

# The Valuation of Unconformities\*

Andrew Miall<sup>1</sup>

Search and Discovery Article #70225 (2016)\*\*

Posted October 31, 2016

\*Adapted from oral presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

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<sup>1</sup>Department of Earth Sciences, University of Toronto, Toronto, Ontario, Canada ([miall@es.utoronto.ca](mailto:miall@es.utoronto.ca))

## Abstract

Eliot Blackwelder published a paper with this title in 1909. He was the first to demonstrate that the Phanerozoic record of North America contains continent-wide regional unconformities that divide the stratigraphy into what we would now call sequences. Subsequent studies by Grabau, Barrell, Wheeler, Ager, Dott, Sadler, and others have helped to clarify the issue of missing time in the rock record, and unconformities now play a key role in the definition and mapping of sequences. Calculated sedimentation rates for the ancient record indicate that as little as 10% of elapsed time is recorded by rock at measured time scales in the 10<sup>6</sup>-year range, the remainder being missing at sedimentary breaks.

Recent refinements in chronostratigraphic methods and the availability of a reliable Global Time Scale permit a more detailed evaluation of the nature of unconformities and other sedimentary breaks. They may be grouped into four broad classes.

- 1) Major breaks spanning 10<sup>6</sup>-10<sup>7</sup> years. These are generated by five distinct processes: a) Orogenic tectonism. Hutton's classic unconformity at Siccar Point in southeast Scotland is of this type. b) Dynamic topography. This is the term for the slow elevation and subsidence of the craton in response to changing thermal properties of the underlying mantle. Example: the great basal Phanerozoic unconformity overlying the Canadian Shield. c) Dynamic unconformities associated with basin formation, including breakup unconformities and flexural onlap in extensional basins, and the onlap/offlap stratigraphy of foreland-basin forebulges. d) Global eustasy, caused by changing rates of seafloor spreading and its effect on the total global volume of the ocean basins. The resulting breaks are the basis for the definition of what have come to be called Sloss sequences. e) Long-term environmental change, generating eolian supersurfaces, and drowning unconformities in carbonates.
- 2) Breaks of two distinct types that span 10<sup>4</sup>-10<sup>5</sup> years: a) Unconformities generated by high-frequency tectonism, including the regional propagation of such breaks by intraplate stresses. Sequences of regional extent may be bounded by breaks of this type. b) Glacioeustatic sea-level changes generated by orbital forcing of global climate change. Example: Cyclothem boundaries in the late Paleozoic record of the US Midcontinent.

- 3) Hiatuses of  $10^0$ - $10^3$ -year duration, the product of autogenic, seasonal to long-term geomorphic processes, which drive the migration and switching of depositional systems, including shelf clinoforms and deltas.
- 4) Minor breaks of  $10^{-6}$ - $10^{-1}$ -year duration (minutes to months), the breaks generated by bedform and bar migration. The product of diurnal, monthly (lunar), and normal meteorological changes in runoff; tidal cycles.

Identification and classification of unconformities and other sedimentary breaks is an essential component of high-resolution stratigraphic mapping.

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# THE VALUATION OF UNCONFORMITIES

Andrew Miall

Department of Earth Sciences, University of Toronto  
Toronto, Ontario M5S 3B1, Canada



	TEXAS REGION	CENTRAL INTERIOR	LAKE REGION	LABRADOR
Quaternary				
Tertiary				
Cretaceous				
Jurassic				
Triassic				
Permian				
Pennsylvanian				
Mississippian				
Devonian				
Silurian				
Ordovician				
Cambrian				
Pre-Cambrian				

Fig. 4.—Diagram of an unconformity with lateral extensions and restrictions. The extent and duration of the principal periods and areas of sedimentation, with their corresponding rock systems, are shown in solid black. The white, on the other hand, denotes the time and extent of erosional conditions and corresponding unconformities.

