Propagation of Environmental Signals within Source-to-Sink Stratigraphy

Summary of SEPM Research Conference, Ainsa 2017

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Introduction

On the week of June 5th - 9th 2017, the authors of this summary report convened in the towns of Tremp and Ainsa, Southern Pyrenean Foreland basin, for a SEPM sponsored Research Conference on "Propagation of Environmental Signals within Source-to-Sink Stratigraphy". Organized around daily field excursions to world-class exposures of outcrops that, through decades of geological studies, permit the investigation of correlative stratigraphy from alluvial, fluvial, shallow marine, slope and deep marine environments, the conference boasted a diversity of selected innovative research presentations thematically unsorted in order to favor cross-pollination and interaction between different components and branches that fall under the broad umbrella of source-to-sink (S2S) research. The "propagation of environmental signal" was the leading thread and unifying concept of the conference as it carries the requirement of considering different segments of sediment routing systems. Furthermore, the manifestation of environmental changes – allogenic, such as tectonics, climate, sea level as well autogenic signals – are expressed and conveyed via erosion, sediment transport and deposition, hence connecting a variety of earth's science disciplines with one another (geomorphology, fluvial and marine sedimentology, stratigraphy, tectonics, crustal dynamics, paleoceanography, paleoclimatology). Following an increasing number of S2S sessions at major international meetings (AGU, EGU, GSA, AAPG), dedicated workshops such as the preceding Rennes Meeting (11.2016) or the upcoming Bremen workshop (09.2017), the conference presented an opportunity to review state-of-the-art concepts and advances in S2S research.

Source-to-Sink (S2S) studies of sedimentary systems aim to understand the erosional and depositional responses from environmental changes and their manifestation along different segments of the depositional system. These environmental changes propagate across sedimentary system as "environmental signals" (see Romans et al., 2016; Clark et al., in press). Earth scientists are invariably left to work with the landscape, as the transient result of erosional processes, and with the stratigraphic record, as the keeper of any preserved "environmental signal" to comprehensively tease out these 'signals'. Throughout the conference, participants discussed the propagation of such signal from its nucleation at the erosional zone to its preservation in the sedimentary record along the transfer zone into the eventual 'sink' within the context of different timescales. The primary questions driving this approach can be summarized as:

1) What signals are produced by allogenic controls and how are they preserved in the stratigraphic record?
2) What role do autogenic sedimentary processes and earth surface dynamics play in generating and propagating signals?
3) What are the challenges in applying analysis and insights from modern source-to-sink systems to the geologic past?
4) How do provenance analyses inform us about evolution of drainage basins?
5) What constraints can be placed from balancing paleo-erosion in the source area with sediment accumulation in the sink?
6) How do source-to-sink approaches improve existing stratigraphic models?

During the meeting, conference presenters shared key insights tackling these questions which are summarized in the following sections, representing a collective state-of-the-art perspective on the source-to-sink approach.

Allogenic Controls on Erosion and Deposition

The fundamental external controls to sedimentary systems are tectonics (including basin physiography), sea-level and climate. Understanding these controls and their magnitude from inverting the stratigraphic record is challenging and complicated by the inherent dependencies between controls. Deconvolving these controls is commonly practiced by relating stratigraphic responses to the time scales and response magnitudes of the controls, e.g. from mantle dynamics controlling orogenic relief over multi-million-year length-scales, to annual climatic variations affecting sediment flux. All scientific investigations into source-to-sink sedimentary systems are ultimately concerned with understanding these controls, but the following presentations are highlighted as providing some key insights into this area of research.

Tectonics and basin physiography:

Robin (presenting ***Guillocheau et al.***) discussed how mantle related anorogenic uplift generated continental-scale topographic wavelengths (>1000km) resulting in increased clastic supply to African margins. Regional erosional planation surfaces have been used as reference levels to quantify and compare erosion volumes and rates in the source, with sediment accumulations observed on regional seismic sections in offshore sinks. Continental-scale uplift in the late Cretaceous and around the Eocene-Oligocene boundary are shown to have the largest effect on sediment budget. ***Schlunegger et al***. showed how slab breakoff prompted the shift from flysch (deep-marine) to molasse (shallow marine and continental) sedimentation in the Northern Alpine Foreland Basin (~30Ma). From proximal to distal regions in the molasse basin, diachronous changes in grainsize and channel-bar sizes recorded the diachronous sedimentary flux change related to a “whiplash” response to slab breakoff over a 6 Myr time-scale.

