GLOBAL SEDIMENTARY GEOLOGY

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Contents

Summary

Sedimentary processes influence the entire surface of the Earth, from the mountaintops down to the deepest ocean basins. Sediments are produced through erosion of pre-existing rocks or through chemical and biological processes, are transported by wind and water, and finally accumulate on the continents or in the oceans. All these processes are controlled by environmental parameters, among which climate is most important. The study of the sedimentary record (the accumulation of sediments through time) thus allows the reconstruction of bygone environments. Many precious resources such as water, oil, gas, or minerals are contained in sedimentary rocks. It is therefore important to be able to predict their occurrences, and to avoid pollution in the case of aquifers. All the processes that today are of utmost importance for the human population (such as sea level changes, coastal erosion, or landslides) have always occurred in the past, and there is no reason to believe that they will not continue in the future. It is therefore important to understand these processes better, in order to mitigate their impacts on our society.

1. The Record of Changing Environments

The production of sediments, their transport, and their final deposition depend directly on environmental parameters. Snowfall and temperature control the advances and retreats of glaciers that scrape sediment from the substrate, rainfall controls the rivers that transport sand, silt, and clays to the fluvial plains and deltas, wind shapes sand dunes in the desert, and arid conditions allow for the precipitation of gypsum and salt. Currents distribute the sediment along the coast or across the shelf into the deep ocean. Water depth, water temperature, water chemistry, and nutrients govern the life of a multitude of organisms that contribute, through their shells and skeletons, to the sediments in lakes and in oceans. Many different depositional environments coexist and evolve through time (Figure 1).

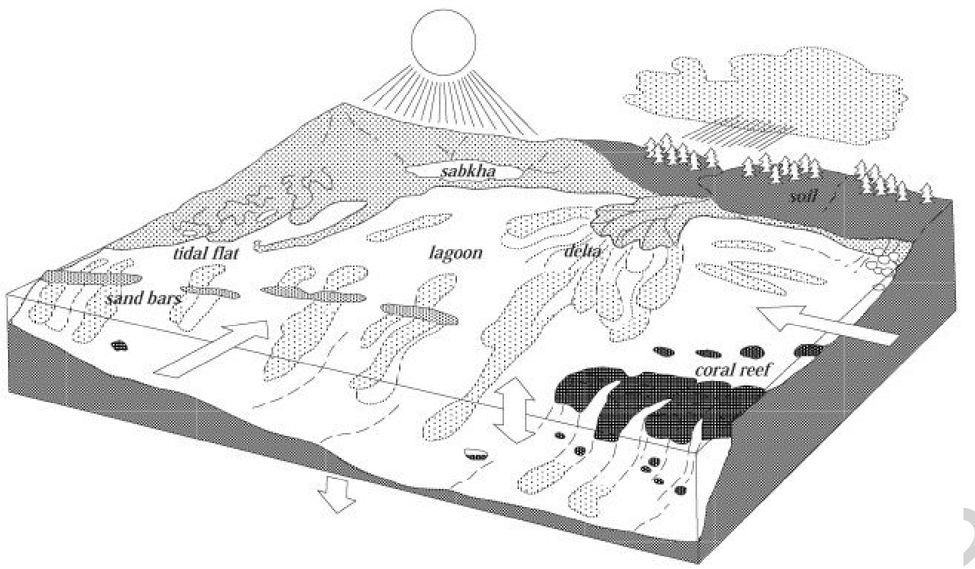

Figure 1. Example of a coastal depositional system where different sedimentary environments coexist. Important factors controlling sediment production and distribution are climate, currents, sea level changes, and subsidence.

These environmental parameters are intimately linked among each other and depend mainly on land and ocean morphology as well as on climate. Tectonic processes create mountains from which sediment is eroded and basins where sediment accumulates, and determine the position of the continental plates and therefore the distribution of climatic zones and oceanic currents. The climate itself is controlled, through a multitude of feedback processes (Figure 2), by variations in insolation due to periodic changes of the Earth's orbit (Milankovitch cycles).