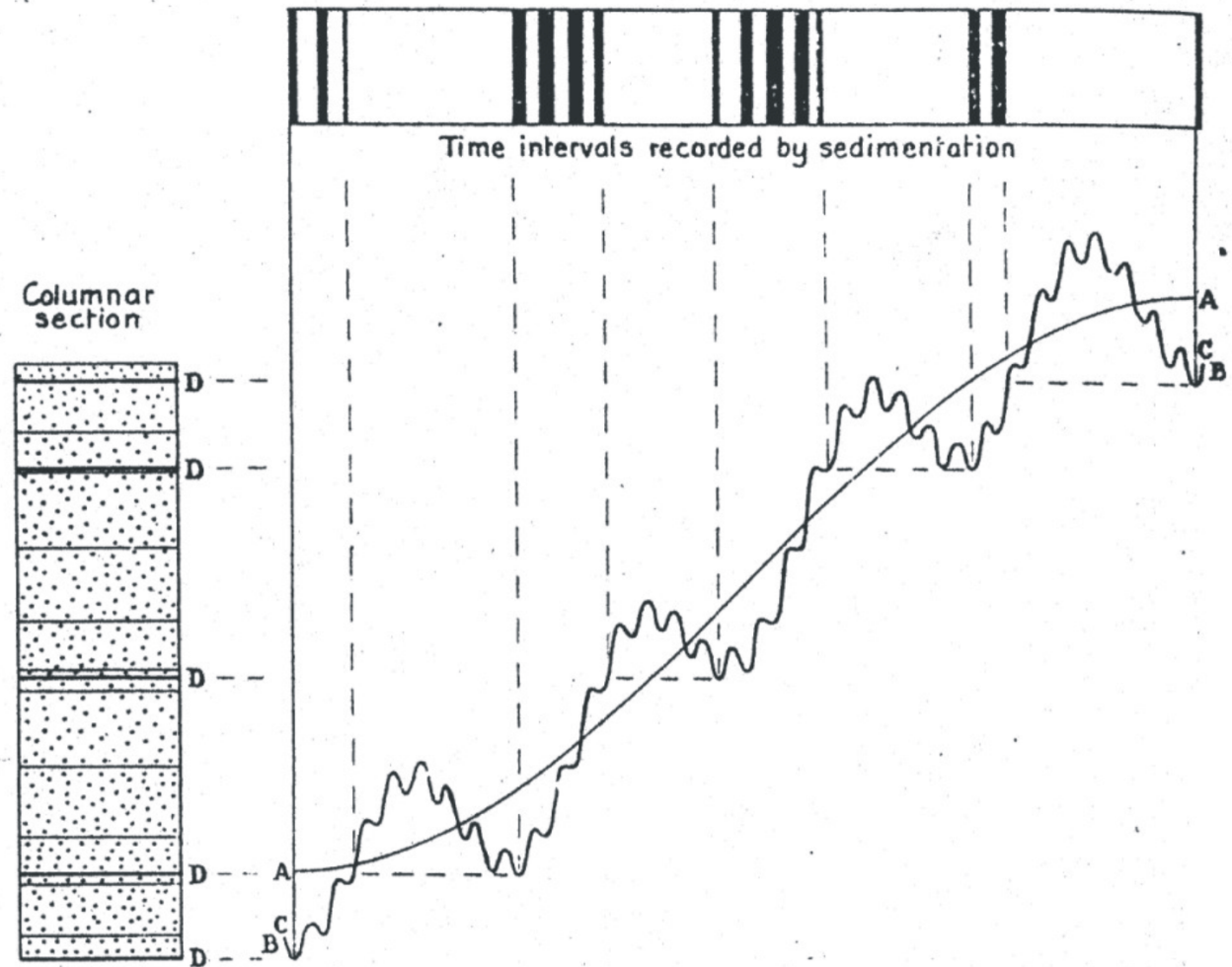


FIGURE 5.—Sedimentary Record made by harmonic Oscillations in Baselevel

A-A. Primary curve of rising baselevel.

B-B. Diastrophic oscillations, giving disconformities D-D.

C-C. Minor oscillations, exaggerated and simplified, due largely to climatic rhythms.

Equation of curve C-C:  $y = \sin x - .25 \cos 8x - .05 \cos 64x$ .

Early studies of stratigraphy and time. Left: Blackwelder (1909): regional unconformities in North America

Right: Barrell (1917): Diagram explaining how depositional episodes relate to combined cycles of accommodation generation





Unconformity between Carboniferous Limestone and Sutton Stone (basal Blue Lias: Early Jurassic), Glamorgan, Wales. (photo: P. Burgess)

This location was the source of a major debate about geology and time Initiated by Derek Ager in 1986



## A reinterpretation of the basal 'Littoral Lias' of the Vale of Glamorgan

Derek Ager

AGER, D. V. 1986. A reinterpretation of the basal 'Littoral Lias' of the Vale of Glamorgan. *Proc. Geol. Ass.* **97** (1), 29–35. The conglomeratic Sutton Stone of the Vale of Glamorgan, which has for many years been thought of as a littoral deposit laid down by the first waves of a transgressive sea during a long period of early Jurassic time, is here interpreted as a mass flow deposit laid down very rapidly, probably by a storm.

But the lower part of the Sutton Formation between Ogmore-by-Sea and Dunraven Bay seems to me to have been deposited very rapidly indeed. There may have been a very long period when nothing much happened. The Sutton Stone was simply the first sediment to be laid down and left for the benefit of future geologists. I do not think it took the three or four million years or so of three or four or five ammonite chronozones.

### 3. CONCLUSION

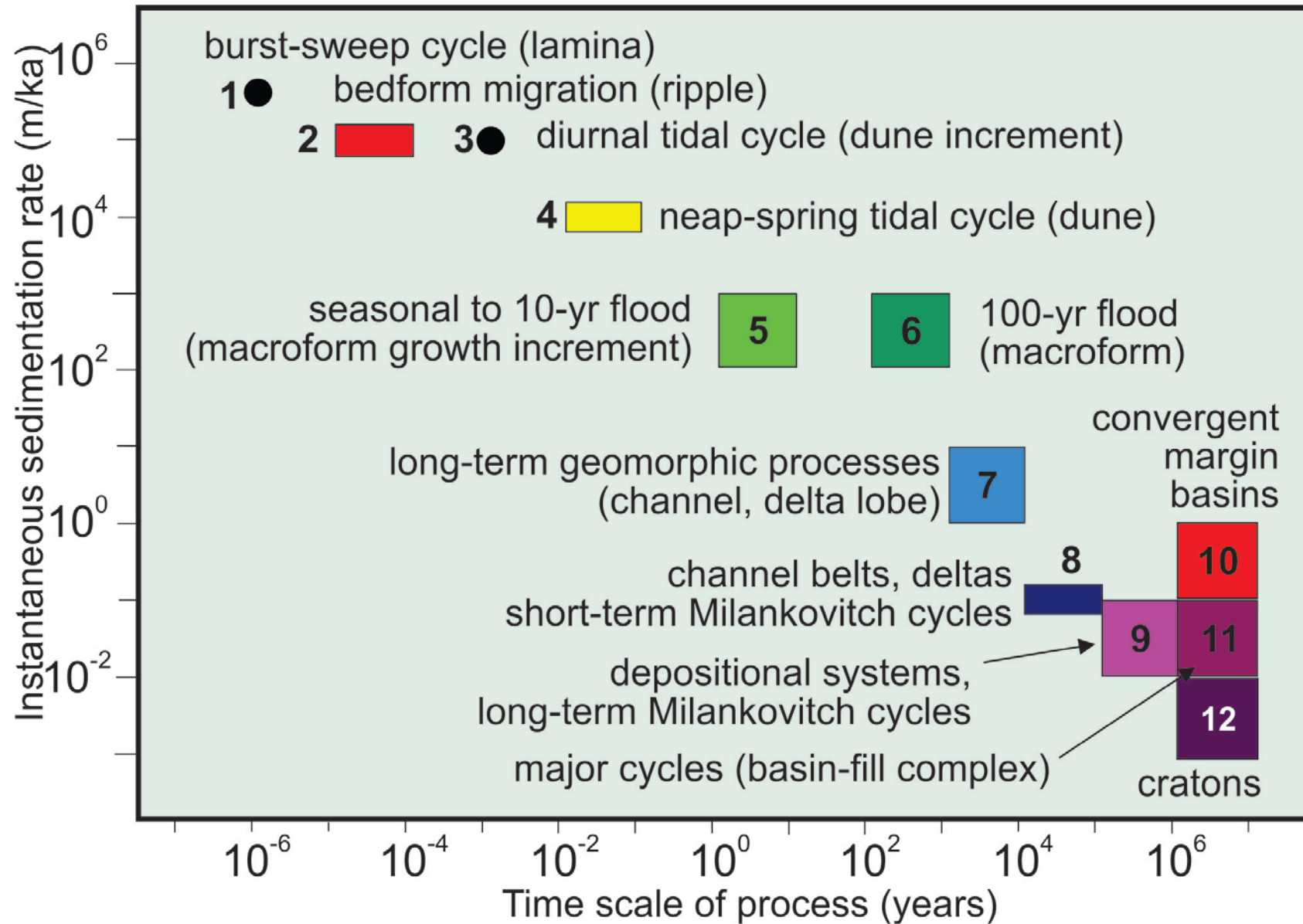
It all happened one Tuesday afternoon.