Martinsen (Keynote Speaker) emphasized the tectonic control of basin physiography in partitioning sediment along the source-to-sink system. He suggested the most important component is the shelf width, depth, and its along-strike variation. The importance of shelf morphology and longshore currents was further emphasized by ***Romans et al.*** showing variability of 'reactive' source-to-sink systems related to along-strike shelf variability on the modern Californian margin. ***Walsh et al***. showed how different margin physiography impacted fined-grained river sediment dispersal and distribution (see also Walsh & Nittrouer, 2009), and how shelves vary greatly in width and depth (i.e. they are not simply restricted to water-depths <125m, Paris et al., 2016).

In the case of the San Andreas transform margin, ***Graham et al***. showed that the modern-day source-to-sink systems are influenced by the inherited tectonics of Cretaceous-Paleogene convergence along this margin. The extent and size of the Sacramento and San Joaquin drainage systems were established from paleogeomorphology of the convergent margin, and modern sediment provenance data shows this relict signature.

Bernhardt et al. investigated the turbidite depositional record (the frequency and thickness of turbidite beds in cores dated with Carbon-14) from different portions of the Chilean margin with differing modern climates (arid, semiarid and humid). ***Bernhardt et al***. showed that the decrease in turbidite frequency is not mainly related to postglacial sea-level rise. In contrast, the delivery of sediment to the sink appears to be controlled by basin physiography, modern landscape and its influence on connectivity and isolation of mountain lakes in the upper reaches of the S2S system.

The importance of tectonics and basin physiography was further emphasized by ***Garcés et al***., showing how the central and western portions of the Southern Pyrenean foreland basin had evolved from open marine to an internally drained continental (endorheic) basin. This profound change resulted in increased sediment accumulation rates and burial of the orogenic wedge, which in turn triggered out-of-sequence and back-thrusting leading to tectonic uplift and exhumation in axial zone. In summary, uplift in axial zone was not the cause, but the effect of high sedimentation rates (see also Costa *et al.,* 2010).

Sea-level:

Wei et al. showed how clay mineralogy from different rivers feeding the Gulf of Papua can be used to determine sediment provenance controlled by sea-level changes. Sediment cores taken offshore show variations in the different provenance signals that relate to sediment bypass and partitioning controlled by sea-level fluctuations. The Fly river erodes into sediment with higher illite:smectite ratios (reflecting a more mature drainage basin). In the marine basin, illite:smectite ratios in the clays show a stronger signal from this provenance during lowstands as incised valleys erode into sediment delivered from the Fly river. In contrast, small mountainous rivers have narrow flood plains, and lack sediment storage, and supply the basin with more immature arkosic sand and muds with low illite:smectite ratios during highstands.

Sharman (presenting ***Covault et al***.) discussed how the record of detrital zircons from deep-water fans offshore California can discriminate relative changes in sediment supply from modern river catchment areas from sediment produced by sea-cliff erosion (i.e. recycling of Cretaceous-Paleogene forearc outcrops with a distinctive detrital zircon character). In such a way, this tool can be used to quantify the proportions of direct fluvial supply versus longshore drift supply to the deep-water fans. During sea-level transgression there is 1 to 2 orders of magnitude increase in ratio of sediment supplied from sea-cliff to river supplied sediment. This is a consequence of both sea-cliff retreat (erosion) and the sequestering of river supplied sediment in lagoons and/or estuaries during transgression.

Climate:

Martinsen (Keynote Speaker) emphasized that temperature (the "T" in the BQART equation) is an important factor in sediment supply, and showed that tropical drainage basins typically produce 12 times more sediment than same size and water discharge arctic basins. ***Simms et al.*** demonstrated how climatic signals can generate contrasting responses in stratigraphy of two incised valley fills within relative proximity. The Nueces delta (western Gulf of Mexico) prograded during wet periods and back-stepped during dry periods on ~$1x10^5$ yr. scales matching climate signals. In contrast the Baffin Bay incised valley fill (~50km to the south) shows progradation during dry periods, tracking enhanced aeolian response to drying rather than the fluvial response. These contrasts demonstrate the way in which an environmental signal is transmitted depends on the environmental setting (i.e. the recorder, and its sensitivity).