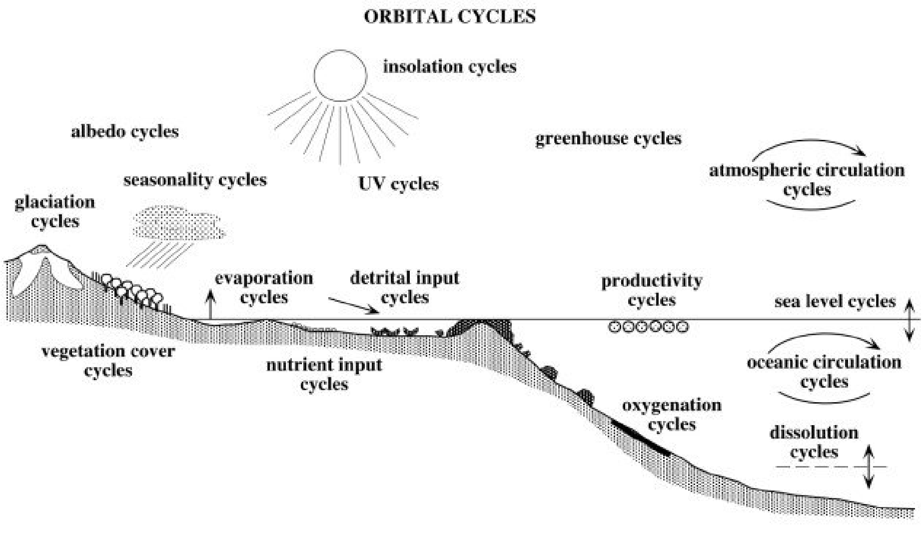

Figure 2. Cyclical processes controlling the various sedimentary systems, from mountain areas to the deep ocean. These processes are linked and depend greatly on orbitally controlled insolation cycles.

Large-scale tectonic changes occur on timescales of a few million to a few tens of millions of years, whereas the orbitally induced climate changes have frequencies of a few tens to a few hundreds of thousands of years.