## SRS 2/3: Storm deposit

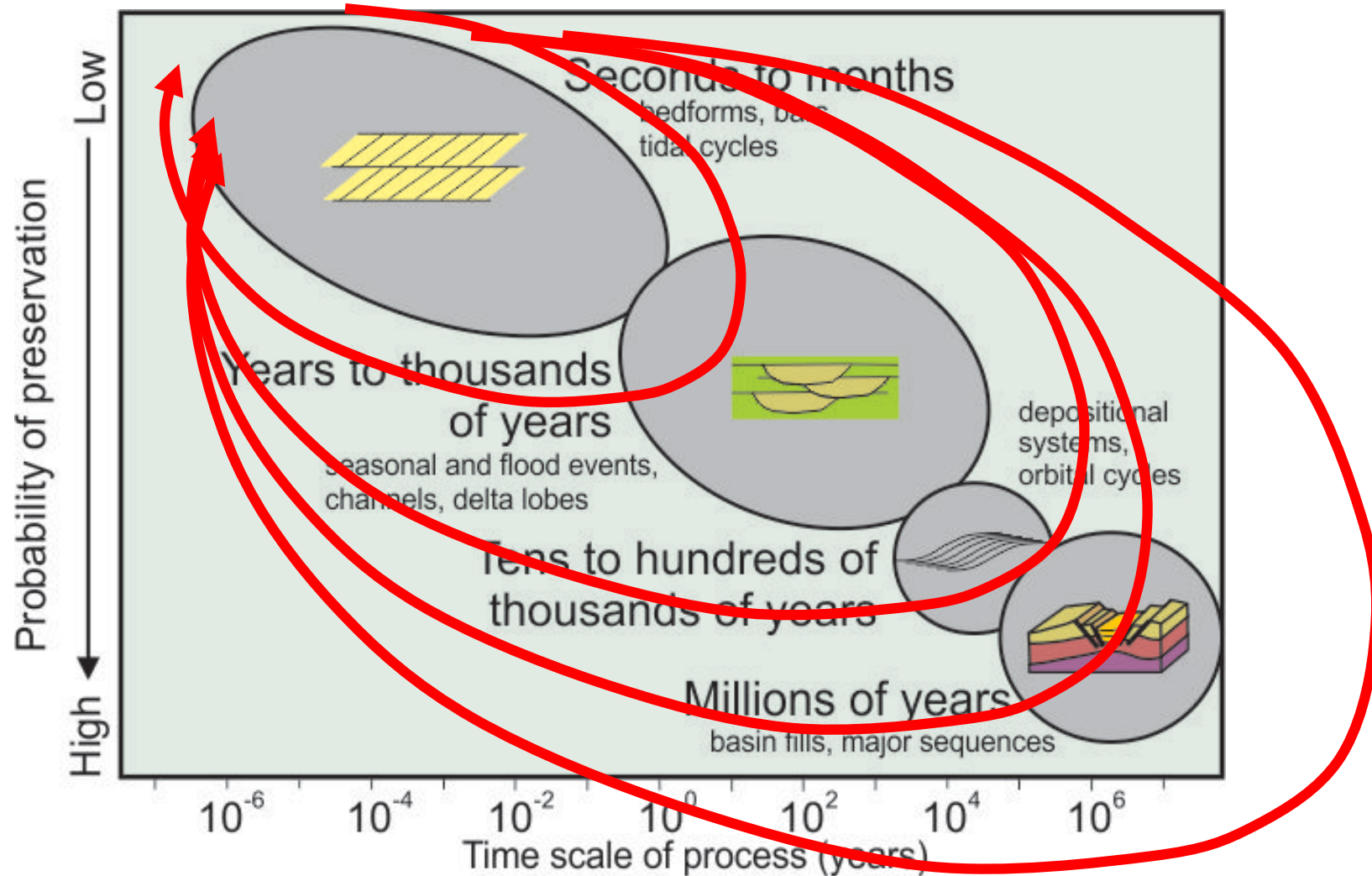
1.2 m conglomerate deposited in 4 hrs = 2,628,000 m/ka ( $10^6$  m/ka)

There were 208,000,000 Tuesdays during the “three or four” ammonite chronozones of the early Jurassic (4 my), but there is only one basal Lias conglomerate. What does it all mean?



Sadler's (1981) data detailing the relationship between sedimentation rate and time scales, Interpreted in terms of geological processes (Miall, 2015)





The geological preservation machine:

The time scale of geological processes

# A classification of unconformities

SRS	Time scale (yrs)	Inst Sed Rate (m/ka)	Process	Description of break	Field characteristics of sedimentary break and/or of beds above and below
1-4	$10^{-6}$ - $10^{-1}$	$10^4$ - $10^6$	Bedform migration; diurnal to normal meteorological change in runoff; tidal cycles	Local channel scours	Nesting of channels, macroforms and bedforms within a structure of minor bounding surfaces (ranks 1-5 of Miall, 1996).
5-7	$10^0$ - $10^3$	$10^0$ - $10^3$	Autogenic seasonal to long-term geomorphic processes  Rare extreme weather events	Migration and switching of depositional systems  Marked facies change, minor regional erosion	Superimposition of alluvial sheets, deltas and shelf-margin clinoform lobes separated by transgressive ravinement surfaces, rare preservation of falling-stage incised distributary channels, incised valleys  Facies blanket, regional marker horizon
7-9	$10^4$ - $10^5$	$10^{-2}$ - $10^0$	High-frequency tectonism  Regional response to flexural loading/unloading  Far-field intraplate stress changes  Orbital forcing	Syn depositional unconformities  Basin-wide low-angle unconformities  Tilting and warping of sequences and sequence sets  Continental (potentially global) - scale, non-angular break	Strong but very localized angularity, coarse clastic wedges ("growth strata")  Low- to very low-angle clinoform sets Evidence of fluvial or marine erosion, transgressive lag deposits at breaks  Widespread shifts in paleocurrent patterns, shoreline trends  Cyclothemic facies changes, potentially deep erosion of unconformity surface, coastal and shelf-margin clinoform onlap-offlap cycles
9-12	$10^6$ - $10^7$	$10^{-3}$ - $10^{-1}$	Orogenic tectonism  Dynamic unconformities associated with basin fm  Dynamic topography  Global eustasy	Regional angular unconformity  Onlap and offlap caused by basin subsidence  Sub-continental unconformity  Global unconformity	May be associated with deep erosional relief, clastic wedges  Onlap of extensional margins during flexural subsidence Onlap/offlap during motion of foreland-basin forebulge  Low-angularity (units above and below have similar dip). Commonly little field evidence of major time break  Similar to above