Adatte et al. proposed that continental deposits in the foreland basin of the south-central Pyrenees have an equal, if not better, preservation of the PETM Carbon isotope record relative to the marine GSSP stratotype section. Pre-Onset Excursion (POE) kaolinite enriched sediments indicate high precipitation rates, in contrast to PETM high smectite weak chemically weathered deposits. High mercury concentrations suggest that PETM events were triggered and accelerated by volcanism. Increases in both coarse- and fine-grained siliciclastics in the Pyrenean foreland basin during PETM can be related to abrupt intensification of seasonal precipitation in an overall dry environment. ***Foreman et al.*** investigated PETM signal preserved in the Molina member (Piceance Creek Basin, CO. USA). The PETM carbon-13 record is coincident with a high-frequency (200 kyr) change in fluvial characteristics, with channels and bars becoming larger. Additionally, overbank deposits show an increase in splay deposits, interpreted as increasing channel mobility resulting from increased sediment flux. In this case, sea-level and tectonic controls can largely be ruled out since the basin was a long way from the sea and no clear tectonic event has been noted at this time.

Whittaker et al. discussed the use of self-similarity based models (*sensu* Fedele & Paola 2007, Whittaker *et al.*, 2011) concerning signal dampening, response-time, sensitivity and autogenic behavior, with field examples from alluvial fans in Death Valley (USA). Grain size fining rates change down-fan reflecting changes in sediment flux attributed to glacial-interglacial cycles. Updates to self-similarity grain size fining models were shown to be improved by incorporating fan width into the scaling relationships (3D fining model D'Arcy *et al*., 2017). The resultant model shows a 30% decrease in precipitation (from 70 kyr ago to present) corresponding to a 20% decrease in sediment flux.

Looking further afield, ***Siebach et al.*** showed data from studies of fluvio-deltaic-lacustrine facies from the Gale Crater, Mars. Mineralogy geochemistry collected from the Mars Rover has been used to unravel source rock composition, transport sorting, and alteration by ground-water/lake chemistry. Chemical Index of Alteration (CIA) analysis shows little chemical weathering occurred in the source area. The geochemistry of the deposits is strongly correlated with grainsize, concluding that sediment transport exerted the largest effect on the geochemistry of the preserved deposits.

Autogenic Processes and Earth Surface Dynamics

Processes of erosion and deposition and their impact on earth surface dynamics directly influence the preserved stratigraphic record. Understanding the magnitude of signals propagating across the earth surface via changes in these processes and their preservation in the stratigraphic record is key for source-to-sink studies of sedimentary systems.

Van der Beek et al. demonstrated that autogenic abandonment and incision on the Lannemezan Megafan (France) is primarily controlled by sediment capture by pre-existing major transverse river; the ancestral Ariège/Garonne river. Climatic variations have modulated the incision but they did not drive it. ***Sincavage et al.*** presented data from the Holocene fill of the Sylhet basin (part of the larger Ganges-Brahmaputra-Meghna delta system), showing that palaeohydrological changes in monsoonal climate had a non-linear response to affected Brahmaputra avulsion cycles. Both contributions really emphasized the nuances and non-linearity of autogenic drivers.

Bijkerk et al. showed that the equilibrium response times for most intermediate and large-scale rivers are >> 100 kyr. Consequently, most large rivers are not in equilibrium during glacio-eustatic sea-level rise. Rivers in a state of disequilibrium produce enhanced grainsize fractionation (i.e. the coarse-grains are trapped upstream). In contrast, sea-level fall promotes river-profile equilibrium, and consequently the fast and effective transfer of sediment to basin. This effect enhances the delivery of coarse-grained sediment from fluvial systems during sea-level falls.

Burbank (Keynote Speaker) presented paleo-erosion rates in the Miocene-Pliocene of the Central Andean foreland basin using cosmogenic radionuclides and detailed magnetostratigraphy. Paleo-erosion rate variations correspond to changes in detrital zircon provenance and quartz trace-element geochemistry. Erosion-rate and provenance changes over periods of several million years can be linked to tectonic induced changes in catchment area. However, higher frequency cyclic 5-fold changes in erosion-rates can be observed at the 400k year scale, demonstrating a coupling between of long-term climate fluctuations and sediment erosion.

Plink-Bjorklund et al. emphasized discharge variability in modern river systems, and the corollary that average river discharges do not represent conditions in which sediment is being transported or in which geomorphology is being formed. Measurements of bankfull discharge are more representative to characterize fluvial systems, and have an advantage over average discharge since they can be measured in the stratigraphic record from bedforms.

