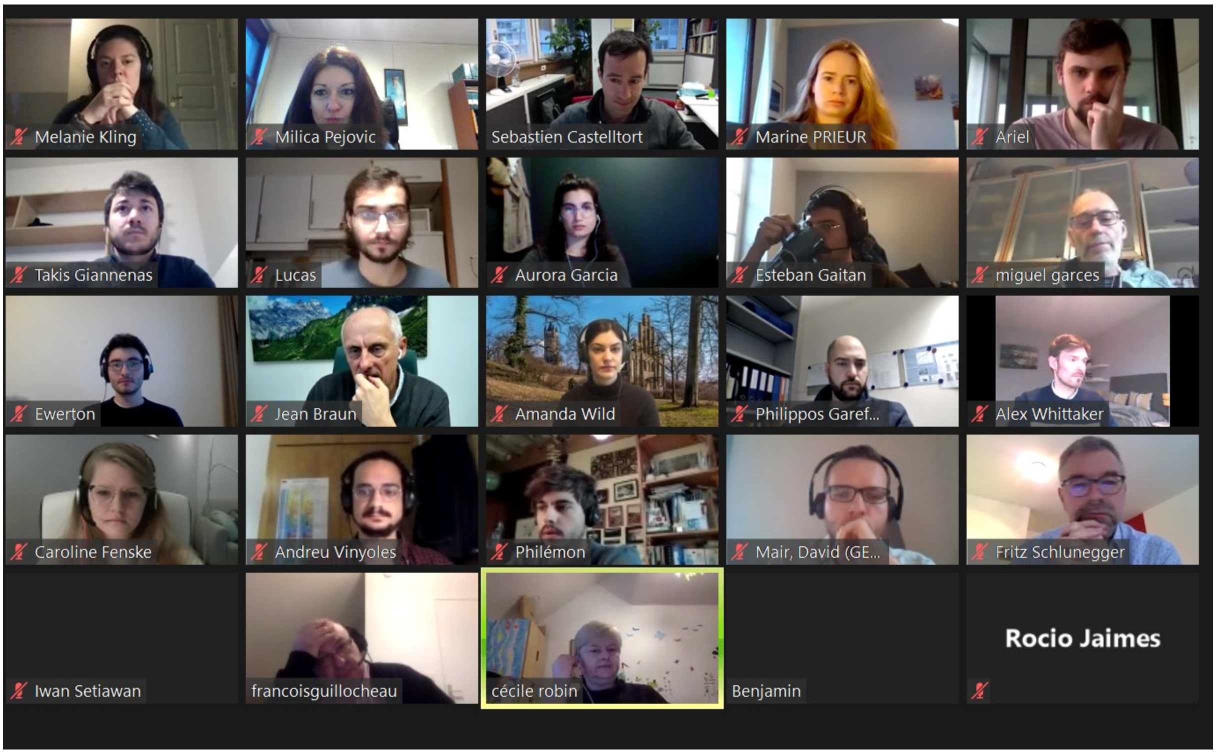
DRAGONSTONE 1

Introduction

Dragonstone 1 was held online from 11 to 15 January 2021. The main organisers of the workshop were the University of Rennes 1 (UR1), the University of Geneva (UNIGE) and GFZ Potsdam. Four lecturers, who are all recognised S2S experts, were François Guillocheau (UR1), Sebastien Castelltort (UNIGE), Jean Braun (GFZ) and Cécile Robin (UR1). Nearly 30 participants joined Dragonstone 1 including S2S-Future early stage researchers (ESRs), principal researchers, external PhD students and post-docs from several European universities.



