Autostratigraphic Responses of Deltaic Clinoforms to Sea Level Forcing*

Tetsuji Muto[1], Ron J. Steel[2], Andrew L. Petter[2], and John B. Swenson[3]

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[1]Graduate School of Science and Technology, Nagasaki University, Nagasaki, Japan (tmuto@nagasaki-u.ac.jp)
[2]Department of Geological Sciences, University of Texas, Austin, TX
[3]Department of Geological Sciences, University of Minnesota, Duluth, MN

Abstract

A common belief in conventional genetic stratigraphy is that given steady external forcing by constant sediment supply (rate Q_s) and constant relative sea level rise (rate R_{slr}), a deltaic system grows to achieve an equilibrium configuration, produces a particular sediment-stacking pattern, and maintains a constant rate of shoreline migration in a particular direction. This presumed mode of stratigraphic response is referred to as equilibrium response, by which steady external forcing results in a steady and uniform stratigraphic pattern of deposition. Theoretically there can be three other modes of stratigraphic response in such a cause-and-effect relationship. These are autogenic nonequilibrium response (unsteady stratigraphic configuration, or stratigraphy with breaks/changes, caused by steady forcing), allogenic nonequilibrium response (steady stratigraphic configuration by unsteady forcing), and allogenic general response (unsteady stratigraphic configuration by unsteady forcing). Conventional genetic stratigraphy inherently relies on the recognition of equilibrium response and, consequently, is apt to prefer the interpretation that any large-scale facies breaks or changes in stratigraphic pattern of deltaic successions reflect unsteady forcing, such as temporal changes in R_{slr} or Q_s (i.e., allogenic general response). We suggest that this happens because of some lack of awareness of nonequilibrium responses. New understanding and insights on how the deltaic clinoform reacts to steady and unsteady forcing, through physical and numerical experimentation, promotes a radically new view (known as autostratigraphy) that (1) though equilibrium response is certainly possible, it is limited to a very specific geomorphic condition and does not generally hold, (2) autogenic nonequilibrium response is much more likely than equilibrium response to steady sea level forcing, and (3) deltaic systems can have different stratigraphic responses to the same forcing depending on basin configuration and clinoform geometry. Autostratigraphy, encompassing equilibrium and autogenic nonequilibrium

responses, suggests that abrupt stratigraphic breaks/changes and discrete geomorphic features of deltaic clinoform are not necessarily associated with sudden changes in R_{slr} or Q_s but can be the purely autogenic response of the system to steady forcing of sea level and supply. Full appreciation of autostratigraphic responses provides an improved basis for stratigraphic interpretation and for exploring the autogenic dynamics of deltaic clinoforms.

References

Muto, T., 2001, Shoreline autoretreat substantiated in flume experiments: Journal of Sedimentary Research, v. 71, p. 246–254.

Muto, T., and J.B. Swenson, 2005, Large-scale fluvial grade as a non-equilibrium state in linked depositional systems: Theory and experiment: Journal of Geophysical Research-Earth Surface, v. 77, no. 1, p. 2-12.

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Tetsuji MUTO[FOJT1], Ron J. STEEL[2], Andrew L. PETTER[2] and John B. SWENSON[3]

[1]Nagasaki University, Grad School of Science and Technology, Japan
[2]University of Texas at Austin, Dept Geol. Sciences, USA
[3]University of Minnesota Duluth, Dept Geol. Sciences, USA

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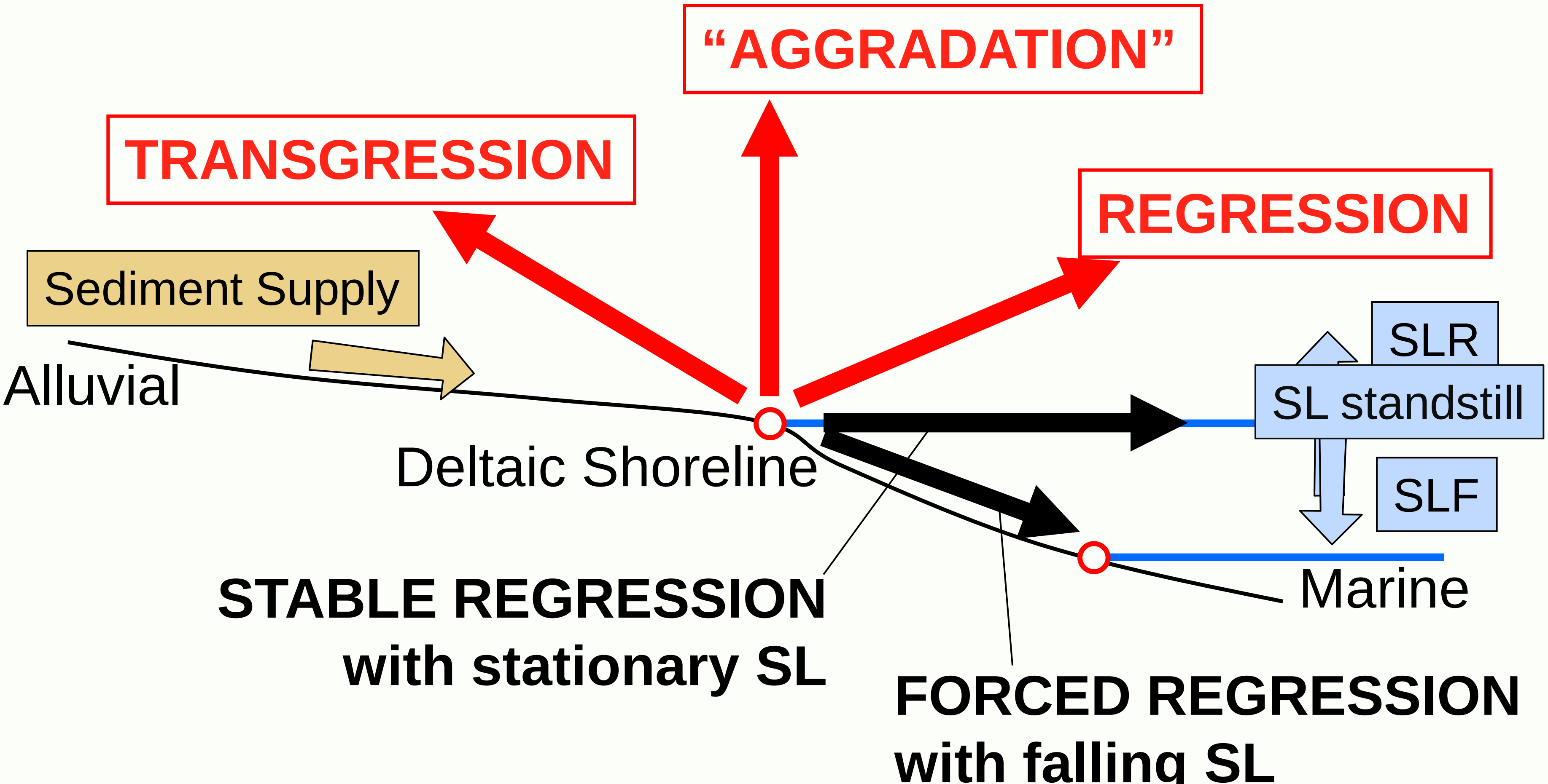
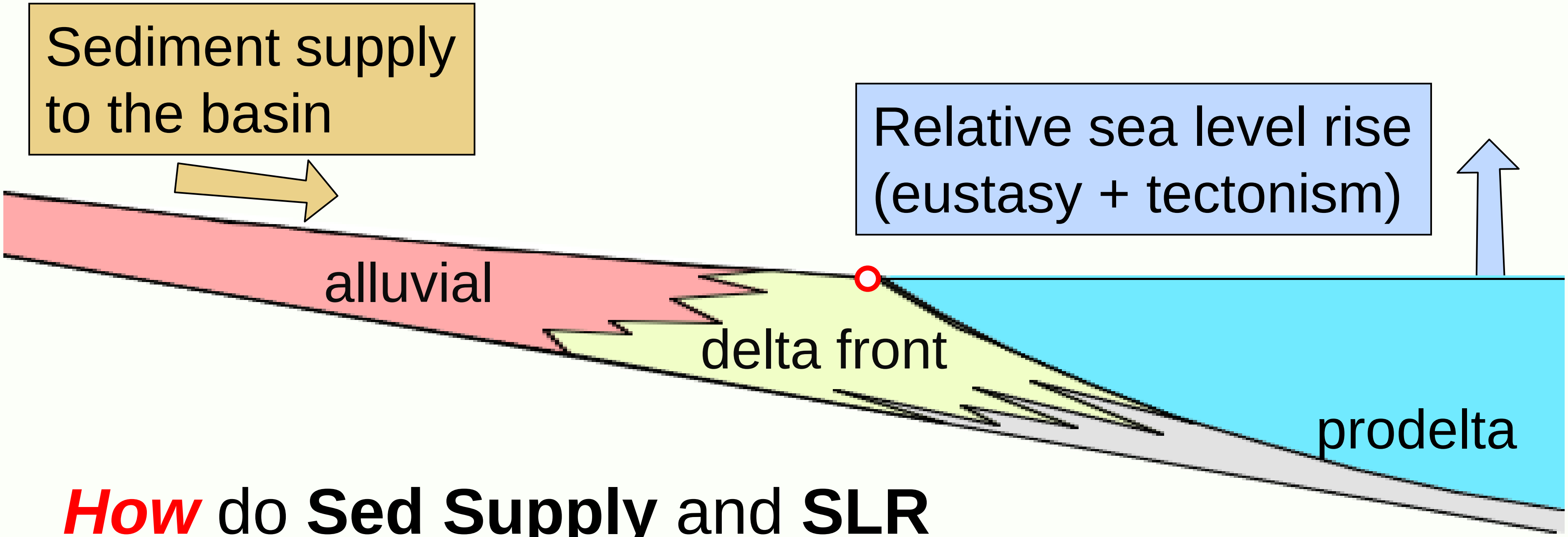
Why do regression and transgression occur with RISING sea level?



