[PS]Reading the Sedimentary Record: A Multiple-Hypotheses Working Methodology*

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Abstract

Reading the sedimentary record to decipher Earth history and predict future changes is one major task for sedimentologists. One of the objectives and challenges is to interpret the main controlling factor (e.g., tectonics, climate, autogenic processes, etc.) on the preserved strata. Recent development of sequence stratigraphy and the realization of the autogenic processes have led the author to reconsider some of the best-known interpretations, and suggest that the method of multiple working hypotheses may work best for interpreting sedimentary record. There are three main reasons why we need a multiple-hypotheses working methodology. First, there are multiple controls on preserved strata. The multiple controls inevitably lead to non-uniqueness in stratal patterns. One example is the transgression of a delta front, which can result from 1) purely autogenic processes, 2) reducing sediment supply during steady accommodation changes, 3) increasing rate of accommodation changes during constant sediment supply, and/or 4) a combination of both autogenic and allogenic changes. This requires us to keep an open mind and have multiple hypotheses at the initial stage of research. Secondly, all the allogenic and autogenic processes have complex and non-linear responses. One common practice of interpreting the main controlling factor is linking the specific time of certain events in source area (e.g., climate change) to the preserved strata. If the time intervals of a certain event and the deposition of the strata match with each other, then the event is usually believed to be responsible for deposition of the strata. This reasoning process, however, might be problematic. This is proved by the increasing numbers of studies on the environmental signal propagation within the source-to-sink system. Thirdly, the limitation of data can lead to misinterpretation or ignorance of other possibilities if we use a single working hypothesis. This phenomenon is common in earlier studies of sequence stratigraphy, which are usually based on one- or two-dimensional datasets. Recent study by Madof et al. (2016) has shown how evaluation of along-strike variability can change our interpretation of the controlling factor. The change of mindset for interpreting depositional sequences will obviously alter our view of how sedimentary systems evolve, and this helps to increase the success rate of reservoir prediction and play exploration.

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MOTIVATION

I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail.

Abraham Maslow

The danger of having one ruling theory in mind has been warned by various authors. One unpleasant result is the unconscious selection of proof in favour of the theory and ignorance of those that fail of coincidence (Chamberlin, 1890). This tendency is so deeply rooted in human nature that even well-trained scientists may become a slave to it.

Unfortunately, it is also true in the sedimentary society. Lots of previous interpretations on stratigraphy, though limited by insufficient data, suffer from this problem. It is largely due to ambiguous definitions of some key terminologies and people's favor for a certain theory.

This poster will focus on interpretation of depositional sequences and will present reasons why some previous interpretations fail to be impartial and unbiased and give advice to each of the problems.

AMBIGUITY IN DEFINITIONS

Although we talk a lot about controlling factors on preserved stratigraphy, we don't actually have a clear definition of what it really means when we say an interval of strata is controlled by climate change, sediment supply, tectonics or eustatic changes (Fig 1).

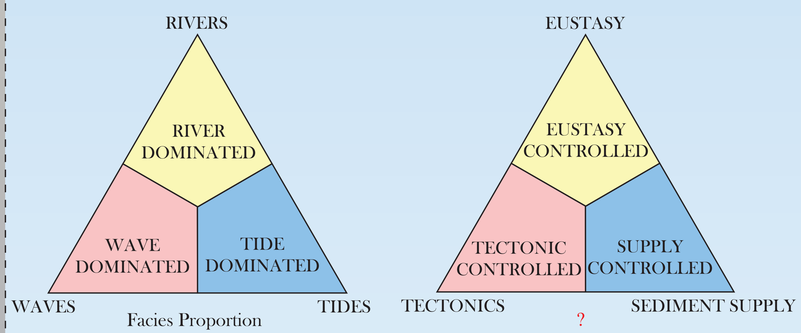

Fig 1 Lack of criteria for defining whether a sequence was controlled by eustasy, tectonics, or sediment supply

A common practice for evaluating the role of eustatic changes in generating a sequence boundary is to correlate between different basins or use global sea level curve (Fig 2). Once synchronous boundaries have been found or large sea level fall has been confirmed on the curve, it is often believed that the boundary results from eustatic changes.

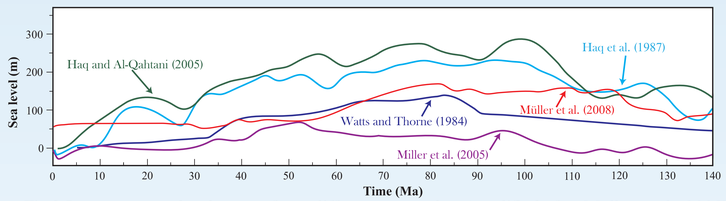

Fig 2 Long term sea level curves from different researches (modified after Müller et al., 2008)

It is clear that a sequence boundary formed by 100 m of relative sea level fall may be eustatic controlled using curve of Haq and Al-Qahtani (2005) while Miller et al. (2005) would suggest it is mainly due to tectonic uplift.

The first step towards a more accurate interpretation should be clear definitions of the terminologies and semi-quantification/quantification of contributions of different allogenic processes. There has been some progress (e.g. the concept of eustasy index by Davies et al. , 2016), but more work still needs to be done.