The first day of training

Objectives of the training

Dragonstone 1 delivered at the onset of the ITN-S2S-Future programme the essential concepts and big picture overview of the scientific objectives and power of the S2S approach through a combination of class-room lectures, essential literature reviews, computer modeling hands-on and experiments to manipulate concepts. The online training kept the promise of offering a comprehensive course on the S2S fundamentals, covering a wide range of topics. The topics addressed during the five-day training were: drainage networks, fluvial erosion and sediment transport models, steady state and response to perturbations, equilibrium times, lags and buffers, complex behaviour (autogenic) in S2S segments, scales and natural variability, grain size trends, sequence stratigraphy, driving forces, lithospheric responses.

Programme

DAY 1

9h00 – 9h30 Personal presentations

9h30– 12h30
INTRODUCTION to the S2S system by presenting (1) concept of erosional, by-passing (transfer) and depositional landscapes, (2) geomorphological and sedimentological characteristics, (3) some modern examples of S2S systems and (4) economic and societal implications of S2S approaches (F. Guillocheau)

As an introduction, the contribution of S.A. Schumm in the definition of erosional, transfer and depositional systems is remembered and the main characteristics of the three systems are defined. We insisted on the sediment production, with the difference between silicilastic (terrigenous) and in basin-produced (carbonates, evaporates, etc..) ones. Four modern systems were presented: the Ganga-Brahmaputra/Bengal (high elevation), Congo (very humid), Ghallam-Erg Chech (W Sahara – hyperarid) and St Lawrence (glacial). We insisted on the response of the sedimentary fluxes (volume, grain-size, mineralogy) to the climate changes during the last glacial cycles. The next step was to show the differences between modern systems and some past ones, e.g. extensive fluvial to estuarine lowlands of Gondwana during Early Ordovician with no modern equivalents. For the end, a summary of the tectonic and climatic controls was proposed, focusing on the different time-scales and on the wavelengths for lithosphere deformation.

14h00 - 16h00
HISTORICAL PERSPECTIVES (S. Castelltort)

In this introductory part, the students are taken through a suite of major breakthroughs of the geological sciences of the last 50 years:
Sequence stratigraphy (1980-1990): a period of "all eustatic".
- Quantitative geomorphology (1990-2000): dates and rates for a better estimation of sediment fluxes.
- Sedimentary budgets (1990-present): cross-disciplinary interpretations of source and sink data
- Source-to-Sink (1999-present): a qualitative jump thanks to a systems approach
- Signal propagation (2000-present): the new "dynamic stratigraphy".

The lectures are an opportunity to review, in a very short time, the most important papers, concepts, advances, and applications that are relevant to source-to-sink approaches and research projects. The students are given papers to read and all the references that they can then keep as a basis for their own research project.

16h00 - 18h00
SOURCE / GEOLOGICAL DATA Characteristics of erosional landforms in orogenic and anorogenic settings, process of physical and chemical (weathering) erosion and sediment production (F. Guillocheau)

As an introduction, we highlighted the difference of four continental "worlds" in term of erosional processes: glacial/peri-glacial, eolian, alluvial and pedogenesis (soils). The first part was devoted to the erosional processes: (i) ice, wind and water mechanical processes were briefly presented; (ii) the weaknesses and contradictions of our knowledge on chemical processes were emphasized. Laterites and calcretes were discussed. The second part focused on the erosional landforms in both orogenic and anorogenic settings. The characteristics of incised valleys common to both were remembered (size, type of terraces, causes), insisting on the different techniques (and limits) of dating of the different steps of incision. The characteristics of plateaus (anorogenic relief), stepping of planation surfaces, known as pediments, pediplains and etchplains were presented and the dating and causes (role of chemical erosion) were discussed.