THE TWO PRIMARY FACTORS

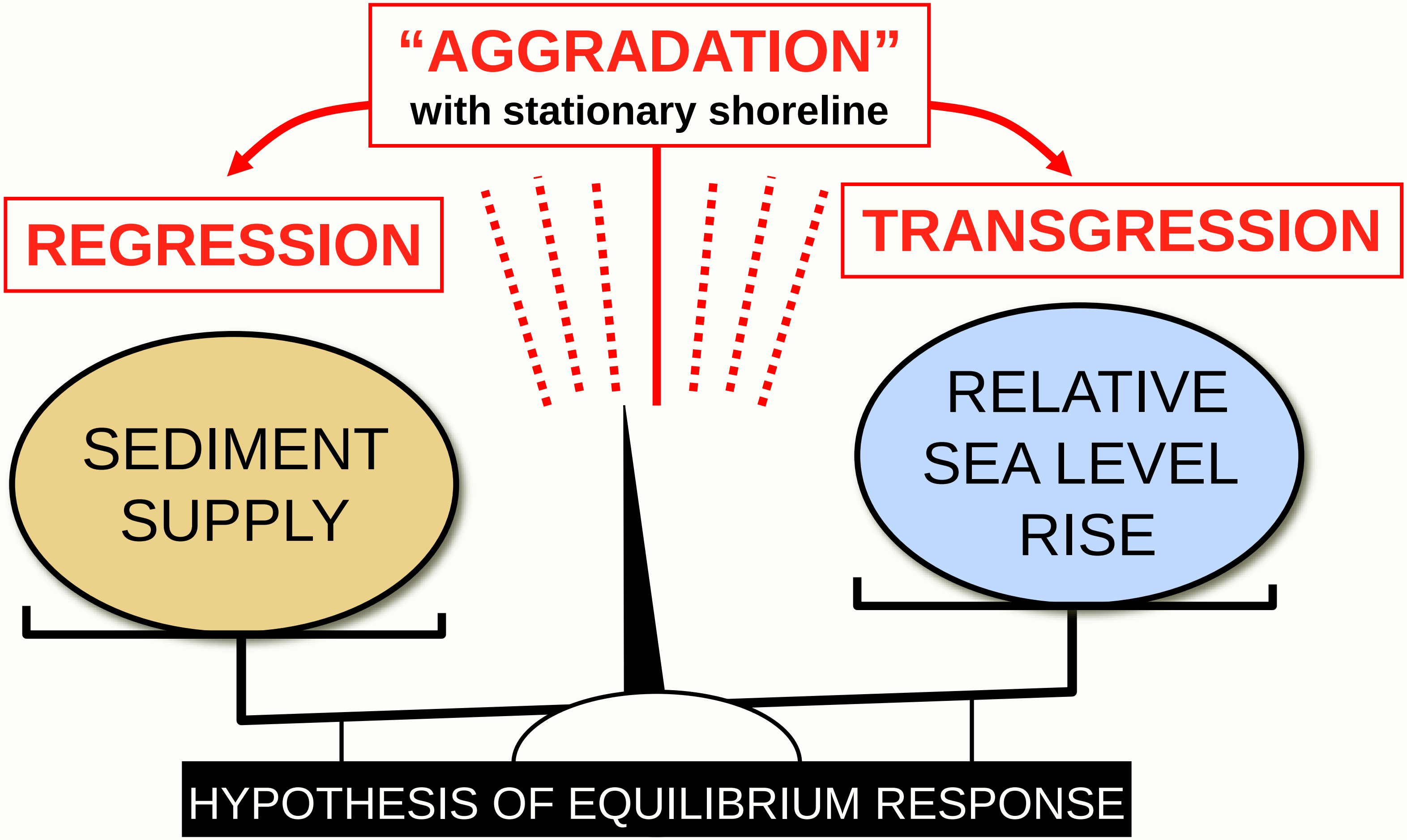


How do **Sed Supply** and **SLR** **function** in building stratigraphic architectures?