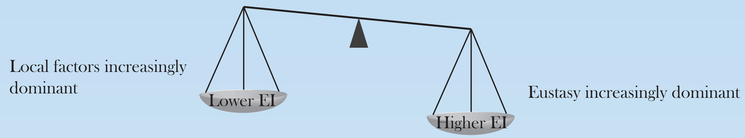

Fig 3 Eustasy index (EI) can be used to semi-quantitatively evaluate the contribution of eustasy and local factors (modified after Davies et al., 2016)

LIMIT OF DATA AND IGNORANCE OF OTHER POSSIBILITIES

The fundamental principle for interpreting sedimentary record has been laid down by Jervey (1988): the interaction between sediment supply and accommodation controls the stratigraphic pattens. This idea, when combined with sediment loss (sediment output or negative sediment supply) at the point of interest, can explain all the complexities and heterogeneities observed in sedimentary record. Different allogenic and autogenic controls influence the ultimate sedimentary record by changing either sediment supply or accommodation or both of these two factors. However, most of the time people tend to forget there is no single one-to-one relationship in stratigraphy due to the nature of its formation (Fig 4).

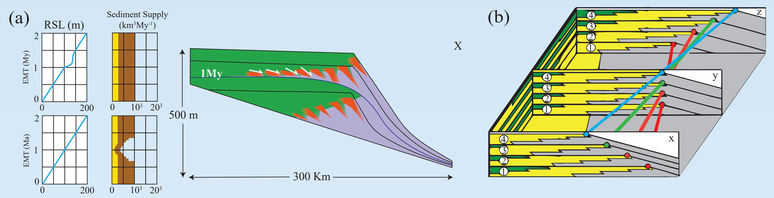

Fig 4 Examples showing there is no simple one-to-one relationship in stratigraphy. (a) Numerical modeling showing the generation of same/similar stratigraphic patterns can result from different combinations of sediment supply and accommodation (modified after Burgess and Prince, 2015); (b) Along-strike variation challenges the use of maximum flooding surface as a synchronous marker bed (modified after Madof et al., 2016)

The difficulty for interpreting sedimentary records results from two major sources: 1) different combinations of allogenic and autogenic processes may result in same/similar sediment supply and accommodation combinations, and 2) different combinations of sediment supply and accommodation can generate same/similar stratigraphic patterns, which further complicates the problem.

Since the data used for stratigraphic interpretation always have some limitation, it might be better to keep an open mind and have multiple hypotheses at hand (even if the evidence may favor one of them). As proposed by Hampson (2016), instead of having one single interpretation, we need to have a solution set for what is known and prepare for what is unknown (e.g. Shiers et al., 2014; Fig 5).

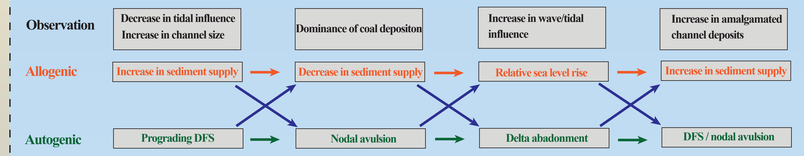

Fig 5 Preferred workflow for interpreting sedimentary records (modified after Shiers et al., 2014)

DELAY AND SHREDDING OF ENVIRONMENTAL SIGNALS

Another aspect to consider is the delay and shredding of environmental signals (e.g., Heller et al., 1988; Jones et al., 2004; Romans et al., 2016). Recent studies have shown travel time distribution in fluvial systems obeys power law and short term signals can be dramatically delayed or totally shredded (Jerolmack and Paola, 2010; Pizzuto, 2016).

Lots of studies make interpretation based on the match between age of deposits and inferred time of boundary condition changes in source area (e.g., Kamola and Huntoon, 1995; Weltje et al., 2001; Macklin et al., 2002) , and few of them, if any, have investigated the problem of environmental signal propagation. Tectonics and climate can have close interactions (e.g., Molnar and England, 1990) and therefore the evaluation of how different signals propagate is crucial to interpretation of preserved sedimentary records.

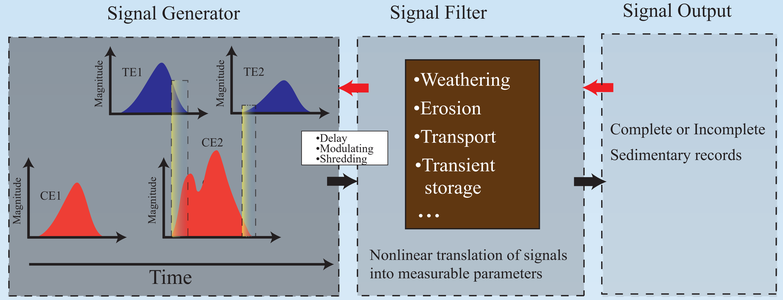

Fig 6 Schematic diagram illustrating the complexity and difficulty of interpreting environemtal signals. TE: tectonic episode; CE: climate episode

CONCLUSIONS AND SUGGESTIONS

1. Problems related to interpreting environmental signals from sedimentary records are largely due to the lack of understanding of how signals transmit and how different signals interact with each other.

2. The complex nature of stratigraphy requires a multiple-hypotheses method.

3. There are two aspects that we can work on to improve our ability to interpret sedimentary records: 1) process-based forward modeling of how environmental signals propagate within the sedimentary system; and 2) more clear and robust definitions of key terms.

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