Earth-Science Reviews 153 (2016) 1–6

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Editorial

Source-to-sink research: economy of the Earth's surface and its strata

1. Introduction to source-to-sink research

The Earth is ~4.6 billion years old, and over this time its complexion has changed dramatically. Geoscientists use remnant information from ancient rocks and sedimentary deposits to unravel the history of the planet. What were the heights of ancient mountains? What events created the stratigraphy seen underneath hillsides or within buried river valleys? What kinds of storms impacted shorelines and oceans? Hutton (1785) and others convinced us that the present is the key to the past, arguing that sediments accumulating in the sea (i.e., the sedimentary sink) eventually become the land upon which we live (the source):

> "As it is not in human record, but in natural history, that we are to look for the means of ascertaining what has already been, it is here proposed to examine the appearances of the earth, in order to be informed of operations which have been transacted in time past. It is thus that, from principles of natural philosophy, we may arrive at some knowledge of order and system in the economy of this globe, and may form a rational opinion with regard to the course of nature, or to events which are in time to happen."

Source-to-sink (S2S) research fundamentally pursues these original ideas. It is a geological approach rather than subdiscipline or process. To borrow words from Hutton, the objective of S2S research is to determine "…order and system in the economy of the globe". Through the quantification of earth processes in a budgetary manner, it is an approach to connect areas of material production with sites of transfer and locations of storage. This special issue focuses on siliciclastic systems, but other sedimentary systems can similarly be examined (e.g., carbonate reefs; Ryan et al., 2009; Perry et al., 2015).

Insights from S2S research not only help us to understand changes to the Earth and the associated driving processes but also are informative to citizens and societies (e.g., resource extraction and management) and critical to evaluating ecosystem functions on the planet. Earth processes are often explained and represented by flows and boxed regions that illustrate exchanges of mass or energy from one component or area to another, such as global or more detailed diagrams (e.g., Fig. 1). Although informative, these representations are more conceptual than explicit, offering little insight about the timing and interactions of processes driving the change. In contrast, the S2S community is working to measure the specific rates of surface altering processes, sediment transport, and strata development as well as the resulting landscapes and seascapes (Fig. 2; NSF MARGINS Program Science Plans, 2004; Allen, 2008). Armed with this information, we strive to model the past and the future. In other words, the S2S approach aims to quantify changes in the continuum of the Earth's surface and relate them to measurable fluxes and accumulations (i.e., strata construction) from specific events or conditions.

2. Brief history of S2S

Source-to-sink investigation is not really a new concept or approach. Like Hutton, geologists from the beginning have recognized the relationship between catchment soils and seafloor strata, and many have understood that a mass- (or volume) balance approach could be used to understand the Earth system and the interconnections between its parts. Since World War I, research related to strategic, resource (e.g., hydrocarbons), and environmental concerns has intensified, and today, the tools and techniques are easier to apply. For example, fluvial systems are key areas for agricultural, environmental and developmental reasons (Fig. 2), and they have received much research attention. Also, geoscientists have maintained a strong focus on understanding continental margins (Fig. 2). This transition zone between land and sea is a critical interface for societies and scientists. These areas, where many humans live and work, are important for resources and serve as key repositories of geological information.

A wonderful early example of S2S research comes from G.K. Gilbert, a legend in the field of geomorphology who worked at the U.S. Geological Survey. His oft-cited study of the impact of hydraulic mining on sedimentation in the Sacramento River and San Francisco Bay region (Gilbert, 1917) provides a thorough analysis of sediment eroded from the catchment and deposited downstream in the 1849–1914 period. This work demonstrates not only the value of an S2S perspective but also the potential hydrological ramifications of sedimentation and the societal relevance of such research (i.e., increased flooding). Hydraulic mining in the late 19th century dramatically altered the landscape in this area, causing profound environmental changes. Gilbert (1917) estimated that 1.8×10^9 m^3 of sediment were eroded from the Sacramento and San Joachim catchments as a result of mining and non-mining processes (e.g., agriculture, roads), and storage of this material occurred in the Sierra (11.1%), piedmont (21.9%), valleys (4.2%), marshes (12.2%), bays (48.3%) and ocean (2.1%). Despite local concern and national attention, this research showed that there was no measurable shoaling near the Bay mouth (i.e., in the vicinity of the Golden Gate Bridge), and thus navigation was not likely to be impacted as some had suggested. However, shoaling of rivers in the piedmont did augment flooding threats within the low-gradient river portion of the source-to-sink system, where evolution continues today (Singer et al., 2013). The work by Gilbert is compelling, illustrating how earth surface dynamics can be greatly affected by human actions.

As demonstrated by Gilbert, estimation of sediment mass added to or removed from various storage zones along its transport pathway is a valuable means to evaluate sedimentary systems, and this is a