HYPOTHESIS OF EQUILIBRIUM RESPONSE

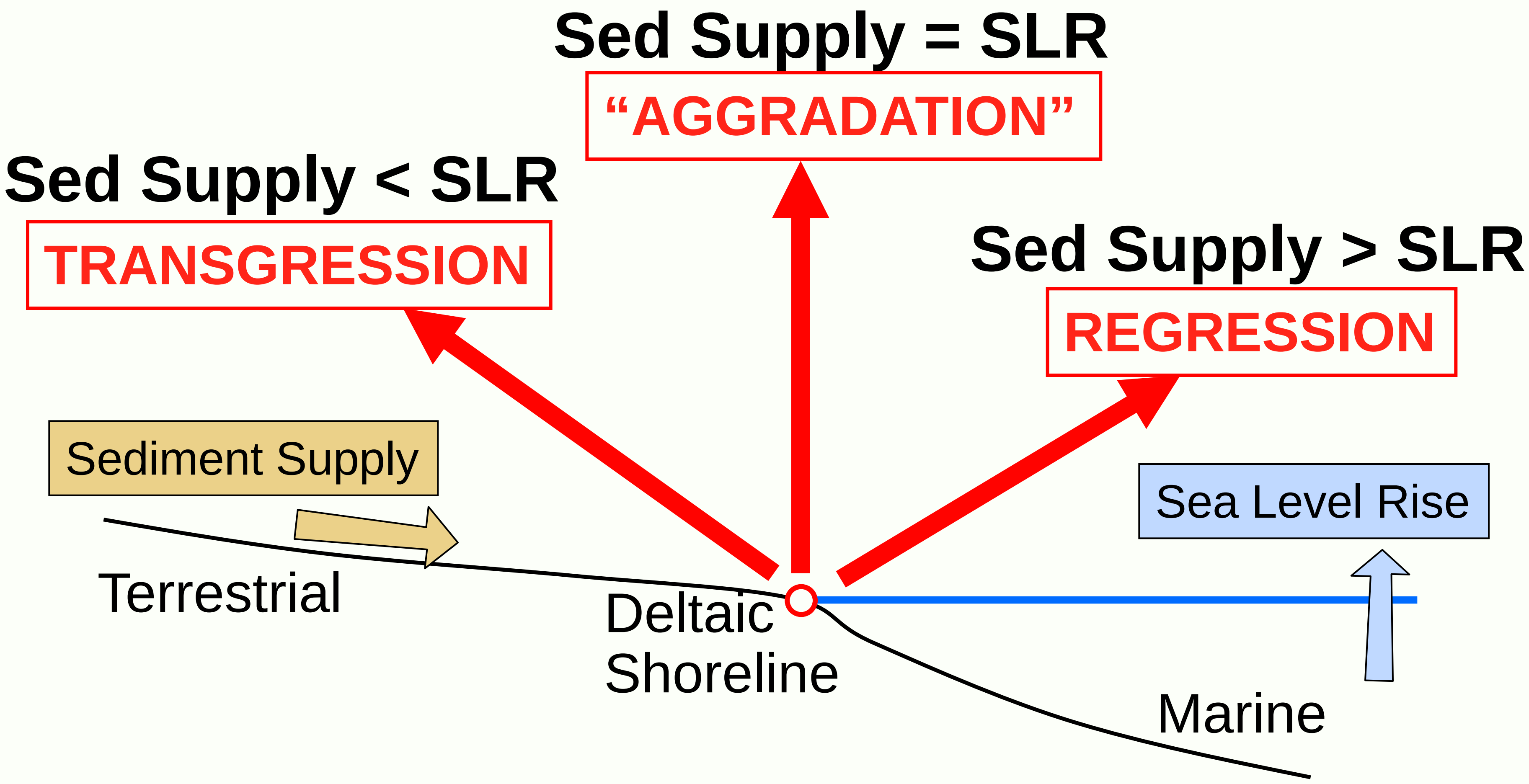
Hypothesis of equilibrium response

A primary stratigraphic function of **Sed Supply** & **SLR**



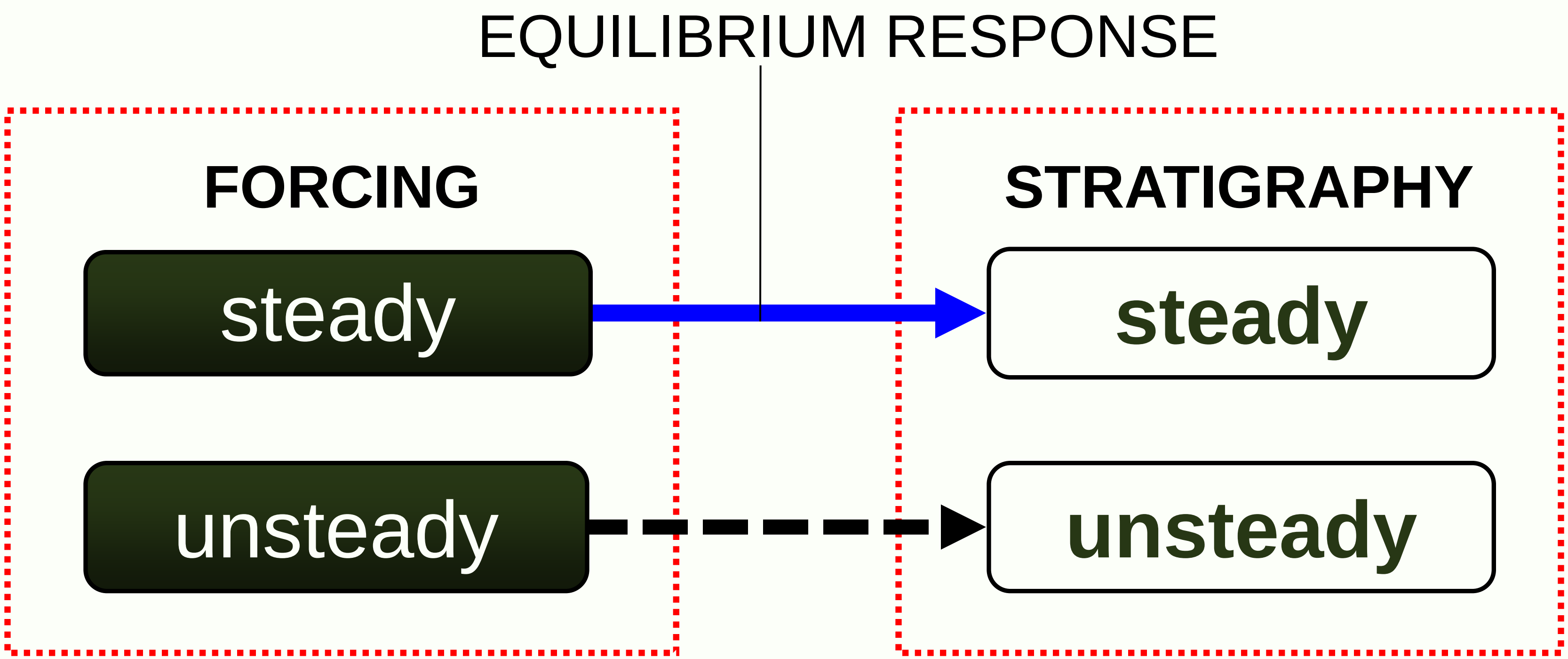
"There can be a state of **equilibrium** between Sed Supply & SLR."

