the inflow towards non allochthonous influenced central lake sediments.

Collecting sediments with the MIR will enable us to find sediments that are mostly undisturbed and therefore highly suitable for our project. Collecting these sediments with normal sampling techniques from the boat would not be possible or at least not in this quality. The MIR diving trips would give us the possibility to find exactly those sediments and sampling sites needed to answer our research questions.

Methods: We would use state of the art methods of gas chromatography and gas chromatography/mass spectrometry and high pressure liquid chromatography, as well as compound specific isotope ratio mass spectrometry. Isotope ratios on single lipid or amino compounds will enable us to make source specific interpretations, i.e., whether organic molecules derived from in the lake produced organisms (autochthonous) or constituents that derived from surrounding land (allochthonous).

The detection and quantification of organic molecules down-core will further enable us to tell the degradation state of those compounds and therefore sediments. Dating of those compounds/sediments will help in the degradation state determination. Analysing pore fluids allows us to quantify the degradation rates and pathways.

Proposal 207

Real-time mapping and measurement of methane ebullition and fate in the River Rhone Delta, Lake Geneva

David B. Senn, Eawag, Department Surface Waters Research and Management, david.senn@eawag.ch
Richard Camilli (WHOI), J Samuel Arey (EPFL)

Methane (CH_4) acts as a powerful greenhouse gas, and CH_4 emissions from lakes comprise approximately 15% of global natural emissions. We hypothesize that the Rhone River Delta is a local hot spot within Lake Geneva for CH_4 ebullition (i.e., bubbling) flux to the atmosphere, and that ebullition from this relatively small area constitutes a disproportionate fraction of the lake's CH_4 emissions. To explore this hypothesis, and to develop an improved understanding of CH_4 ebullition in river deltas, we will conduct a 1 year field study of CH_4 dynamics in the Rhone River Delta. A centerpiece of this study will be submersible-based techniques including: i) High-resolution mapping of ebullition zones along with delta bottom features; ii) Real-time 3-dimensional tracking of the delta's dissolved CH_4 plume using an in situ mass spectrometer, and precision water sample collection (e.g., for calibration and for $\delta 13CH_4$); and iii) Precision collection of sediment cores and placement/retrieval of devices for measuring porewater CH_4 along gradients of low-to-high ebullition zones. Combined with surface vessel measurements over the course of 1 year (e.g., vertically-downward oriented sonar for quantifying ebullition flux), this project will yield an unprecedented data set for characterizing the major factors that influence CH_4 ebullition flux in river deltas and the subsequent fate of dissolved CH_4, and quantifying the potential importance of CH_4 ebullition from river deltas to the atmosphere.

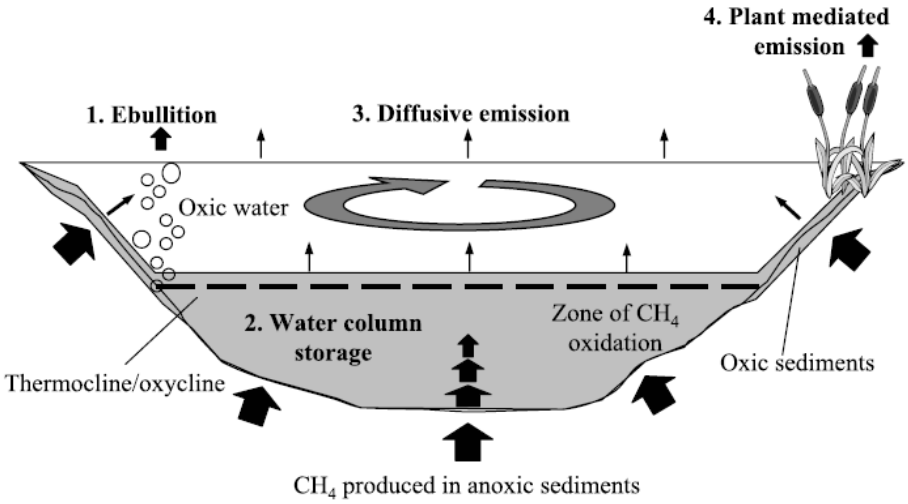

Figure 1 Sources and fate of CH_4 in lakes (Source: Bastivken et al., 2004). **I. Introduction and**