http://dx.doi.org/10.1016/j.earscirev.2015.11.010

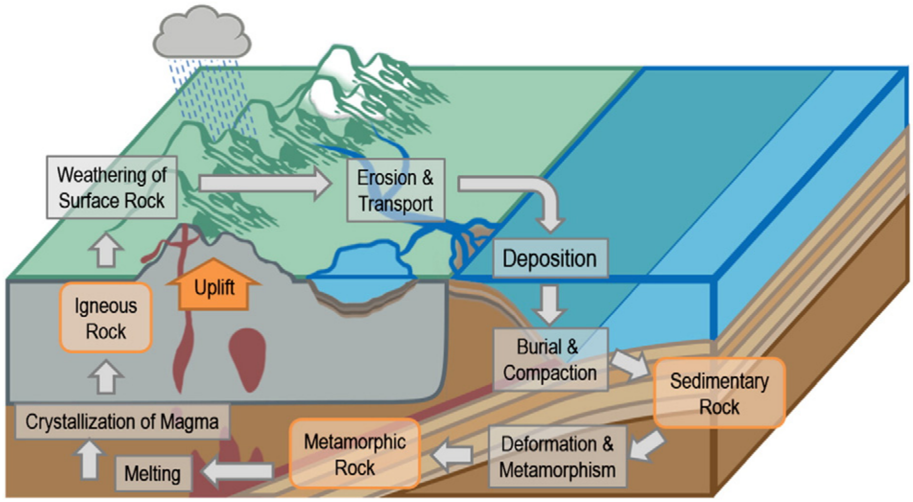

Fig. 1. A conceptual diagram of the evolving Earth, showing mass flows over geologic time, often referred to as the "Rock Cycle". Note, sediment erosion, transport and deposition are fundamental and variable components of siliciclastic S2S systems and have been quantified and modeled in many areas.

fundamental component of S2S research. In simple terms, this is the application of mass conservation to geomorphic processes; a sediment budget is literally an assessment of the economy of the Earth's surface. The sediment budget approach has been a fundamental part of coastal research since Bowen and Inman (1966) evaluated littoral cells in southern California. Many similar studies have since transpired, and a variety of concerns must be considered when constructing a meaningful nearshore sediment budget (Komar, 1996; Rosati, 2005). These coastal studies differ from S2S investigation in that they focus on the functioning of a specific component (i.e., the littoral zone) rather than a whole production and dispersal system. Nevertheless, even in localized studies, a broad S2S perspective is important to maintain. For example, Limber et al. (2008) recommended the use of a "Littoral Cutoff Diameter" because the entire sediment population from a river source does not factor into nearshore sediment dynamics, and thus a littoral sediment budget should be adjusted accordingly.

Efforts to construct system sediment budgets have become more common as techniques to quantify sediment production (e.g., with ^{10}Be; Bierman and Nichols, 2004; Nichols et al., 2005) and sediment accumulation (e.g., with ^{210}Pb; Nittrouer et al., 1979; Sommerfield and Nittrouer, 1999) have improved. Volumetrically linking catchment erosion and deep marine strata over late Quaternary (e.g., Covault et al., 2011) and longer timescales (Carvajal and Steel, 2011) supports the utility of a S2S sediment budget approach at large spatial and temporal scales. As studies continue to improve in resolution and expand to other sites, there is a potential to compare and contrast systems. Somme et al. (2009) used sediment volume to find general relationships between river sediment load (source) and submarine fans (sinks). Sediment budgets have also been employed to show how shelf width relates to off-shelf transport (Walsh and Nittrouer, 2003), and can explain differences in S2S dispersal systems when coupled with other data (Walsh and Nittrouer, 2009).

A key paper published in the early 1990s was very influential to S2S research. Milliman and Syvitski (1992) documented the great number of small rivers with large sediment yields on active margins, and hypothesized that rapid delivery of sediment to steep-gradient continental

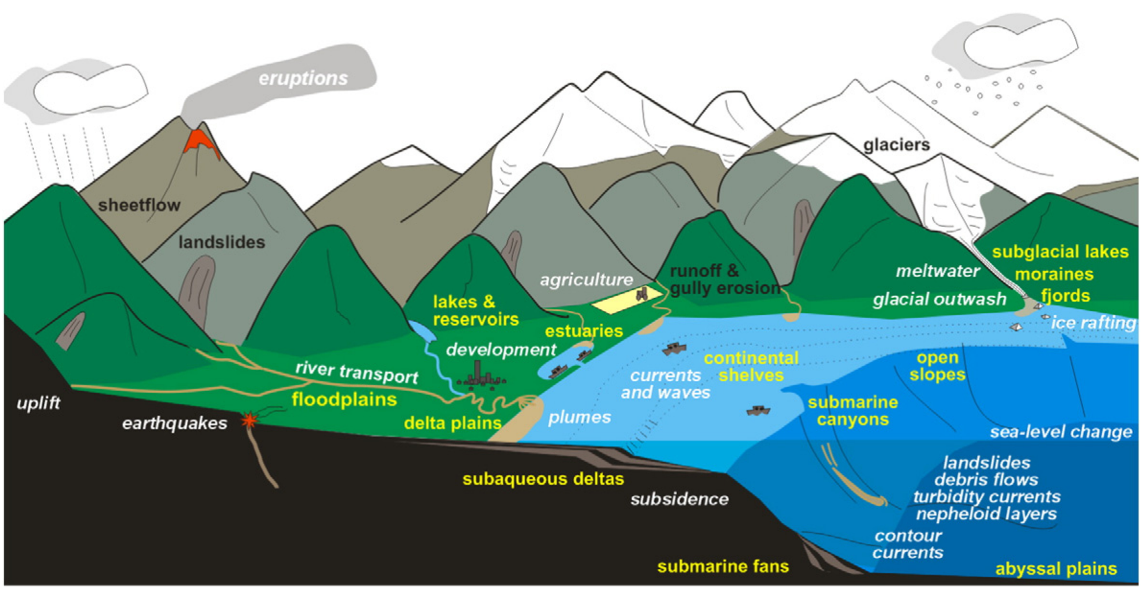

Fig. 2. Sources (black), sinks (yellow) and processes (white) moving sediment (modified from NSF MARGINS Program Science Plans, 2004). Note, carbonate systems are excluded to simplify.