The hypothesis of equilibrium response



The rationale for regression and transgression by the Hypothesis of Equilibrium Response

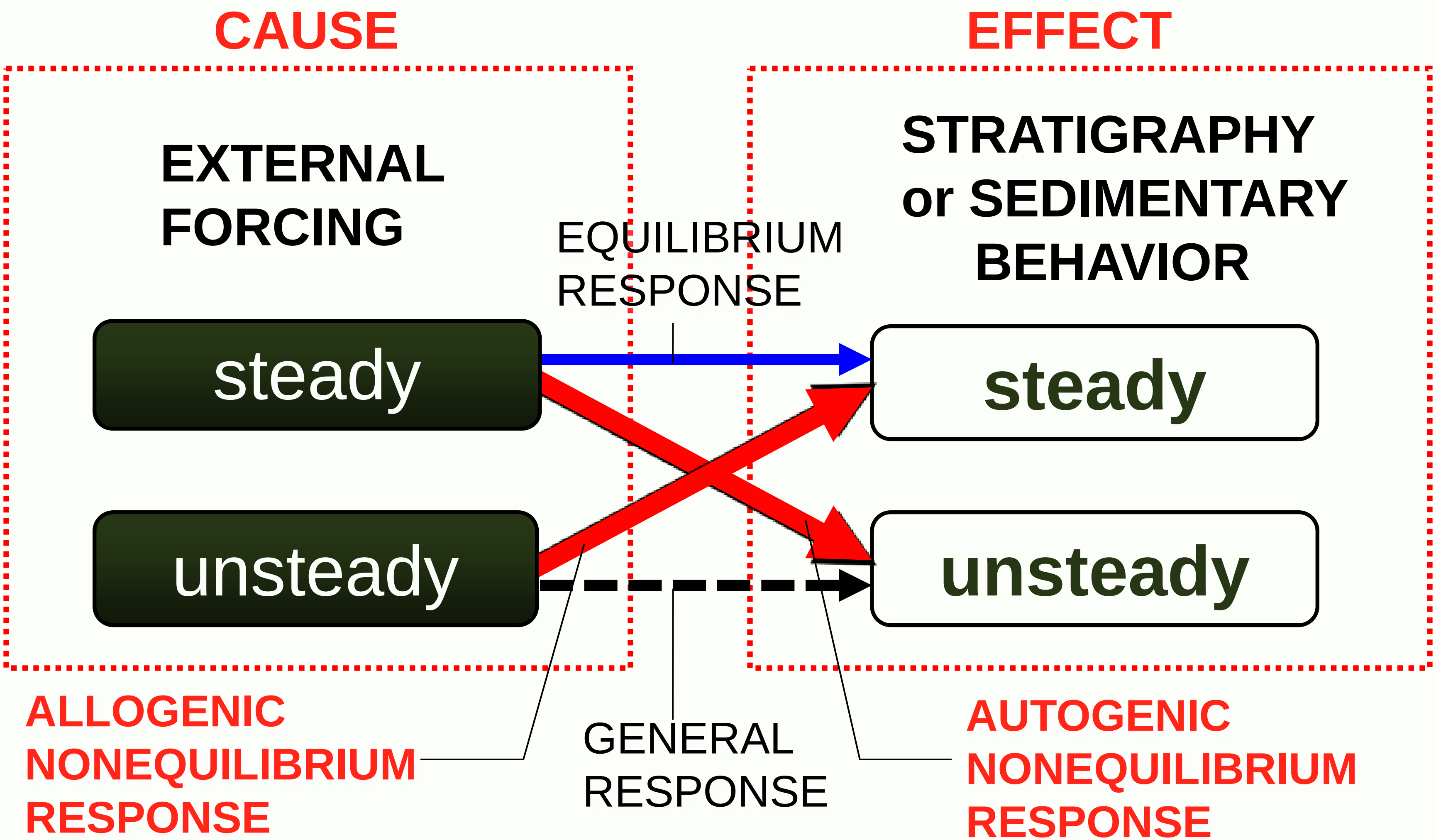
The hypothesis of equilibrium response



HER is based on the assumption that ER is **general**.

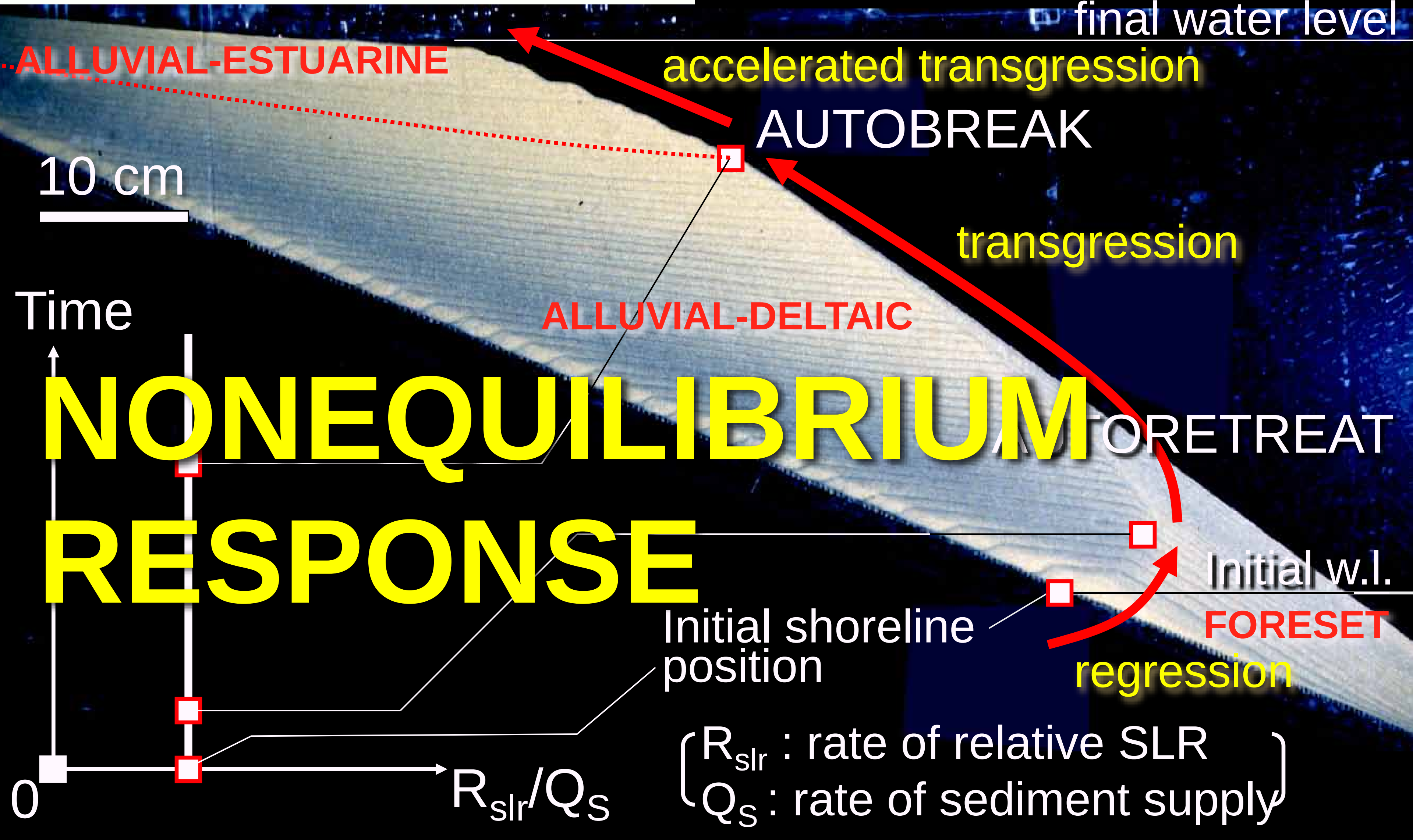
Unsteady stratigraphy is commonly attributed to **unsteady forcing** (i.e. allogenesis-biased interpretations).

Theoretically there can be four modes of stratigraphic response in terms of a **cause-and-effect** relationship.