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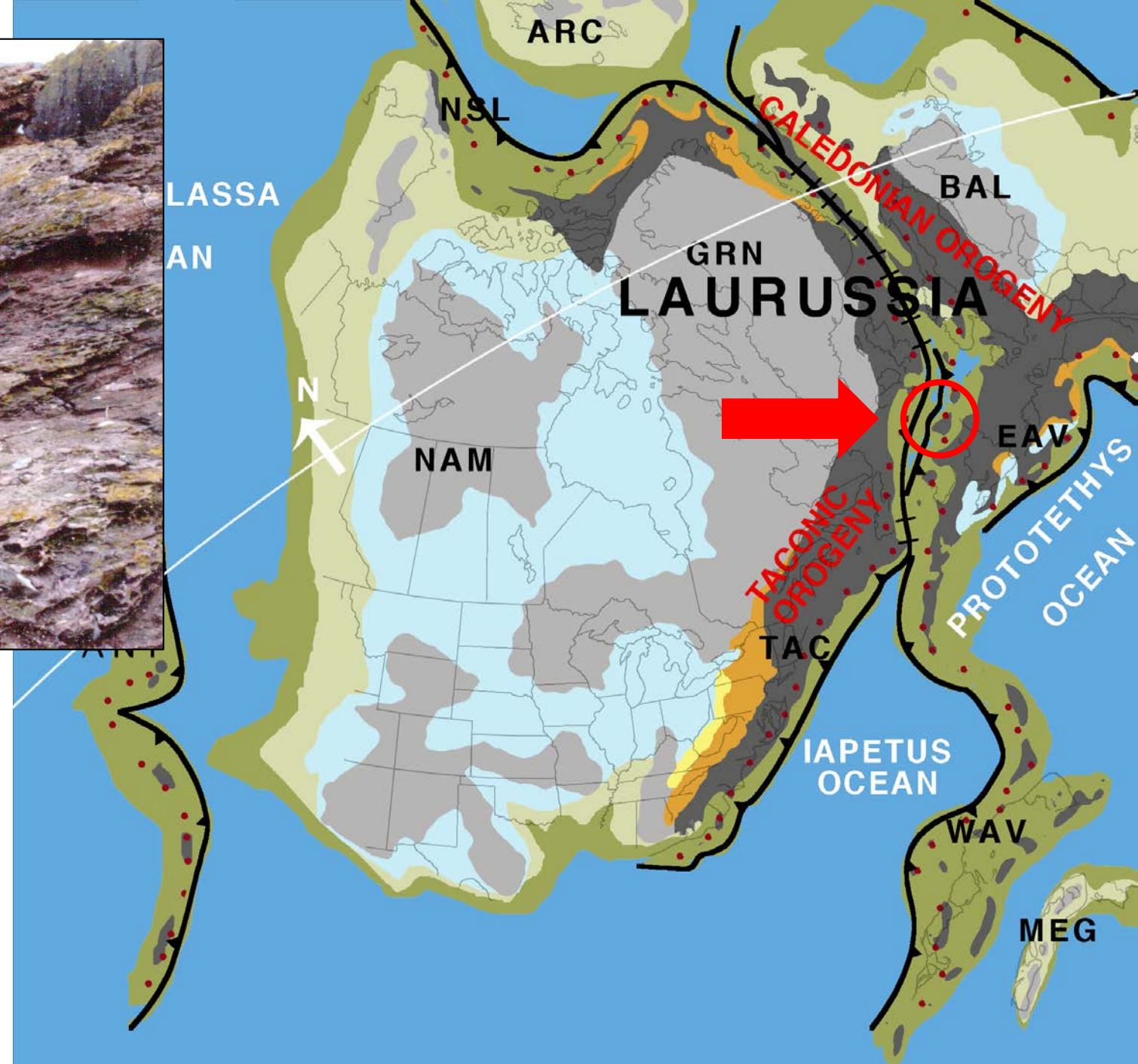


### Major orogenic unconformity

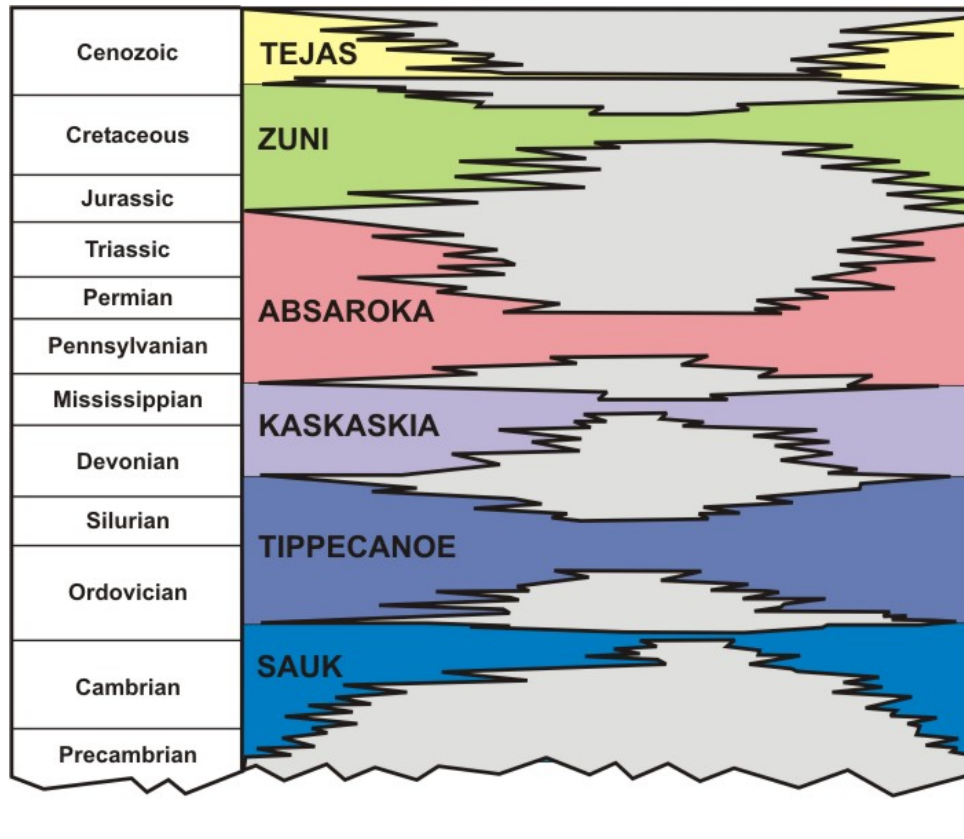
Siccar Point, southeast Scotland.