Background Methane production and fate: Methane (CH_4) is a potent greenhouse gas that is readily produced during the terminal degradation of organic matter in anoxic sediments. In the organic-rich, sulfate-poor, anoxic sediments of lakes, 10-50% of autochthonous (externally-sourced) and allochtonous (internally-produced) organic matter (OM) undergoes methanogenesis (Bastviken et al., 2008). Given the large surface area of lakes on a global scale and their key role in trapping particulate organic matter along the aquatic continuum from land to ocean, methane production in lakes is a quantitatively important pathway for carbon cycling at the global scale. In addition atmospheric CH_4 emissions from lakes accounts for ~15% of all natural CH_4 emissions (Bastviken et al., 2004).

Once produced in lake sediments, CH_4 can experience a variety of potential fates (Figure 1). When sediments are overlain by an oxic water column, most upward diffusing CH_4 undergoes oxidation as it diffuses across the oxic:anoxic interface. However, when the overlying water is anoxic, e.g., an anoxic hypolimnion, CH_4 diffuses freely into the water column and may accumulate to high concentrations. After deep mixing in seasonally stratified lakes with anoxic hypolimnia, this stock of CH_4 can exchange with atmosphere across the air:water interface or undergo oxidation in the water column (Bastviken et al., 2008; Schubert et al., 2010). Methane can also be released from the sediments via bubbles, i.e., ebullition (Bastviken et al., 2004; Ostrovsky et al., 2008). During bubble rise, some methane dissolves from the bubble into the water column (McGinnis et al., 2006). However, since ebullition occurs most strongly in shallow areas due to lower hydrostatic pressure, most of the CH_4 in rising bubbles is efficiently delivered directly to the atmosphere (e.g., ~80% for a 10 m water column and 2mm bubble diameter; McGinnis et al., 2006).

Ebullition flux has the potential to be a dominant pathway for CH_4 release from lakes and reservoirs to the atmosphere (e.g., Bastviken et al., 2008; Del Sontro et al., 2010). However, ebullition's contribution to atmospheric emissions is often poorly constrained, and it may in fact be substantially underestimated due to difficulties in accurately quantifying this highly stochastic process under field conditions. While the importance of CH_4 ebullition in lakes and reservoirs has received increasing attention lately (Bastviken et al., 2004, 2008; Del Sontro et al., 2010), the importance of deltaic zones adjacent to river inflows has not been sufficiently studied. The high OM loadings and rapid OM burial that occur in deltaic zones foster high rates of methane production (e.g., Del Sontro et al., 2010). The relatively shallow depths (low hydrostatic pressure) more readily allow formation of methane bubbles in sediments, and the short travel path for rising bubbles through the water column ensures that a large fraction of the methane escapes directly to the atmosphere, as opposed to dissolving into the water column during the bubble's ascent. Combined, these factors create a situation where deltaic zones in lakes, despite representing a small proportion of lake surface area, could have among the highest rates of methane production within lakes and be lakes' largest source of methane to the atmosphere.