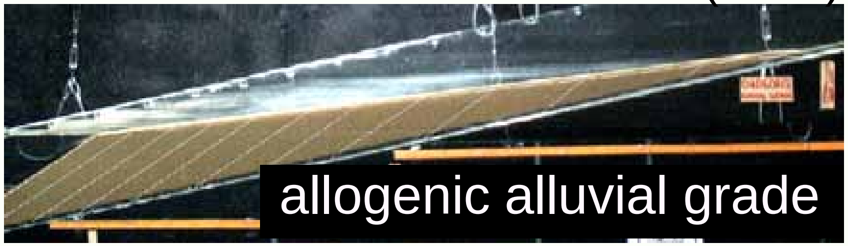
This deltaic clinoform was constructed in flume experiment with steady “sea” level rise. (Muto, 2001)

Rate of water-level rise R_{slr} = 0.0251cm/s
Sediment discharge Q_S = 1.029cm^2/s
Upstream water discharge Q_W = 4.36cm^2/s
Flume width W = 0.50 cm
Flume slope g= f = 25.4°



Nonequilibrium Responses

Muto and Swenson (2005)



ALLOGENIC
NONEQUILIBRIUM
RESPONSE

FORCING

steady

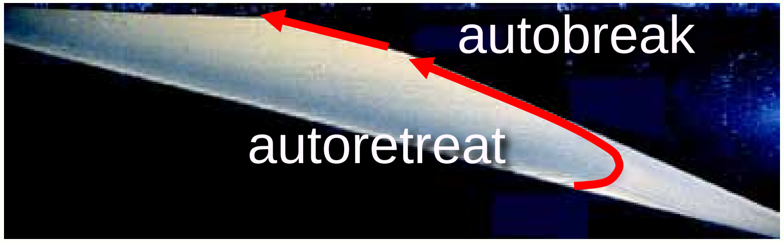
unsteady

STRATIGRAPHY

steady

unsteady

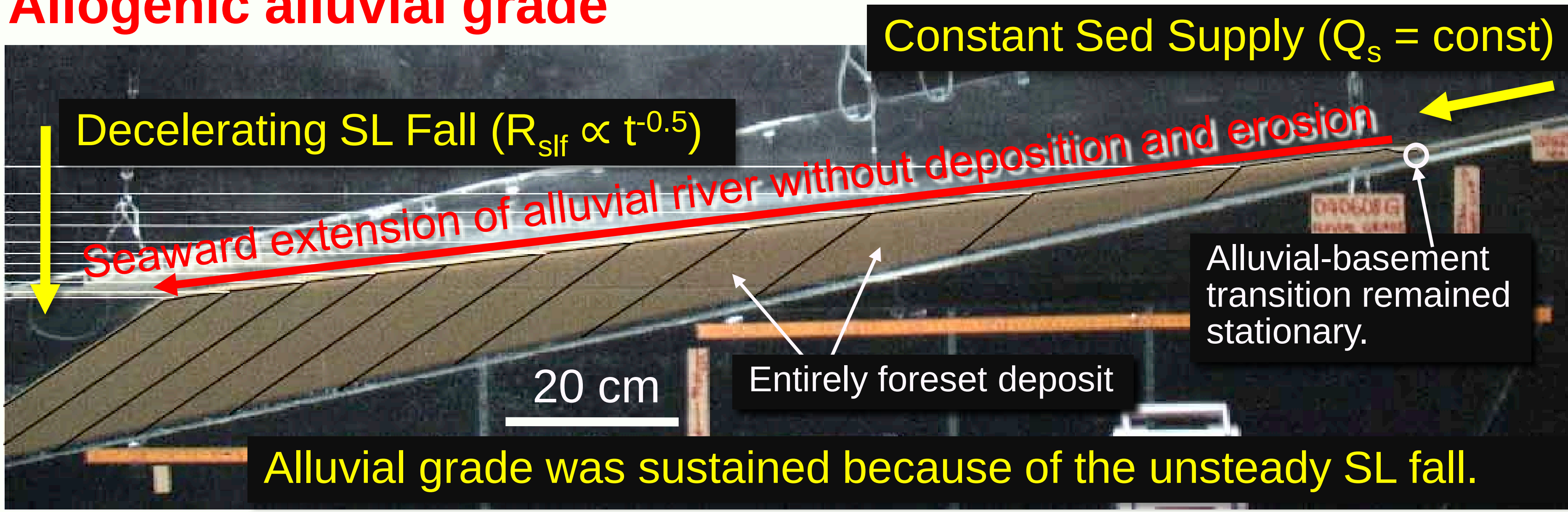
AUTOGENIC
NONEQUILIBRIUM
RESPONSE



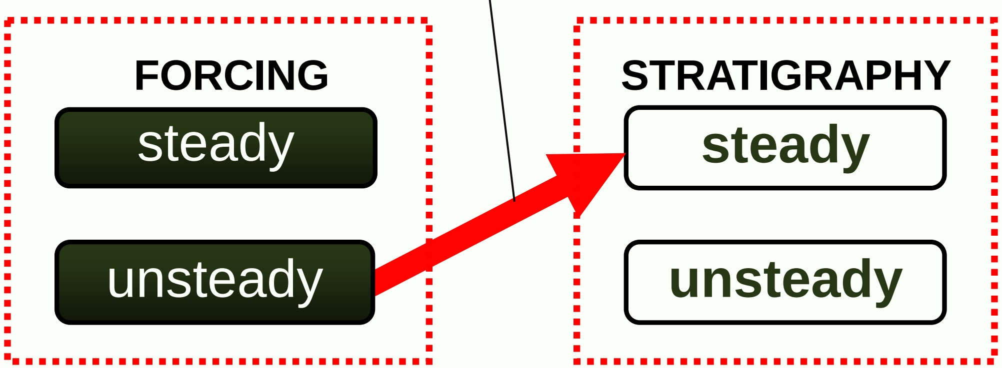
Muto (2001)

