International Subcommission on Stratigraphic Classification: guidelines for sequence stratigraphy

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Summary

Sequence stratigraphy provides the means of correlation of sedimentary successions on the basis of stratal stacking patterns and key bounding surfaces. Stratal stacking patterns form in response to the interplay of accommodation (space available for sediments to fill) and sediment supply, and reflect combinations of depositional trends that include forestepping, backstepping, upstepping and downstepping. Changes in stratal stacking patterns through time result in the formation of key bounding surfaces in the rock record, referred to as sequence stratigraphic surfaces. The recurrence of the same types of sequence stratigraphic surface through geologic time defines cycles of change in accommodation or sediment supply, which correspond to sequences in the rock record.

Sequences can be subdivided into systems tracts, which are units bounded by sequence stratigraphic surfaces and defined by specific stratal stacking patterns. Stratal stacking patterns may be linked to shoreline trajectories, in which case they define lowstand, transgressive, highstand and falling-stage systems tracts, or may be independent of shoreline trajectories, such as in the case of low- and high-accommodation systems tracts in fully continental settings. Depending on the scale of observation, sequences, systems tracts, and their bounding surfaces may be ascribed to different hierarchical orders. The nomenclature of sequence stratigraphic units and surfaces remains independent of scale.

The observation of stratal stacking patterns (i.e., systems tracts) and changes thereof (i.e., sequence stratigraphic surfaces) is key to the sequence stratigraphic methodology. The construction of a framework of systems tracts and bounding surfaces ensures the success of the method, and constitutes the model-independent platform of sequence stratigraphy. Beyond this standard workflow, the interpreter may make model-dependent choices with respect to which sequences stratigraphic surfaces should be elevated in importance and be selected as sequence boundaries. In practice, the data often dictate which surfaces are best expressed and hold the greatest utility at defining sequence boundaries, and implicitly at defining different types of sequence, in each particular succession.

Introduction

Sequence stratigraphy developed largely without formal guidance from any international stratigraphic commission over the past decades. The result is the proliferation of an unnecessarily complex and sometimes conflicting terminology, as well as the proposal of several different approaches with respect to the application of the method (Fig. 1). Even though all existing approaches share a common ground of fundamental principles, the development of sequence stratigraphy was punctuated by debates which focused arguably on aspects that are not essential to the application of the method, such as issues of nomenclature or ranking of sequence stratigraphic surfaces in terms of their relative importance. These debates were counterproductive in the sense that they introduced more confusion than clarification, and undermined the confidence of the less experienced practitioner in applying the sequence stratigraphic methodology. The International Subcommission on Stratigraphic Classification (ISSC) of the International Commission on Stratigraphy strived to provide definitions and guidelines for methodology and nomenclature since 1995, by appointing three consecutive working groups on sequence stratigraphy, in 1995, 2004 and 2008. The first two working groups were disbanded in 2003 and 2007, respectively, for lack of success in providing a neutral platform for a standard, model-independent methodology that honors the various approaches but transcends their differences.

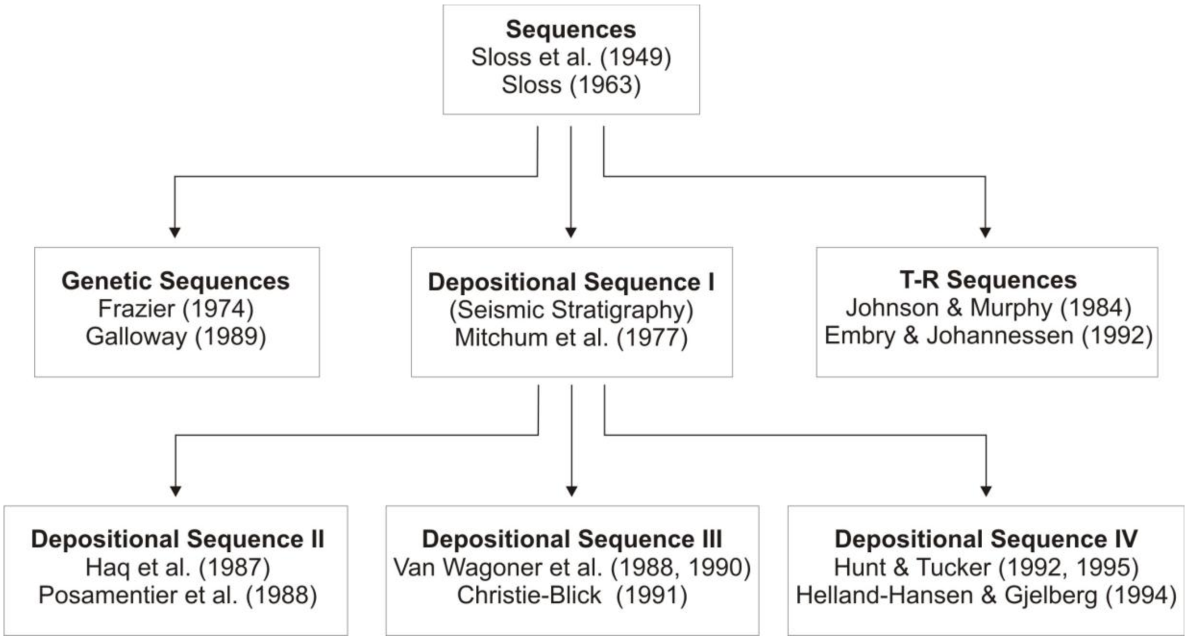

Figure 1: Sequence stratigraphic approaches (from Catuneanu et al., 2011)