Marks the contact between Caledonian subduction complex (Silurian) and post-orogenic Old Red Sandstone (Devonian).

Time missing at break ~65 my



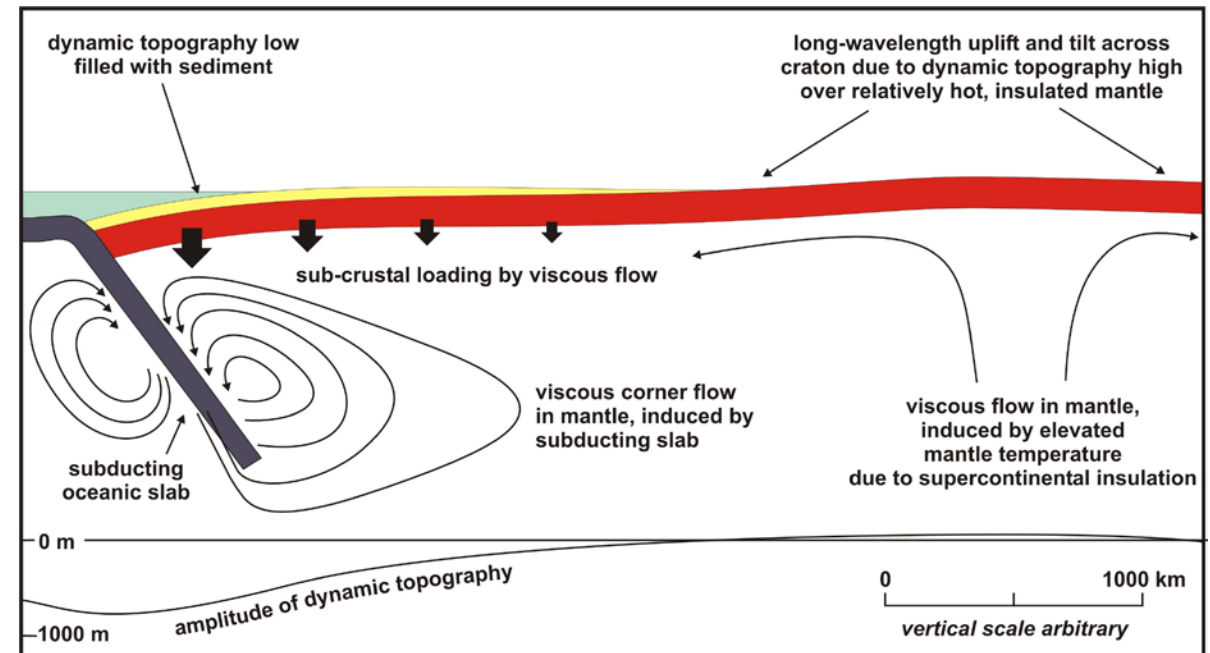
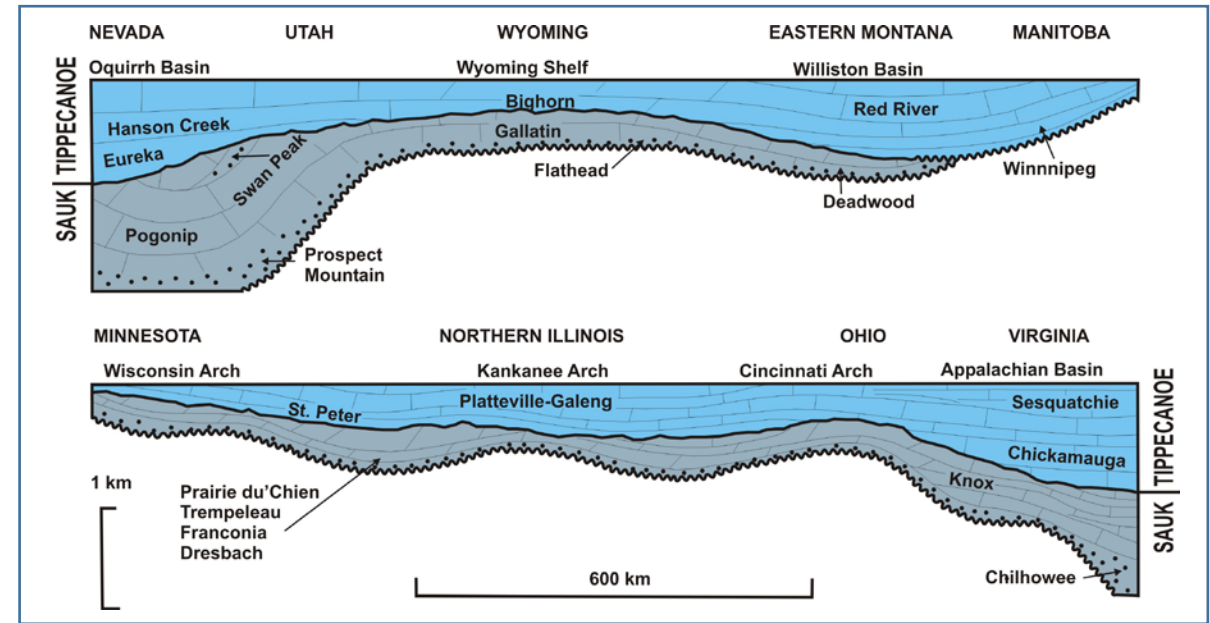




## Sloss sequences

A combined product of eustasy and dynamic topography on a  $10^6$ - $10^7$ -year time scale.