Allogenic nonequilibrium response

Allogenic alluvial grade



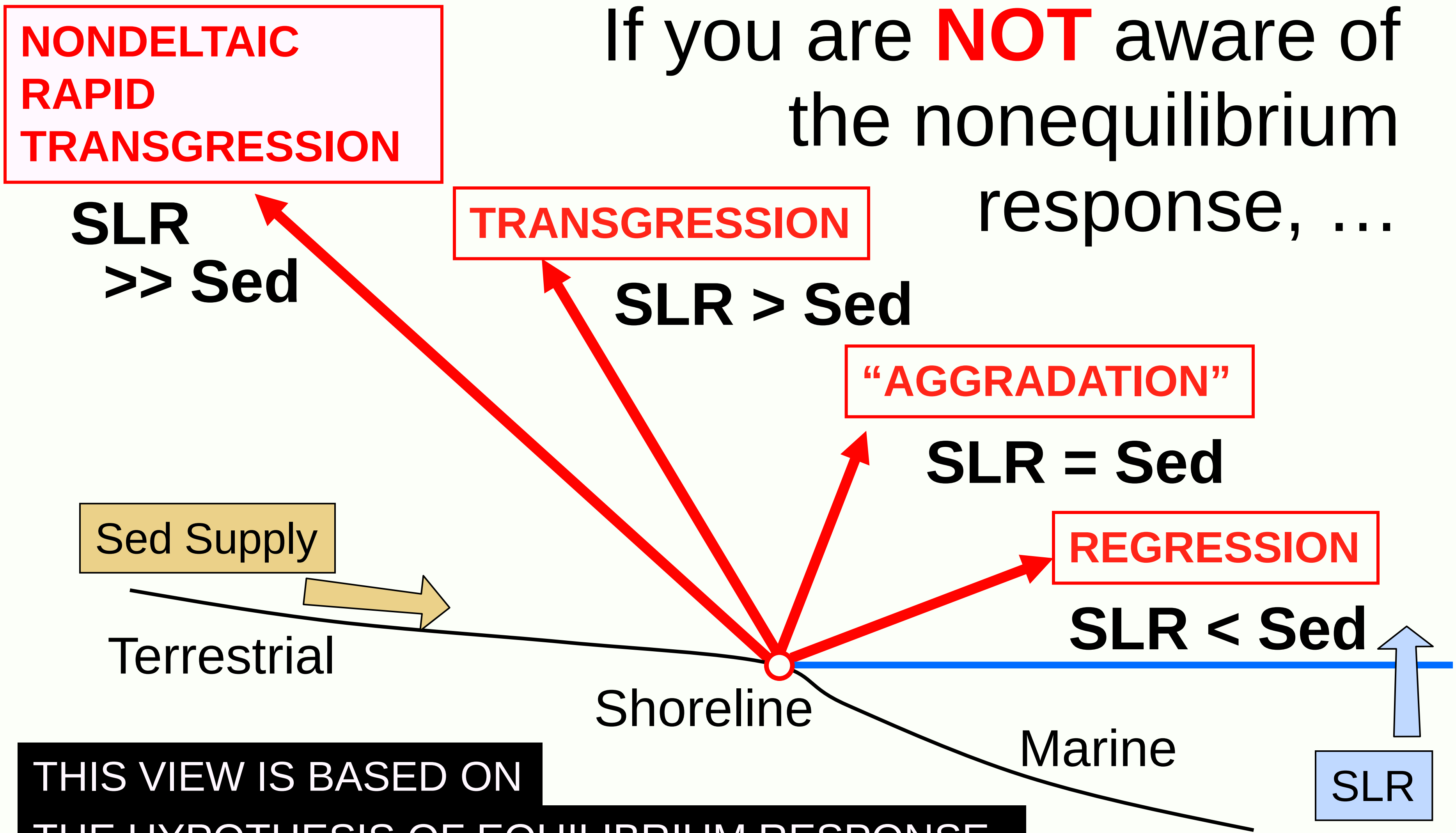
ALLOGENIC NONEQUILIBRIUM RESPONSE



The feeder alluvial river sustained **grade**, and the deltaic clinoform retained its original shape during progradation. This was possible because the **sea level fall decelerated** in a particular pattern.

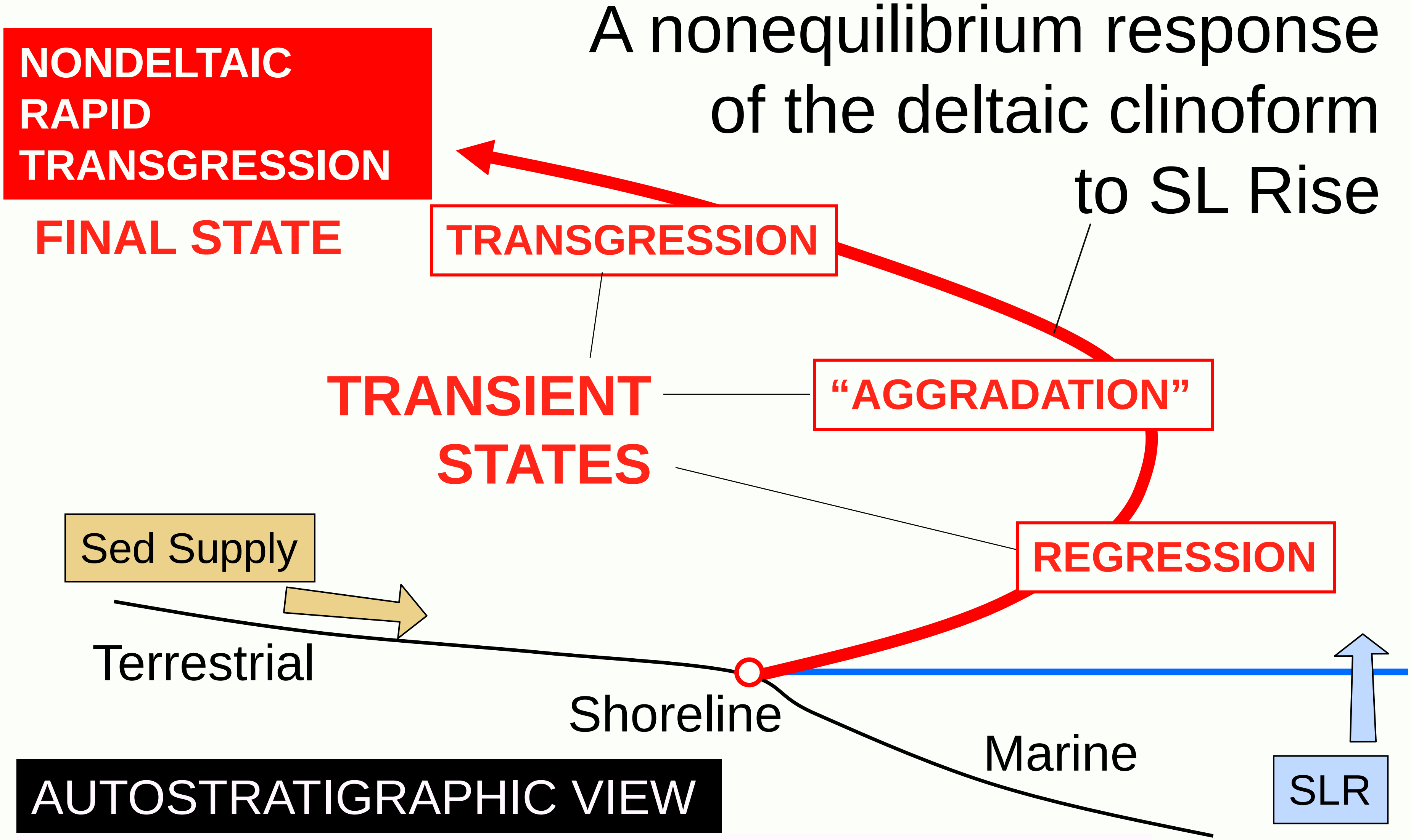
The conventional view of regression and transgression

If you are **NOT** aware of the nonequilibrium response, …



THIS VIEW IS BASED ON
THE HYPOTHESIS OF EQUILIBRIUM RESPONSE.