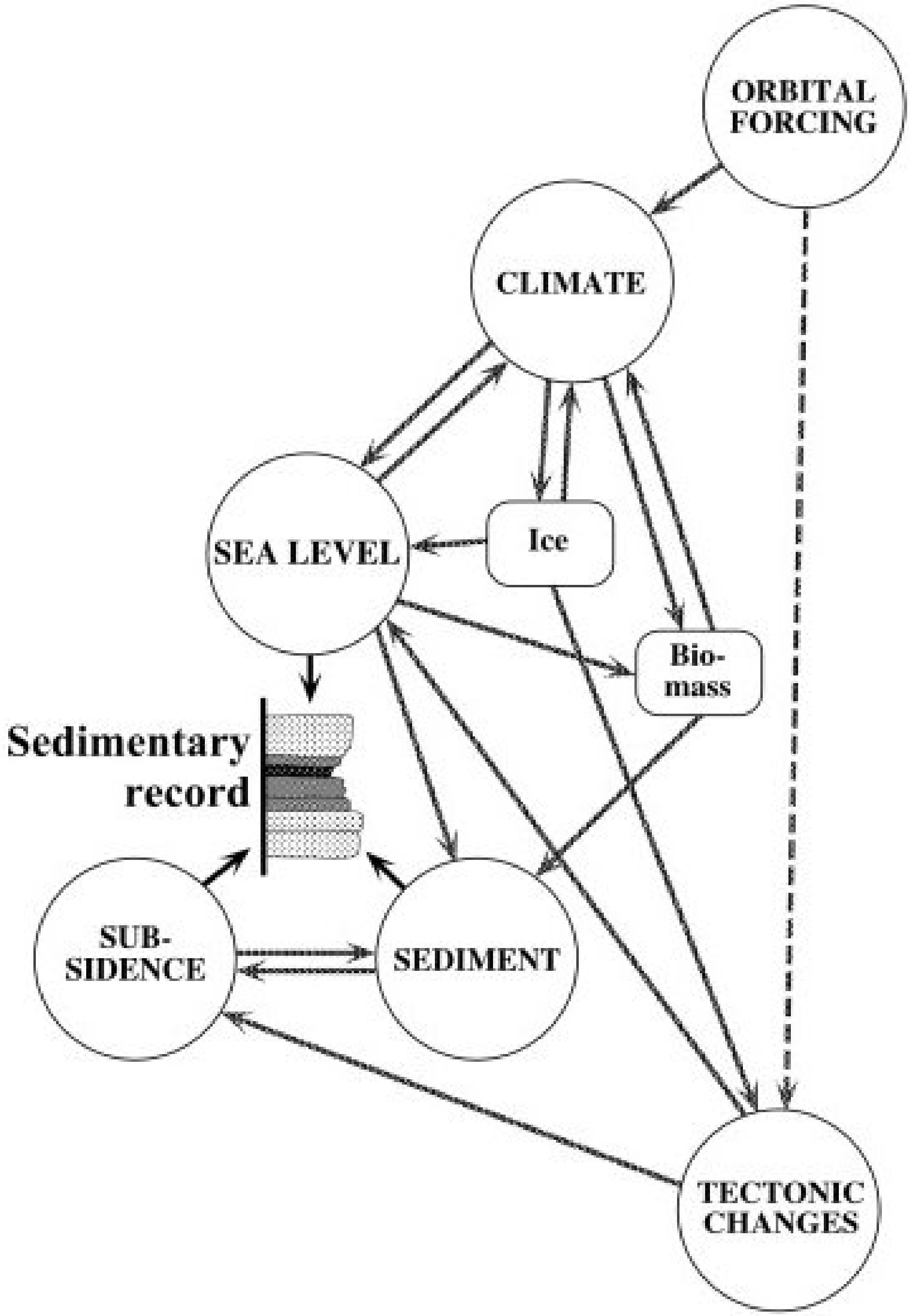

Figure 3. The sedimentary record reflects accommodation changes defined by changes in sea level and subsidence pattern, as well as the sedimentary system itself. These three main parameters are linked and depend mainly on climate and tectonics. The interactions between the parameters occur with different amplitudes and frequencies.

Sediment is constantly produced and redistributed. Its final preservation, however, is much more episodic and localized, and depends mainly on the availability of space for accumulation and on the absence of subsequent erosion. Accommodation space is created by subsidence on the one hand and by the level up to which the sediment can accumulate on the other (most commonly sea or lake level, but also storm-wave base, fluvial equilibrium profile, or wind shadow). Again, these parameters defining accommodation are linked among each other and depend on tectonics and climate (Figure 3). They vary through time with different amplitudes and frequencies, implying that the sedimentary record is not continuous but episodic, especially in shallow depositional environments (Figure 4). A very fragmentary sedimentary record also occurs on slopes where gravitational processes do not allow for deposition or even cause erosion, or in environments where episodic processes such as flash floods or storms predominate.

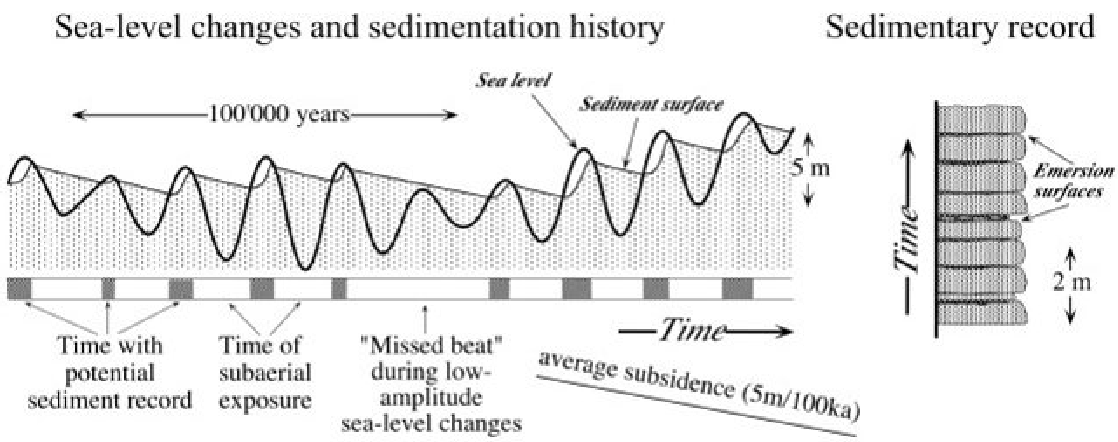

Figure 4. In shallow marine depositional environments, the sedimentary record generally is fragmentary. Sediment accumulation and preservation can only occur when sea level rise is fast enough to create accommodation. Sea level falls lead to emersion and potential erosion. Sea level changes are drawn to reflect the orbital cycle with a periodicity of 20 000 years. The amplitudes are estimated based on a study of Cretaceous rocks in the French Jura Mountains.
Source: modified from Strasser et al. (1999).