Willett (Keynote Speaker) used χ analysis (theoretical steady-state channel elevations) to characterize the degree of disequilibrium in landscape, and effects on drainage area (see Willett et al., 2014). Water divides between drainage basins migrate in the direction of higher χ to achieve equilibrium. Examples of geomorphological disequilibrium were shown from the Danube (which is a topographic remnant) and the Great Plains of the US (dynamic topography effects related to uplift of Colorado Plateau). These examples emphasize the possible "long" (10^6 yr) timescales of upstream signal propagation.

The Complexity of Modern Systems – is there Hope for Stratigraphy?

The study of source-to-sink systems has grown from understanding erosion and deposition in modern systems. Taking these approaches into past, relying on the preserved stratigraphic record presents many challenges, e.g.: (1) the incompleteness of the stratigraphic record; (2) constraining geologic time for time-scales over which these processes operate; and (3) the inherent complexity of source to sink systems (as observed in modern S2S systems). Several presenters focused on these issues, summarized by the question raised by ***Simms et al.***: "is there hope for stratigraphy" in being able to detect signals?

Integrated studies from the Waipaoa River & Poverty Bay (NE New Zealand) presented by ***Walsh et al.*** show that fine-grained dilute sediment gravity flows and wave-enhanced sediment gravity flows are the main process for redistribution mud across the shelf. Detailed monitoring river discharge, storm activity and sediment accumulation on the shelf over an annual cycle shows not all large discharges are associated with sediment accumulation. Furthermore, post-depositional reworking by bioturbation destroys many records of events. These observations show the difficulties in preserving a complete record of geologic events in the stratigraphic record. ***Trampush & Hajek*** tested the completeness of the stratigraphic record in different environments and the impact on preservation of signals (e.g. the PETM negative isotope excursion) by use of a numerical model. The model simulated different depositional regimes and then tested the preservation of a pre-determined input signal in synthetic 1D stratigraphic sections. High sedimentation rates with low variability produced the best results, although all models produced some realizations where the record was not detectable.

Countering the argument that the complexity of modern systems makes source-to-sink too challenging for ancient systems, ***Martinsen*** emphasized that predictability comes from first-order controls, rather than details. Likewise, ***Bernhardt et al.*** emphasized that preserved climatic changes can never-the-less be detected in the stratigraphic record, despite variations in topographic and bathymetric gradients, shelf-widths and connectivity of sedimentary systems from terrestrial to marine preserved climatic changes.

Sediment Provenance

Several presenters demonstrated the value of using provenance data to reconstruct sediment source areas, their applications to constrain the catchments' evolution, and their impact on the stratigraphic record. The use of detrital zircon geo-thermochronology lends itself very well to these studies due to the chemical durability of zircon grains. ***Stockli*** (Keynote Speaker) provided a state-of-the art review on provenance techniques using detrital zircon grains. He emphasized that most sedimentary systems have multiple phases of recycling that complicate unraveling of evolution of drainage basins. But new techniques (e.g. double or triple dating, U-Th/He, grain depth-profiling) have the potential to add other dimensions to fingerprinting distinct provenances.

Lawton et al. highlighted the use of depth-profiling zircon grains to differentiate crystallization and metamorphic themochronological history for better resolving source terrains in the continental drainage of North America, through the paleo-California-Brazos, paleo-Pecos, and paleo-Chihuahua drainage systems. Their work emphasized the importance of foreland recycling, and implications for different sediment compositions and reservoir quality predictions in the Wilcox fans (Paleogene). ***Horton et al.*** used detrital zircon provenance to track changes in long-lived paleodrainage systems from the Andes from Cretaceous to modern-day. Distinctive sediment sources (magmatic arc, foreland thrust belt, and craton) allowed testing of unroofing vs temporal shifts in drainage areas.

Source-to-Sink Mass Balance

Many workers are attempting to balance the material removed from erosion to that deposited in the sink as a method to check and account for all sediment contributions and deposits within a closed source-to-sink system. Understanding the issues with addressing mass balance calculations in modern systems can be used to apply these techniques to constraining sediment budgets of ancient source-to-sink systems.

Regarding modern, or recent Holocene systems, ***Romans et al.*** highlighted the difficulties in balancing erosion rates and sediment accumulation from well-constrained modern source-to-sink systems. In the California Borderland area, cosmogenic radionuclides were used to constrain erosion rates from source areas, but these rates do not seem to match the submarine sediment accumulations. In addressing the causes for imbalance, ***Romans et al.*** suggest additional sediment sources from lateral longshore transport cells (*sensu* Covault et al., 2007), and the complexity of sediment supply patterns even in short high relief reactive modern systems.