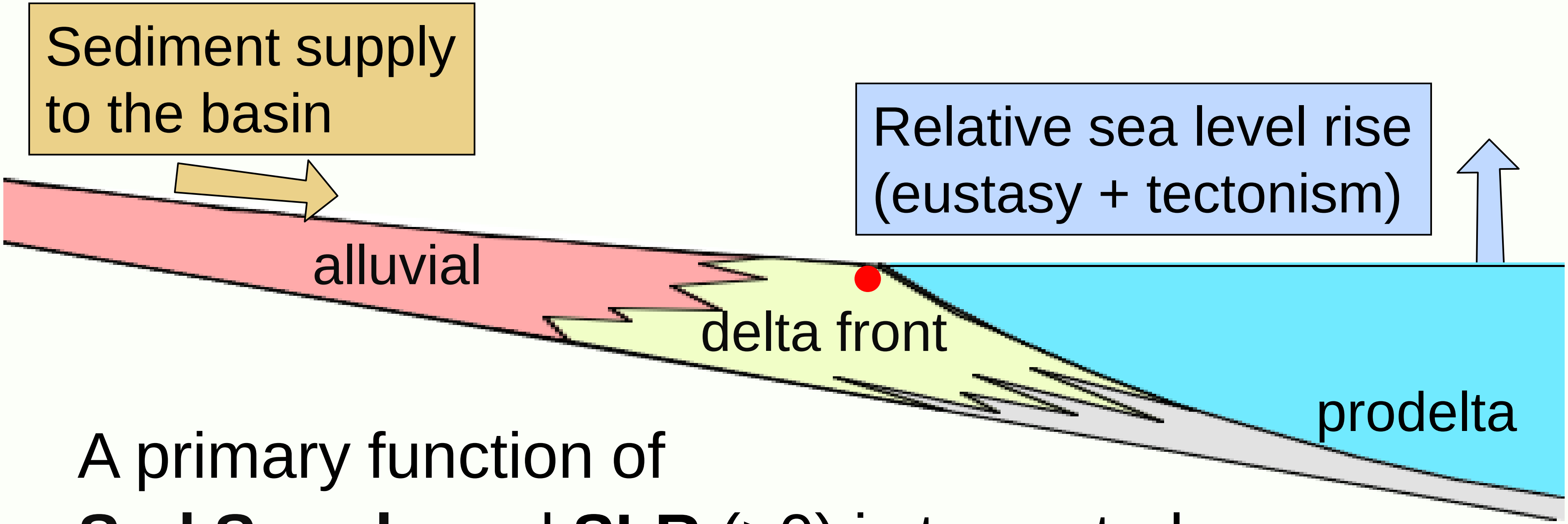
Autostratigraphic view of regression and transgression



Large-scale Deterministic Autogenesis + NonEquilibrium Responses

Primary function of Sed Supply and SLR

Rates (or relative rates) of Sed Supply and SLR (>0) do **NOT** determine which one of regression, transgression and "aggradation" occurs.



A primary function of **Sed Supply** and **SLR** (>0) is to control **length and time scales** of deltaic systems.

Primary function of Sed Supply and SLR

Deltaic clinoforms growing during sea level changes have **particular time and length scales** that are specified with magnitudes of rate of SL change and rate of Sed Supply.

rate of sediment supply in unit width

Autostratigraphic Length Scale

$$D = \frac{Q_S}{|R_{slr}|}$$

(where considered in unit width or in cross section)

rate of relative SL change

averaged alluvial slope

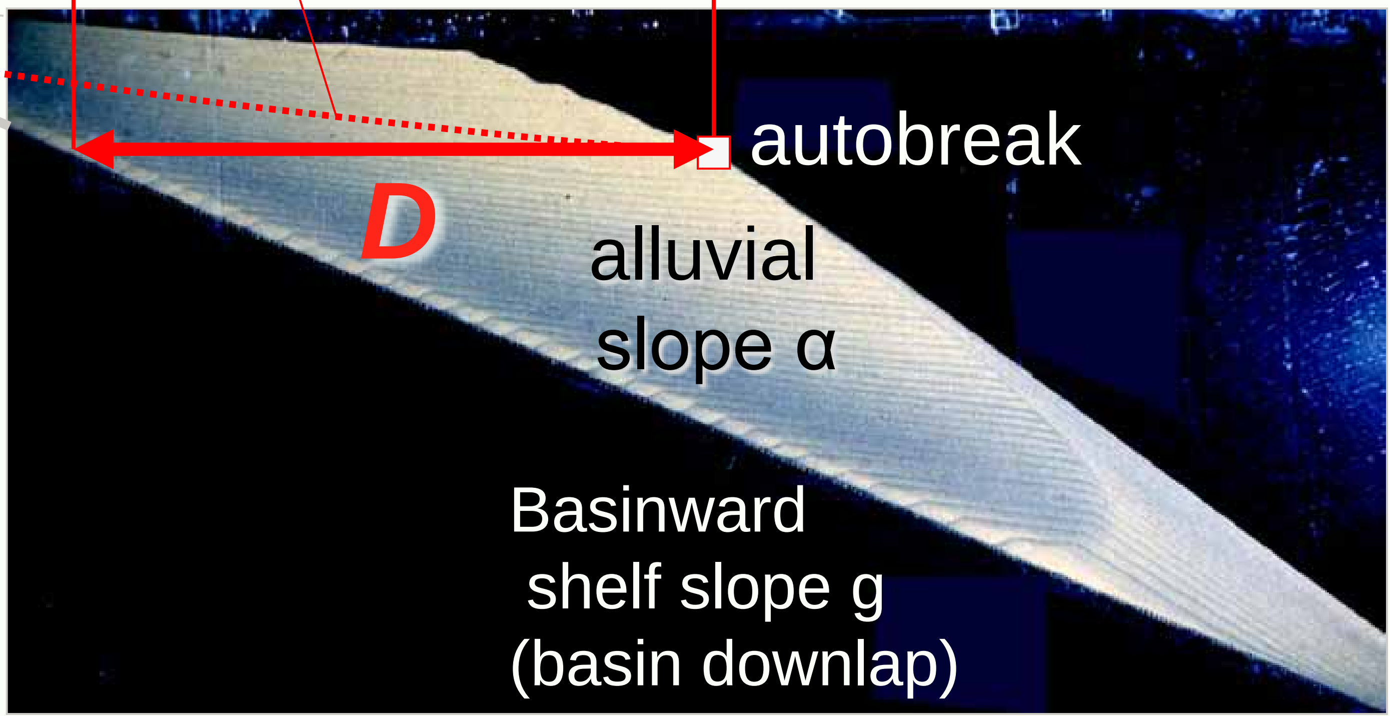
Autostratigraphic Time Scale

$$t = \frac{D^2}{u} = a\frac{D^2}{Q_S}\mu\frac{D}{|R_{slr}|}$$

diffusivity of alluvial sedimentation

$$L_{break} = D \frac{\sin g}{\sin(g - a)} » D$$

(if g >> a)



Landward
shelf slope g
(coastal onlap)

$$D = \frac{Q_S}{|R_{slr}|}$$

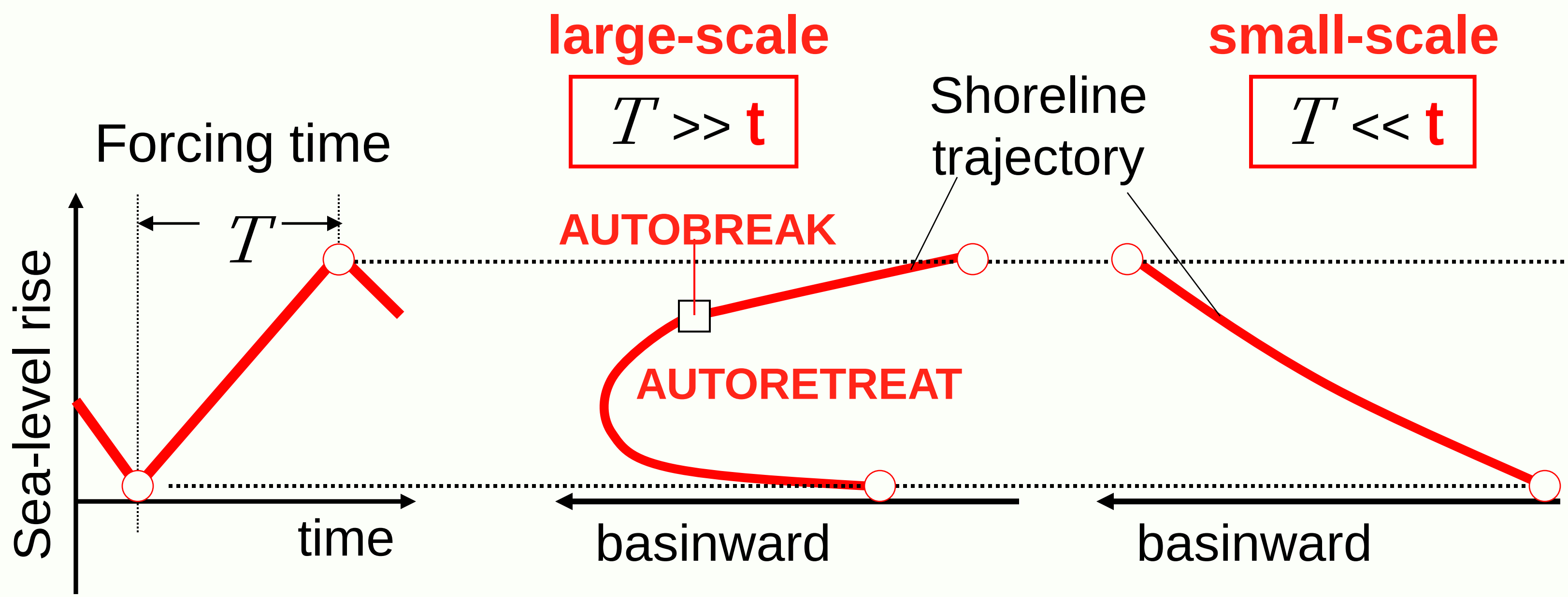
D represents the critical length of the alluvial river at the attainment of autobreak.