Note the low-angle unconformity defining the sequence boundary (top right)



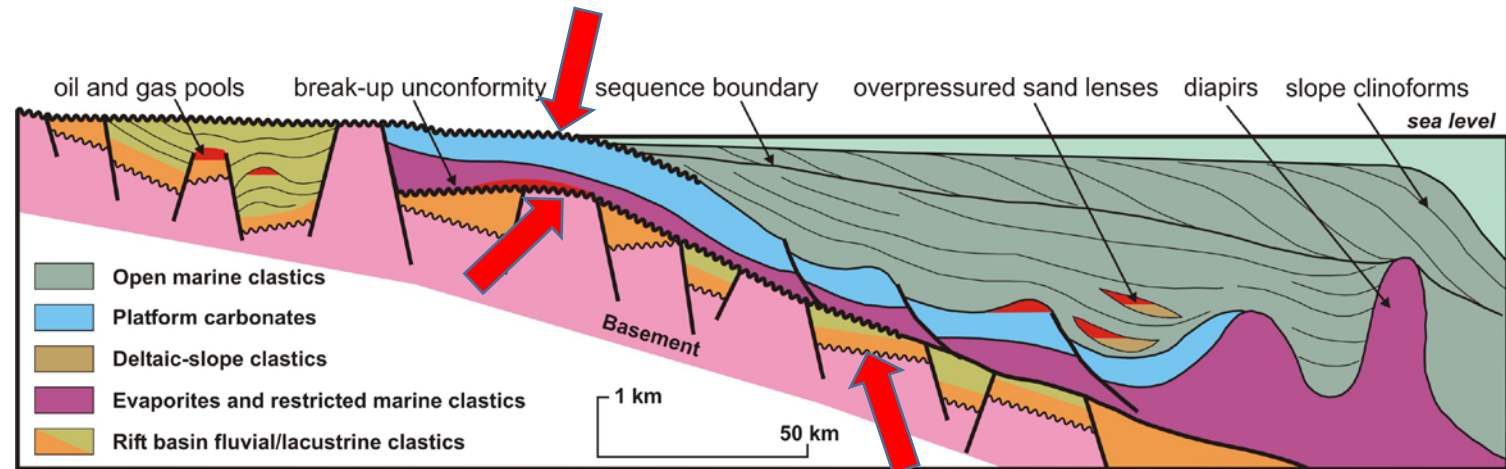
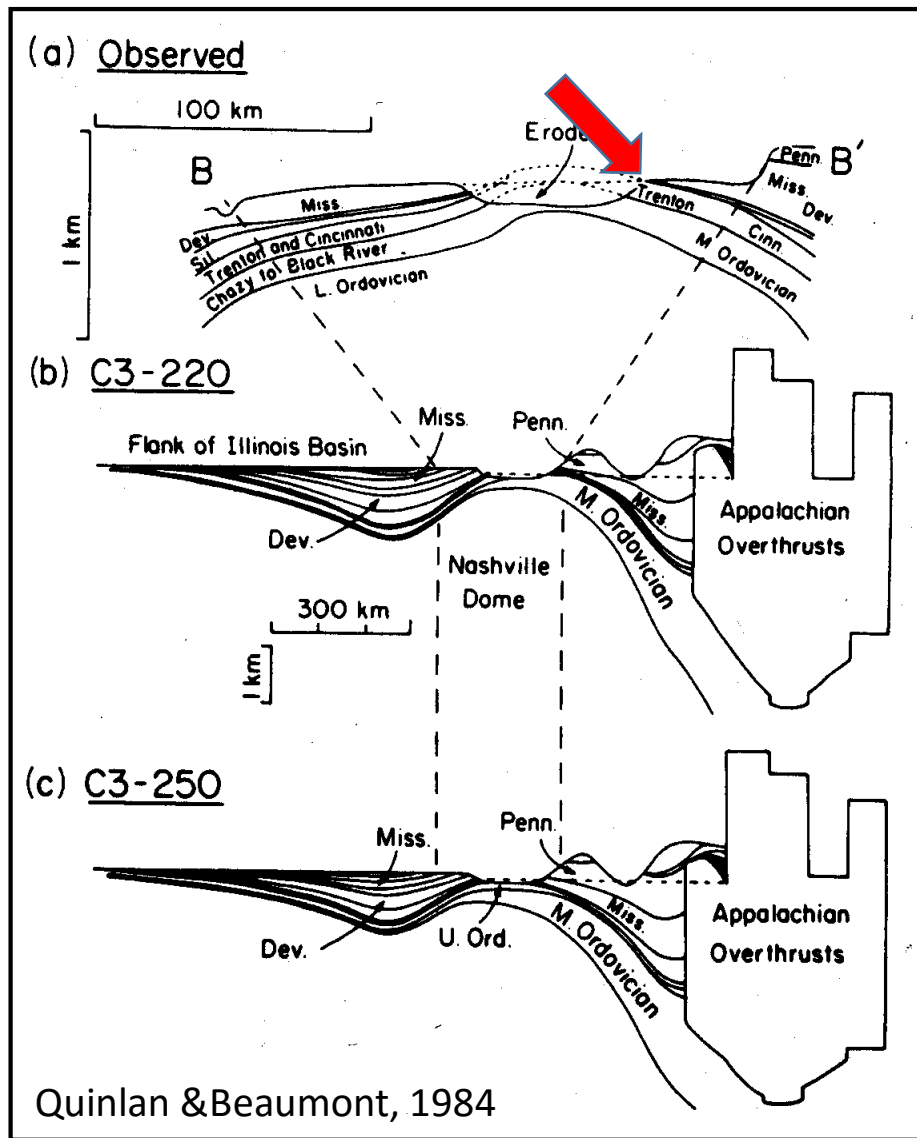




The continental-scale unconformity defining the boundary between the Precambrian Shield and Paleozoic strata across the interior of North America. A product of dynamic topography. Duration of break: at least several hundred million years