Watkins et al. showed sediment flux from the source and sedimentation rates in sink can be approximately matched in Gulf of Corinth (which approximates a closed system). Furthermore, both flux and sedimentation rate show a 25% decrease in glacial periods, attributed to stormier climates in interglacial periods during which there is an increase in the variability of sediment discharge. ***Pechlivanidou et al.*** quantified erosional and depositional sediment volumes and performed mass-balance analysis in the Holocene of the Sperchios rift (Greece). The drainage basin supplies sediment to a delta within an enclosed marine gulf. Depositional volumes were used to test predicted sediment bypass volumes from grainsize fining trends observed on alluvial fans (*sensu* Fedele & Paola 2007, Duller et al., 2010). Higher sediment supply from parts of the drainage area are explained by both bed-rock erodibility and lateral variability in tectonic uplift.

For ancient systems, ***Hodgson et al.*** emphasized findings of Tinker *et al.* (2008) that showed offshore volumes in South Africa equate to an order of magnitude lower than erosion estimates calculated from Apatite fission track (AFT) analysis, and an even greater disparity exists when using structural reconstructions to assess volume of sediment removed. Fluvial system scaling relationships (*sensu* Sømme et al., 2009) and long-term river catchment (since Cretaceous) also point to a large-scale drainage basin with major trunk river systems crossing structural grain. To address this imbalance, much of sediment deposited can be attributed to the early Cretaceous sedimentary sinks north of the Falkland Islands, now separated by 6000km displacement along a major transform fault (Richardson et al., 2017).

Schildgen & van der Beek investigated if the documented increase in erosion rates (calculated by low-temperature thermochronology data by Herman *et al.,* 2013) in the late Cenozoic, can be attributed to the onset of Quaternary glaciations (as suggested by Hay *et al.* 1988; Peizhen *et al.,* 2001). Other proxies for weathering do not show an increase, raising the question as to whether this increased erosion actually took place, or whether it is an effect of preservation vs recycling biasing (Sadler effect, Sadler 1981). ***Schildgen & van der Beek*** demonstrated how the geologic spatial variability in exhumation rates (associated with local faults or erosion) can originate errors in erosion-rates from correlation of uncorrelated data, suggesting that there has been no increase in erosion rates in the late Cenozoic.

Predictive Models

Martinsen (Keynote Speaker) emphasized the value of holistic, semi-quantitative nature of source-to-sink 'thinking' to predict sediment distribution and partitioning, providing a historic overview of the source-to sink concepts. He highlighted the need for further refinement of concepts (e.g. influence of ice-house vs greenhouse systems in the morphology and scaling relationships of source-to-sink systems), and demonstrated the use of paleo-topography and paleo-earth models in understanding sedimentary systems.

Blum (Keynote Speaker) presented the use of channel bar scaling relationships integrated with provenance data, which can be used to make first-order predictions of sediment accumulations in deep-water fans while expanding on original work from Sømme *et al*., (2009). Field-based sedimentology in the Lower Cretaceous Manville Group shows large point bars suggesting a large drainage system. Provenance analysis of detrital zircon U-Pb also supports a large drainage basin area, that potentially fed a large submarine fan system. These predictions remain to be tested, e.g. there should be a Late Triassic "Chinle" fan offshore southwest North America.

Beelen et al. highlighted the effect of differential compaction on shelf-edge trajectories (used to predict deep-water sands), and emphasized the use of sequential decompaction results in different geometry relative to non-sequential decompaction. Accounting for compaction results in more accurate shelf-edge trajectory reconstructions, and leads to improved predictions and correlations to deep-water deposits and overall amount of sediment transfer into the 'sink'.

Olariu et al. discussed the morphology of shelf-margin clinoforms in outcrop from the Neuquen Basin Argentina. Clinoform geometries, walked out in the outcrops of Lajas-Los Molles formations, are the expression of 200-300m high clinoforms with angles of 2-4° and direct correlation to sedimentation rates. ***Rasmussen et al.*** described a source-to-sink analysis of the Miocene Ribe Group in the eastern North Sea Basin. The sediment source area has been constrained by provenance studies and the geology of source terrain. Paleorelief has been determined by *Abies picea* spruce tree pollen spores. Understanding the sea-level and oceanic current circulation changes have been used to model sediment grainsize partitioning constrained by sediment supply from the source-to-sink analysis.