The state of sequence stratigraphy in 2007 was perhaps best summarized by the Chair of the International Subcommission on Stratigraphic Classification (ISSC), Dr. Maria Bianca Cita, after having to disband the second ISSC working group on sequence stratigraphy: "What is wrong in Sequence Stratigraphy? What is wrong with the most popular, the best represented in Google, in special courses or short courses run by professional sequence stratigraphers all over the world, in textbooks and monographs published by the most authoritative publishing companies? What is wrong in that branch of Stratigraphy that substantially contributed to increase the success of the geological exploration of oil and gas resources?" (ISSC Newsletter No. 12, December 2007). The short answer is that nothing was wrong with sequence stratigraphy, but only with the level of collaboration between international experts to define a model-independent workflow that could be applied irrespective of personal preferences, types of data available, depositional and tectonic settings, and the scale of observation. In fact, in 2007 work was already underway in order to reach consensus among a working group of nearly 30 experts worldwide, representing various schools of methodological approach. This work resulted in two journal articles (Catuneanu et al., 2009, 2010), which paved the way for the long-anticipated ISSC report on sequence stratigraphy (Catuneanu et al., 2011). This paper presents the key points of the ISSC guidelines for sequence stratigraphic methodology and nomenclature, as well as a look forward to the frontier areas of sequence stratigraphic research where future developments may be expected.

Nomenclature

Sequence stratigraphy is the study of cyclic changes in stratal stacking patterns in response to variations in accommodation (space available to sediments to fill) and sediment supply. The cycles of change in stratal stacking pattern correspond to sequences in the rock record, and are defined by the recurrence of the same types of sequence stratigraphic surface through geologic time.

1. Sequence stratigraphic units

Sequence stratigraphic units are defined by their bounding surfaces, as well as by their internal stratal stacking patterns. Three types of sequence stratigraphic unit are in use: sequences, systems tracts and parasequences.

Stratigraphic sequence: a unit which corresponds to a cycle of change in accommodation or sediment supply (Catuneanu et al., 2009). As a function of the specific type of sequence stratigraphic surface designated as sequence boundary, three types of sequence can be defined: depositional, genetic stratigraphic, and transgressive-regressive.

Depositional sequence: a type of sequence bounded by subaerial unconformities or their marine correlative conformities (Mitchum, 1977; Vail, 1987; Posamentier et al., 1988; Van Wagoner et al., 1988, 1990; Vail et al., 1991; Hunt and Tucker, 1992).

Genetic stratigraphic sequence: a type of sequence bounded by maximum flooding surfaces (Galloway, 1989).

Transgressive-regressive (T-R) sequence: a type of sequence bounded by maximum regressive surfaces (Johnson and Murphy, 1984; Johnson et al., 1985). The T-R sequence was subsequently redefined as a unit bounded by a composite surface that includes the subaerial unconformity and the marine portion of the maximum regressive surface (Embry and Johannessen, 1992).

Lowstand systems tract (LST): a unit defined by 'normal regressive' stratal stacking patterns (a combination of forestepping and upstepping), bounded by the subaerial unconformity and its correlative conformity at the base, and by the maximum regressive surface at the top.

Transgressive systems tract (TST): a unit defined by backstepping stratal stacking patterns, bounded by the maximum regressive surface at the base and the maximum flooding surface at the top.

Highstand systems tract (HST): a unit defined by 'normal regressive' stratal stacking patterns (a combination of forestepping and upstepping), bounded by the maximum flooding surface at the base, and by the subaerial unconformity and the basal surface of forced regression at the top.

Falling-stage systems tract (FSST): a unit defined by 'forced regressive' stratal stacking patterns (a combination of forestepping and downstepping), bounded by the basal surface of forced regression at the base, and by the subaerial unconformity and its correlative conformity at the top.

Low-accommodation systems tract: the subdivision of a fully continental depositional sequence that forms independently of shoreline shifts, dominated by amalgamated fluvial channel fills.

High-accommodation systems tract: the subdivision of a fully continental depositional sequence that forms independently of shoreline shifts, dominated by fluvial floodplain sediment with isolated channel fills.

Parasequence: a dominantly progradational unit bounded by flooding surfaces.