DAY 2

9h00 – 9h30 Personal presentations

9h30 – 12h30 and 14h00 – 15h00
SOURCE / **PHYSICAL PROCESS** Terminology and key numbers: geomorphologic physics (S. Castelltort)

This second part of Castelltort's lecture focuses on providing, for each sub-zone of source-to-sink systems, the essential elements that describe the forms and processes active in erosion, sediment transport and deposition, and definitions for the vocabulary in use. This chapter is an essential pedagogic block because it allows, in one single (albeit long) lecture, to give a teaching in disciplines that are traditionally separated: geomorphology and sedimentary geology.
We start with the source area and define concepts of drainage area, fluvial profile, uplift, erosion, landslides, streams and interfluves, Hack's law, basin outlets, mountain front, outlet spacing, divides, catchments, Horton's distance, self-similar and allometric scaling. We also train the students to manipulate rainfall, drainage area and outlet water discharge data.
The second zone is the transfer zone. We define the conditions of sediment transfer versus storage and erosion. We also address the concept of time scale at which an area of the land surface is in transfer and discuss the implications for understanding source to sink sediment transfer at different time scales.
The last zone is the basin: we address briefly the variety of depositional environments, the imbrications of erosion-transfer-deposition processes at a range of spatial scales, and the definition of a sedimentary wedge and implications for understanding sediment extraction.
In addition, this last part on the sink is the opportunity to give the students a synthetic refresher on sequence stratigraphy as a method to describe sedimentary successions.
For each zone, an original synthetic figure has been prepared and given to the students.

15h00 - 17h00
SOURCE / MODELS Introduction to the notion of Stream Power Law (J. Braun)

Jean Braun, in charge of the WP4 "Modeling", provided all ESRs with an introduction to the use of the FatsScape software to illustrate the behaviour of source-to-sink systems to a variety of tectonic and climatic forcings. The course was built on concepts and observations described to the students during the other parts of the training camp. It was delivered over four sessions in the late afternoons around topics seen earlier in the day.

We focused on the source (the mountain), the transfer (the basin) and the sink (marine) areas separately first, to ultimately build a complete numerical source-to-sink system. Together we subjected it to periodic variations in climate and uplift rate (in the source area) and investigated how the climatic and/or tectonic signals propagated through the system and were recorded in the sedimentary record.

The course was organised around a set of Jupyter notebooks that contained the theoretical foundations (i.e. the equations being solved) and the definition of critical concepts such as the response time of each parts of the S2S system, time lags and gain functions, in addition to a large number of python lines of codes that showed to the ESRs how to use the FastScape software. The course also contained a series of simple exercices for the students to complete during the course or as homework.

The course's objectives were:

- To provide the ESRs with the basic skills necessary to use the FastScape surface process model;
- To illustrate theoretical concepts seen during other parts of the course/training camp;
- To reproduce some of the key observations described in other parts of the course;
- To provide additional theoretical concepts (such as the response time, the gain and lag of the response to periodic forcing, etc.)
- To illustrate how S2S systems can be studied using signal propagation theory;
- To prepare the students to use FastScape and (for some of them) the framework (xarray-simlab) in which it has been developed to help them develop additional modules.

The course notebooks have been stored in a GitHub repository (https://github.com/fastscape-lem/s2s-future-dragonstone) and remain available to all for further use.

DAY 3

9h00 – 9h30 Personal presentations

9h30 – 11h30
SINK / GEOLOGICAL DATA Characteristics and variability of depositional profiles in different basin settings, concept of accommodation, impact of the A/S balance on the sedimentary record, prediction in terms of sediments preservation (C. Robin)

Cécile Robin provided a lecture dedicated to sedimentary archives and their understanding in stratigraphic and sedimentological terms in order to discuss their capacity to preserve the S2S signal. After a short review of the most important studies on the quantification of preserved sediment flows (Poag and Sevon, 1989 for example), Cécile Robin provided ESRs with the basics of sequential stratigraphy, a new basic (but extremely powerful) tool for reconstructing basin geometries. The aim was more particularly to demonstrate to ESRs that sequential stratigraphy truly offers an important tool for predicting the location and the capacity to preserve sedimentary volumes and environments. It was pointed out that depending on the timescale and the temporal resolution at which a study is conducted, the stratigraphic signal in response to the S2S signal could differ in terms of volumetric partitioning, among others. A part of the lecture was also devoted to the way sequential stratigraphy has been used as a tool for characterizing basin dynamics (subsidence measurement), by recalling the characteristics of the different types of sedimentary basins in their geodynamic context. The measurement of accommodation has been particularly developed. Finally, C. Robin provided the students with the insights into the method of measuring the sediment fluxes preserved in the basins (notion of "sink"). Particular attention was paid to the importance of estimating the errors associated with these measures.