Quantification of ebulltion flux in lakes has traditionally been a matter of capturing – or not capturing – bubbles during deployment of relatively small (e.g., 1 m2) surface floating chambers (Bastviken et al., 2004; DelSontro et al., 2010). This approach provides only a coarse estimate (with large uncertainty) of ebullition flux derived from a small measured area (i.e., the width of the chamber × the distance drifted), offers limited insights into the mechanisms controlling ebullition, and does not allow one to clearly identify locations of ebullition events. Because of the inability to accurately locate zones of high ebullition, and precisely sample both sediments and water from those areas, there exists limited information about the factors that most strongly regulate ebullition. Important open research questions related to ebullition include: To what depth does (substantial) ebullition occur? and What geochemical characteristics (e.g., OM freshness, OM burial rate, allochthonous vs. autochthonous OM), physical characteristics (sediment cohesiveness or grain size), and characteristics of the microbial community are important factors regulating ebullition? Such critical mechanistic information is needed to enable more accurate assessments of the importance of ebullition, both within individual lakes and when scaling-up such estimates to assess their global importance.

Recent advances in techniques for real-time in situ CH_4 concentration measurements and for visualizing ebullition and quantifying ebullition flux open up new opportunities for identifying 3 important ebullition zones in lakes, quantifying the fluxes in these areas, and studying the factors that most strongly influence ebullition. Real-time measurement and mapping of CH_4 concentrations in deep-sea environments have recently been carried out using a submersible-deployed in situ membrane inlet mass spectrometer (MIMS; Valentine et al., 2010a,b; Camilli et al., 2010). Valentine et al (2010a) combined in situ MIMS CH_4 measurements with multibeam sonar to develop high-resolution maps of seafloor features and CH_4 seeps. Camilli et al. (2010) used real-time MIMS on-board an autonomous underwater vehicle to track a 35 km CH_4 plume emanating from the Deepwater Horizon oil spill in the Gulf of Mexico (depth =1100m). Vertically-down oriented sonar approaches, used on surface vessels performing transects and grid surveys in lakes, have been used for real-time visualization of individual rising CH_4 bubbles and bubble plumes (Ostrovsky et al., 2008; DelSontro et al., in prep). With a calibrated sonar, it is possible to quantify CH_4 ebullition flux by essentially counting bubbles of various sizes moving across a given depth horizon (if gas composition is also measured). We recently applied sonar measurements and floating chambers to study CH_4 dynamics in a tropical reservoir (Lake Kariba, Zambia), and observed that CH_4 ebullition fluxes and water:air exchange of CH_4 were 2 orders of magnitude greater in small river deltas and river-associated embayments than in shallow littoral areas with no associated river (Del Sontro et al., in prep.). Our results indicate that CH_4 ebullition flux in the river-associated embayments was the dominant source of CH_4 from Lake Kariba, despite the fact that these areas represent less than 10% of the total lake area. In addition, although other studies suggest that ebullition does not occur from sediments deeper than 10-20m, we observed substantial ebullition to depths of 40 m, which represents a large expansion of the area over which ebullition fluxes must be applied when calculating CH_4 mass transfer.

We hypothesize that the Rhone River Delta is a local hot spot within Lake Geneva for CH_4 ebullition to the atmosphere, and that ebullition from this relatively small area constitutes a disproportionate fraction of the lake's CH_4 emissions. To explore this hypothesis, and to develop an improved understanding of CH_4 ebullition in river deltas, we will conduct a 1 year field study of CH_4 dynamics in the Rhone River Delta. A centerpiece of this study will be submersible-based techniques including: i) Detection and high-resolution mapping of ebullition zones and associated delta bottom features; ii) Real-time 3-dimensional tracking of the delta's dissolved CH_4 plume using an in situ mass spectrometer, and precision water sample collection (e.g., for calibration and for $\delta 13CH_4$); and iii) Precision collection of sediment cores and placement/retrieval of devices for measuring porewater CH_4 along gradients of low-to-high ebullition zones. These submarine based measurements will be combined with surface vessel measurements over the course of 1 year (e.g., vertically-oriented sonar for quantifying ebullition flux) to develop a CH_4 budget for the lake. The study's unprecedented data set for visualizing and quantifying CH_4 ebullition will yield valuable insights into the major factors influencing CH_4 ebullition flux in lakes in general, and specifically in river deltas. CH_4