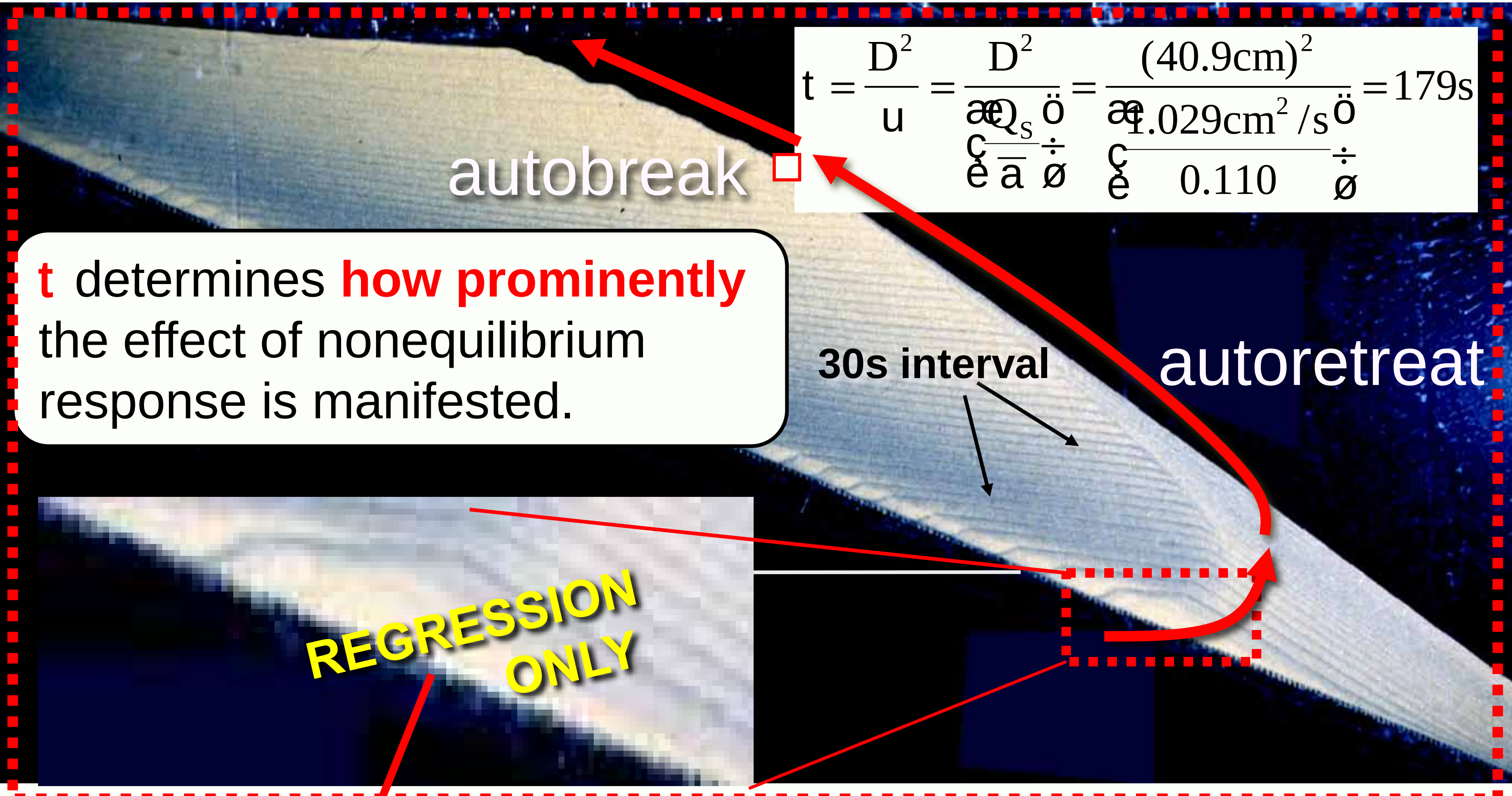
Autostratigraphic time scale τ

The primary meaning of t

$$t = \frac{D^2}{u} = a\frac{D^2}{Q_S}\,\mu\,\frac{D}{|R_{slr}|}$$

- T >> t ➞ Clear manifestation of nonequilibrium response
- T << t ➞ Apparent equilibrium response





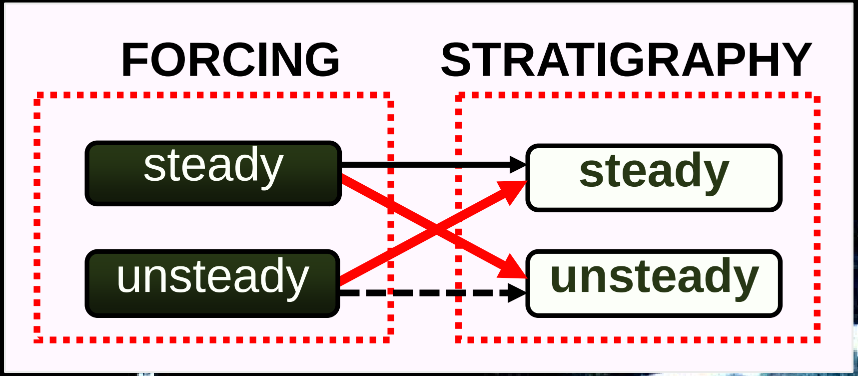
$$t = \frac{D^2}{u} = \frac{D^2}{\left(\frac{Q_s}{a}\right)} = \frac{(40.9\text{cm})^2}{\left(\frac{1.029\text{cm}^2/\text{s}}{0.110}\right)} = 179\text{s}$$

t determines **how prominently** the effect of nonequilibrium response is manifested.

If T = 60s << **t**, we hardly see the nonequilibrium response.

If ***T* = 1470s** >> **t**, the nonequilibrium response is prominent.

When ***autogenesis*** of deltaic clinoforms in response to sea level forcing is argued, it is recommended to take full account of the following key notions:



- ***Nonequilibrium*** Responses
- ***Large-scale Deterministic*** behavior
- ***Scales*** related to Sed Supply and SLR