11h30 – 12h30 and 14h00 – 15h00
SINK / **PHYSICAL PROCESS** Terminology et key numbers: major reports of the world's rivers (S. Castelltort)

In this part we address the main mechanisms and processes that are relevant to understand the functioning of entire sediment routing systems. We first introduce concepts of rock and surface uplift as an opportunity to examine conditions of topographic growth or decline and the idea of topographic steady state, which is central to landscape evolution. An analogy is drawn for sedimentary basin, where subsidence is the equivalent of uplift, and sedimentation is the equivalent of erosion, the interaction of both giving water depth as an equivalent of elevation in the source area. The concepts of growth, decline and steady state are expressed in terms of progradation, retrogradation and aggradation. As in the previous chapter, this lesson is an opportunity to show the similarity between geomorphological and sedimentological concepts.
Secondly, we explain the stream power erosion model and how it allows one to understand the concavity of steady state bedrock river profiles. The students are guided through a self-exercise in which they themselves draw theoretical river profiles.

15h00 - 17h00
SINK / MODELS Fastcape modeling sediment transport module and marine sedimentation module (J. Braun)

See above.

DAY 4

9h00 – 9h30 Personal presentations

9h30 – 12h30
SOURCE TO SINK / FACTORS OF CONTROL
Control parameters of the S2S system (S. Castelltort)

This chapter of the course address the factors of control of sediment routing systems in the perspective of signals. We first review tectonics signals, in contexts of convergence, divergence and dynamic topography. A focus is made on the amplitude, duration and spatial scale of tectonic phenomena in order to deliver time and spatial and constraints that are then precious to decipher such signals from the sedimentary record.
Second, we spend a lot of time on climatic signals. In a single figure, we describe long term climatic variations over the entire phanerozoic, then we review the “trends, rhythms, and aberrations” that one can observe over the Cenozoic, and finally we examine high-frequency sea-level and temperature signals of the Pleistocene to Holocene in relation with astronomical forcing. This part allows to define climate and climate variables, and give as for tectonics, a range of timescale constraints and constraints on the amplitude of climate variations that are fundamental for the inversion of the stratigraphic record.
Third, we review autogenic signals in sediment routing systems. The concept of internal dynamics is explained with analogies from simple mechanical systems, and is the developed for hillslopes and alluvial fans and applied to the timescale of compensation for large deltas with the example of the lower Mississippi.

14H00 – 15h00
SOURCE TO SINK / SIGNAL PROPAGATION
Theory and examples (S. Castelltort)

The Signal Propagation chapter is the core of this course. We first introduce concepts of signal propagation with the example of heat diffusion in a metal bar. We work out concepts of signal, response, delay/lag, buffer, amplitude, and heat transport efficiency and their controls. The main take home message is the idea of a characteristic response time for a perturbation to be transmitted from one end of the bar to the other, and the fundamental importance of the ratio between the timescale of a perturbation and the response time in order to differentiate "rapid" and "slow" perturbations.
We use these concepts to introduce qualitative predictions of the response of S2S systems, in particular orogens, to climatic and tectonic perturbations. This gives key elements on expected sediment flux and topographic responses that can be used to decipher between climate and tectonic forcing.
In a last part, we compute together and discuss some typical orders of magnitude of sediment production in small active orogens and anorogenic cratons. We compare these predictions with data on sediment fluxes for large rivers worldwide and discuss implications for the production and delivery of sediment in different geodynamic contexts.

15h00 - 17h00
SIGNAL PROPAGATION MODELS: numerical applications (J. Braun)

See above.