Left: southern Ontario, Right: Grand Canyon



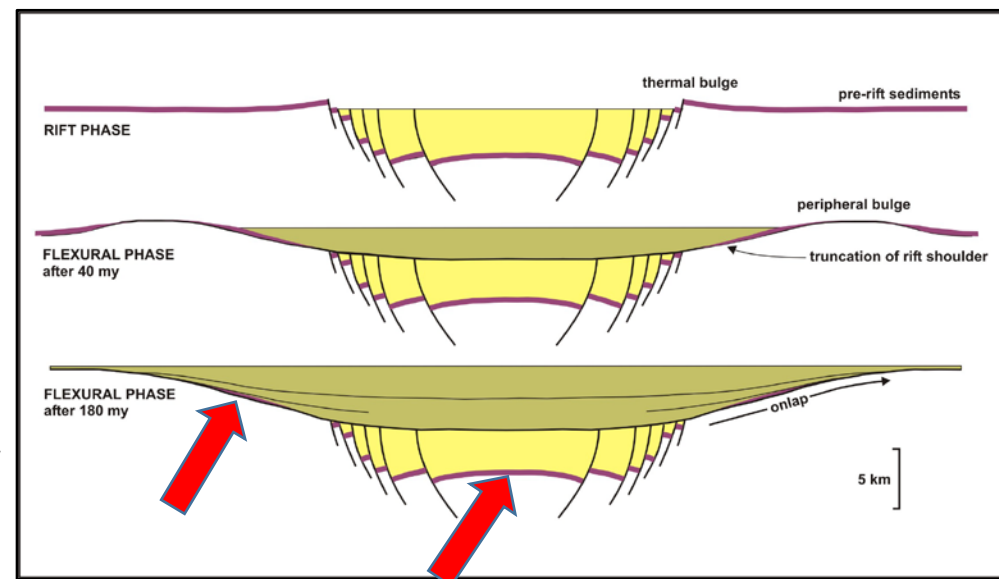


Brazilian Atlantic margin: Murris (1980)

Dynamic unconformities  
associated with  
basin-forming  
tectonism.

Left: forebulge  
within foreland basin  
Top and Right: basal rift  
and breakup unconformity  
within extensional margin  
Basins

Time scale:  $10^6$ - $10^7$  years

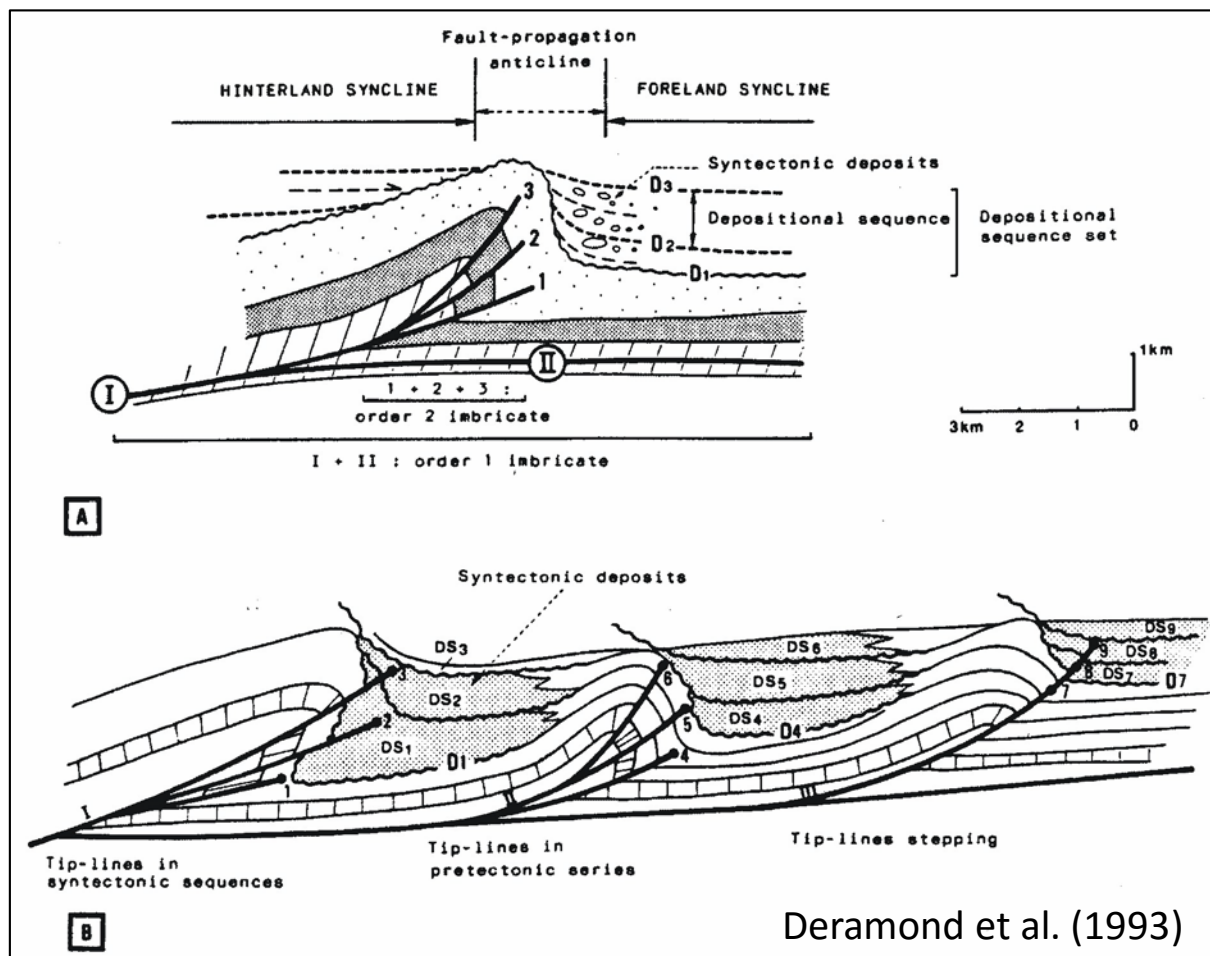


Texas Longhorn model: Dewey (1982)