Pyrenean Foreland Basin S2S systems.

The conference was convened in the Spanish Pyrenees because of the spectacular outcrops and the insights they provide to the Conference's topic. The field itinerary enabled the conference attendees to follow key segments of the Eocene foreland basin fill from source (alluvial fans shedding off the axial zone) to sink (turbidite lobes). These outcrops have been studied for many decades, providing insights into the sedimentology, stratigraphy in association with the structural development of the Pyrenees. The latest contribution to this body of work is a geologic map by ***Puigdefàbregas et al.***, depicting the correlation of high resolution stratigraphy from the source, to the sink. The map was recently compiled from decades of detailed field mapping and integration of biostratigraphic data, and presents some revised correlations across the basin. The map will also provide a foundation for future source-to-sink studies in this basin.

Posters related to on-going research in the basin were presented in the field, contributing to the source-to-sink understanding of the south-central Pyrenean foreland basin. These contributions focused on: detailed stratigraphic reconstructions and high-resolution field mapping, provenance studies using detrital zircon geochronology, sandstone petrography, whole-rock geochemistry, and heavy mineral assemblages (***Chanvry et al.(A), Coll et al., Odlum et al., Poyatos-More et al. (A), Roige et al. (A & B), Thomson et al.***); the record and effect of the PETM in the basin (***Arevalo et al.***, ***Chen et al.***); detailed mapping, detailed stratigraphic correlation and sequence stratigraphic analyses (***Martinius & Puigdefàbregas***, ***Pyles et al. (A & B)***, ***Chanvry et al.(B)***, ***Poyatos-More et al. (B), Boya et al.***); records of carbon isotopes in the basin as proxy for sea-level changes (***Honegger et al.***, ***Läuchli et al.***); and, new magnetostratigraphy data and correlations between the Ainsa and Jaca basins (***Vinyols et al.***).

Conference Poster Session & Core Workshop

In addition to the field posters, the following presenters contributed to the Conference's themes during the poster session. The presentations included studies on: the quantification of grainsize fining trends on alluvial fans (***Brooke et al. (A), (B)*** and ***Watkins et al***.); shelf-margin accommodation and its linkage to delivery to deep-water environment (***Cosgrove et al***. and ***Poyatos-More et al***.); quantification of paleo-erosion rates and application to source-to-sink analysis (***Scherler et al.*** and ***Mason & Romans***);

fluvial terrace generation and evolution related to eccentricity driven climate changes (***Tofelde et al***.); scaling relationships between channel-forming fluvial discharge and fluvial architecture (***Jones & Plink-Bjorklund***, presented by ***Plink-Bjorklund***); tectonic reorganization of drainage areas detected by sediment provenance (***Blayney et al***., presented by ***Sobel***); use of physical sedimentation models to investigate the role of channel networks in buffering or promoting sediment supply signals (***Toby et al***.); and a theoretical look at signal-and-noise concepts and its application to source-to-sink sedimentology (***Li & Plink-Bjorklund***).

Lastly the conference conveners are grateful to ***Vitor Abreu*** who led a hands-on core workshop. This provided the conference participants an opportunity to examine and describe cores obtained from behind the outcrops of the Ainsa turbidite channel complex. This workshop concluded with a collation of the group's core descriptions and analysis and discussion of predictive cyclical patterns at different scales preserved in the stratigraphic record.

Summary

The conference was successful in bringing together researchers from very diverse backgrounds to tackle source-to-sink studies of sedimentary systems. While many questions are still unanswered, a clear message from the Conference was the need for multidisciplinary approaches and a much more interconnected community of practitioners pursuing collaboration and creative approaches. In the summary above, one can see that a broadly defined source-to-sink approach involves a variety of tools, including: thermochronology, strontium geochemistry, Carbon isotopes, bulk-rock geochemistry, Chemical Indices of Alteration (CIA), magnetostratigraphy, grain size analyses trends, mass-balance (of yielded sediments and solutes), structural reconstructions, numerical modeling, geomorphology and landscape analysis, and sedimentary morphometric and scaling relationships. The future development of the science relies on fostering collaborations between researchers applying these different techniques. It is hoped that this conference will have contributed to that effort and that future similar research meetings can be arranged to share such knowledge and trigger interactions within the larger S2S community.

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