The sedimentary rocks that geologists study in the field or in cores thus tell only a fraction of the story of past environments because they are only partly preserved. Furthermore, only a small part of the organisms of bygone ecosystems are found as fossils or have left traces of their activities. Geochemical analyses allow us to reconstruct the cycling of certain elements in the ancient oceans and atmosphere. For example, changes in the isotopic composition of oxygen give clues about paleotemperature, whereas carbon isotopes are used to reconstruct scenarios of global warming, increased water and nutrient cycling, and ensuing increased organic productivity (Figure 5). However, such reconstructions are rather crude and cannot reflect the complexity of a coupled geosphere–hydrosphere–atmosphere–biosphere system.

Dating of ancient sediments is important in order to estimate the speeds of sedimentary and evolutionary processes. Very precise timescales have been elaborated for the Holocene and the younger Pleistocene based on radiometric dating and on dendrochronology, and the analysis of Milankovitch cyclicity allowed the elaboration of a continuous timescale from today back to about 20 million years ago. In older sediments, a relative timescale with the resolution of a few ten thousand years can be established if Milankovitch cyclicity is recognized. Varves in ancient lake sediments or cyclical changes in planktonic microfossil associations can even give an annual resolution in a time window of the distant past. The time resolution by paleontological methods (fossils calibrated with absolute, radiometric ages) is in the order of half a million years.

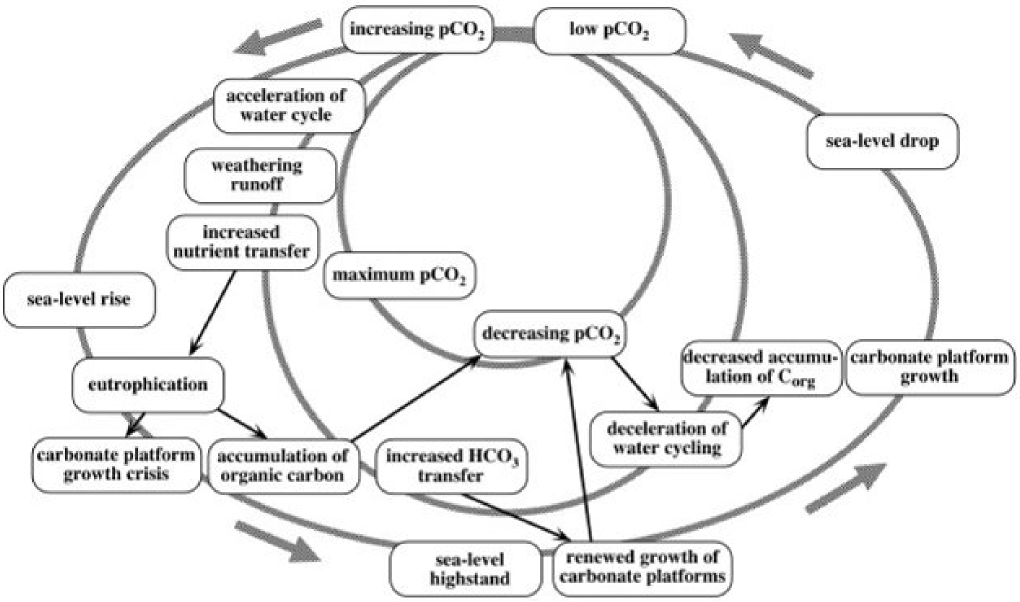

Figure 5. Conceptual link between atmospheric CO_2 cycling (inner circle), water cycling (middle circle), and sea level changes and associated growth or demise of carbonate platforms (outer circle). Increase of CO_2, for example through increased ocean-floor spreading, leads to greenhouse conditions, which accelerate the water cycle. Sea level rise together with increased continental run-off and nutrient input leads to a crisis in carbonate production. At the same time, massive production and accumulation of organic matter under eutrophic conditions causes a decrease in atmospheric CO_2 and a decrease in greenhouse conditions. Sea level falls, and carbonate production resumes. Source: modified from Weissert and Mohr (1996).

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Biographical Sketch

André Strasser has been Associate Professor at Fribourg University, Switzerland, since 1989 and is currently General Secretary of the International Association of Sedimentologists. He is also a member of the Council for the Protection of Geotopes and President of the Swiss GeoForum. Born at Chur, Switzerland, in 1947, he took his Ph.D. at the Zurich ETH in 1979 and then spent several years at Geneva University. He leads several research projects on sedimentology, high-resolution sequence stratigraphy, and cyclostratigraphy, combined with facies analysis, paleoecology, and early diagenesis, on the Jurassic and Lower Cretaceous of Switzerland, France, and Spain, as well as in the Pleistocene and Holocene of Sinai (Egypt), Tunisia, and the Bahamas.