DAY 5

9h00 – 9h30 Personal presentations

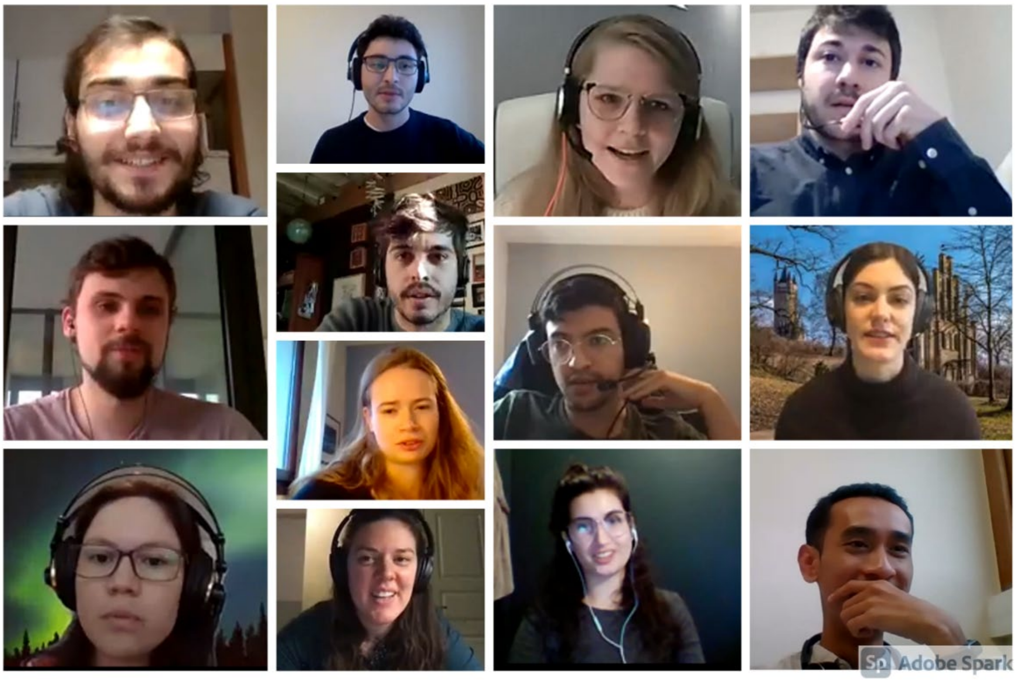
9h30 – 12h30
GAINS and LIMITATIONS of the S2S approach (S. Castelltort)

In this part we evaluate the added value of the S2S approach. The first major gain presented is with respect to the improvement of geologists' ability to predict reservoir properties. We suggest that the S2S approach is essential for improving the prediction of reservoir lithology, and is also of obvious interest for the selection of future CO2 storage sites as part of the deployment of the CCUS (Carbon Capture, Utilization and Storage), a major axis in the fight against global warming.
The second major gain is linked with the understanding of Earth's history: comprehending Source-to-Sink systems represents a fundamental step forward in tracing the history of the Earth. This approach makes it possible to extract from the sedimentary record a wealth of information on the upstream sedimentary system, both in terms of the response of the earth's surface to tectonic and climatic signals over geological time and to major geochemical cycles. One of the challenges of this approach is, for example, to decipher the responses of sedimentary systems to past aberrant climatic events, such as hyperthermal events associated with intense CO2 releases into the atmosphere, in order to use these sedimentary records in the past as an analogue to support predictions of the consequences of current global warming.
We terminate this chapter with several limitations that are presented as perspectives of evolution: absolute dating techniques, a better understanding of solid versus solute production and transport, developing new proxies for climate and paleoenvironments, among others.

14H00 – 17h00
GAINS and LIMITATIONS of the S2S / MODELISATION (J. Braun)

See above.

Dragonstone 1 lecturers: S. Castelltort, F. Guillocheau, J. Braun and C. Robin



ESRs presenting their academic paths and ongoing PhD projects