2. Sequence stratigraphic surfaces

Sequence stratigraphic surfaces are surfaces that may serve as systems tract boundaries. The following types of surface are used in sequence stratigraphic work:

Subaerial unconformity: an unconformity that forms under subaerial conditions as a result of fluvial erosion or bypass, pedogenesis, wind degradation, or dissolution and karstification.

Basal surface of forced regression (i.e., correlative conformity *sensu* Posamentier et al., 1988): the paleo-seafloor at the onset of forced regression; it marks a change in stratal stacking pattern from forestepping with aggradation (HST) to forestepping with downstepping (FSST).

Correlative conformity (*sensu* Hunt and Tucker, 1992): the paleo-seafloor at the end of forced regression; it marks a change in stratal stacking pattern from forestepping with downstepping (FSST) to forestepping with upstepping (LST).

Maximum regressive surface: paleo-seafloor at the end of regression, and its correlative land surface in the continental realm; it marks a change in stratal stacking pattern from forestepping with upstepping (LST) to backstepping (TST). Commonly used synonymous term: transgressive surface.

Maximum flooding surface: paleo-seafloor at the end of transgression, and its correlative land surface in the continental realm; it marks a change in stratal stacking pattern from backstepping (TST) to forestepping with upstepping (HST).

Transgressive ravinement surfaces: erosional surfaces that form by means of wave scouring (i.e., wave-ravinement surfaces) or tidal scouring (i.e., tidal-ravinement surfaces) during shoreline transgression. Commonly used synonymous term: transgressive surface of erosion.

Regressive surface of marine erosion: an erosional surface that forms typically by means of wave scouring during forced regression in wave-dominated settings.

Flooding surface: a lithological discontinuity across which there is an abrupt shift of facies that commonly indicates an abrupt increase in water depth.

Methodology

The optimal approach to the application of sequence stratigraphy relies on the integration of outcrop, core, well-log and seismic data. Each data set provides unique insights toward the identification of stratal stacking patterns and bounding surfaces, and mutual corroboration is important to reduce the error margin of interpretations. Not all data sets may be available in every case study, a factor which may limit the 'resolution' of the sequence stratigraphic interpretation. At the same time, not all types of data afford the recognition of all sequence stratigraphic surfaces, and not all sequence stratigraphic surfaces are present in every depositional setting. The area of transition between fluvial and shallow-water systems affords the formation of the entire array of sequence stratigraphic surfaces. In contrast, within fluvial and deep-water systems, conditions are favorable for the formation of fewer key bounding surfaces.

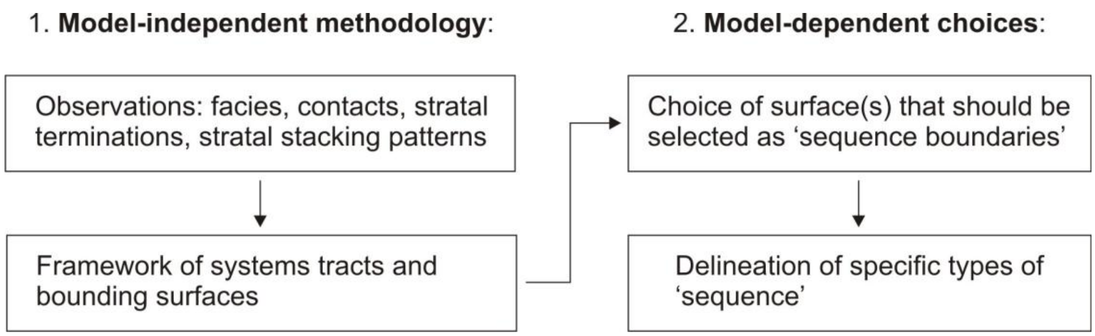

Figure 2. Model-independent methodology versus model-dependent choices in sequence stratigraphy (from Catuneanu et al., 2011)

The sequence stratigraphic method relies on the observation of stratal stacking patterns (i.e., systems tracts) and changes thereof (i.e., sequence stratigraphic surfaces). Construction of a framework of systems tracts and bounding surfaces ensures the success of the method in terms of its objective to provide a process-based understanding of the stratigraphic architecture. This defines a model-independent methodology that honors all existing approaches but transcends their differences. Beyond the model-independent workflow, the interpreter may make model-dependent choices with respect to the selection of surfaces that should be elevated to the rank of sequence boundary (Fig. 2). In practice, this selection is often a function of which surfaces are best expressed on the data available.

A look forward

Future developments may be expected in the following areas of sequence stratigraphic research:

- The role of autocyclicity in sequence stratigraphy
- The role of sediment preservation patterns in sequence stratigraphy
- The development of new systems of sequence hierarchy
- Integration of sequence stratigraphy with other disciplines:
  - seismic geomorphology
  - diagenesis
  - geochemistry
  - micropaleontology and ichnology
- Lithological expression of correlative conformities in outcrop and core
  - lithology/sedimentology
  - fossils and trace fossils
  - geochemistry
  - mineralogy and diagenesis

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