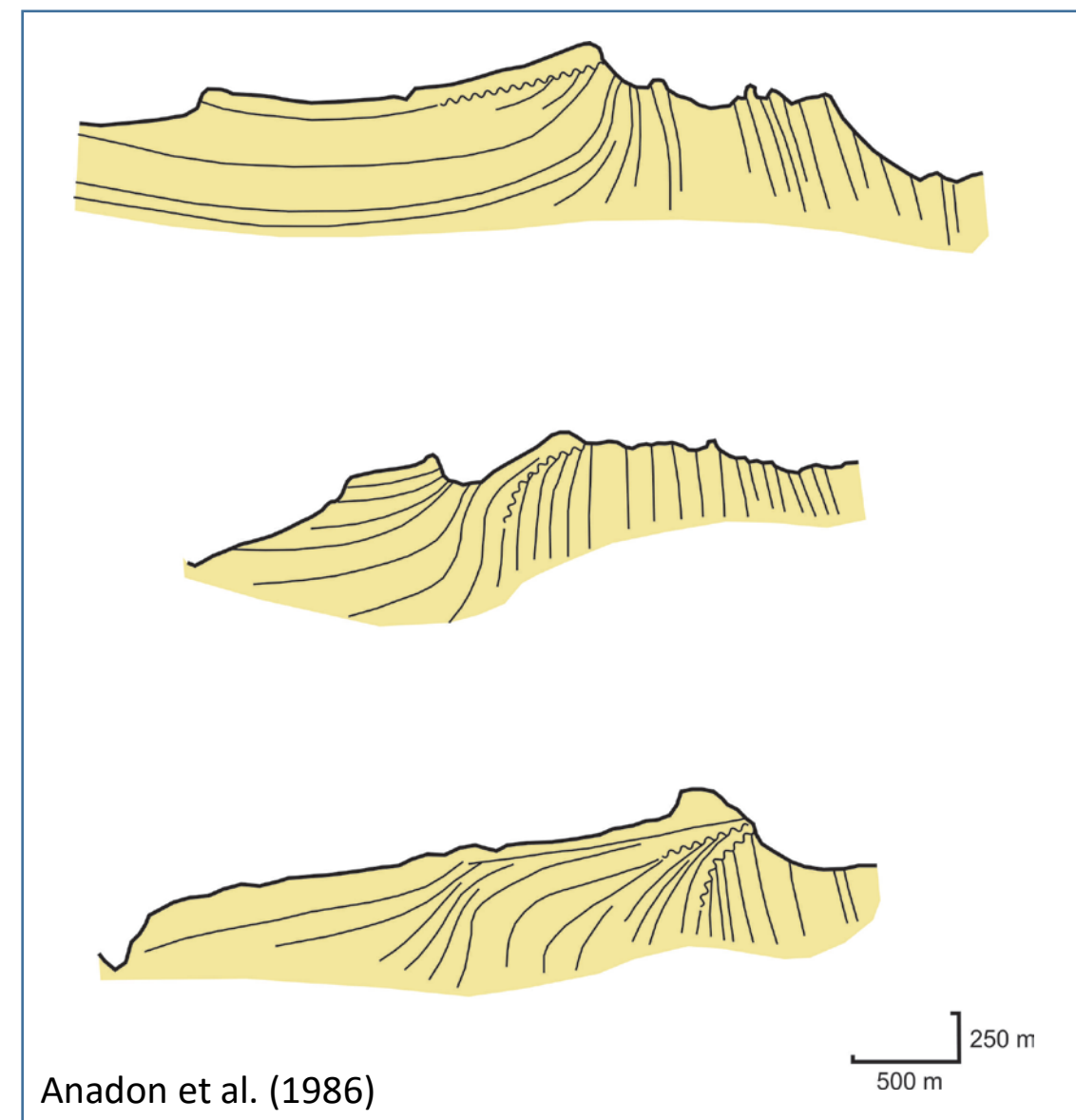
# A classification of unconformities

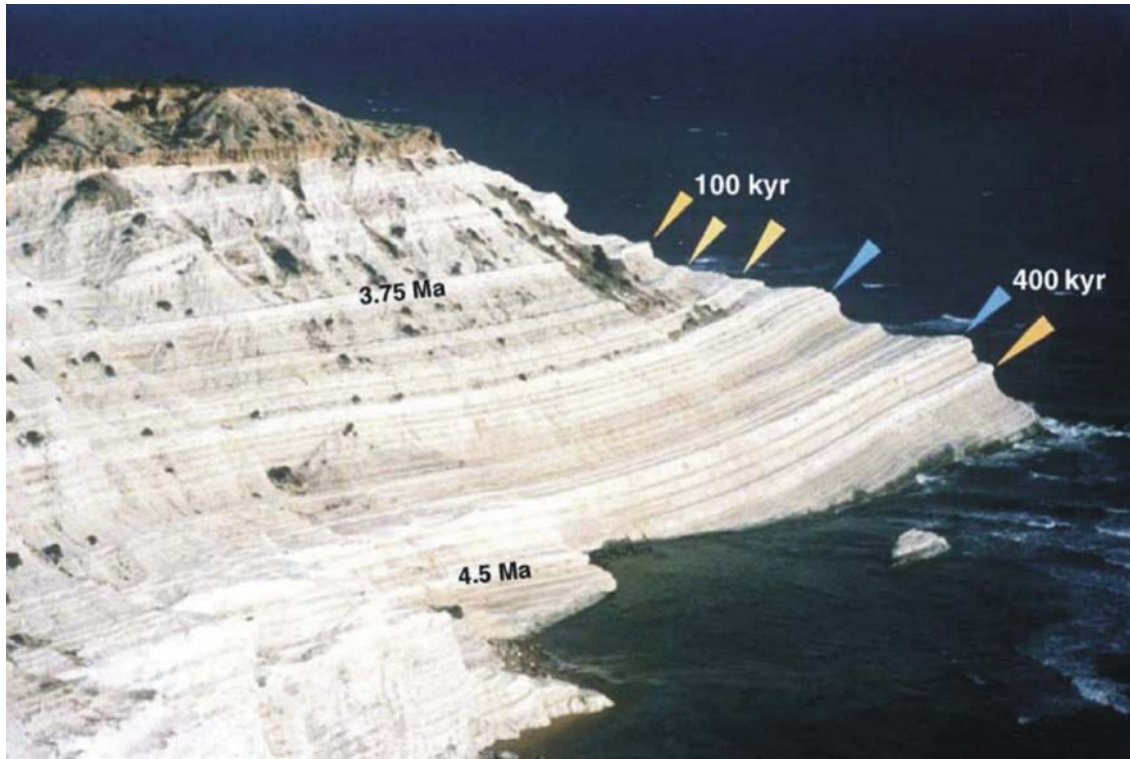
SRS	Time scale (yrs)	Inst Sed Rate (m/ka)	Process	Description of break	Field characteristics of sedimentary break and/or of beds above and below
1-4	$10^{-6}$ - $10^{-1}$	$10^4$ - $10^6$	Bedform migration; diurnal to normal meteorological change in runoff; tidal cycles	Local channel scours	Nesting of channels, macroforms and bedforms within a structure of minor bounding surfaces (ranks 1-5 of Miall, 1996).
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**Progressive unconformities**  
 caused by syndepositional tectonism  
 at active basin margins.  
 Both examples are from the Pyrenees  
 Time scale:  $10^5$  years



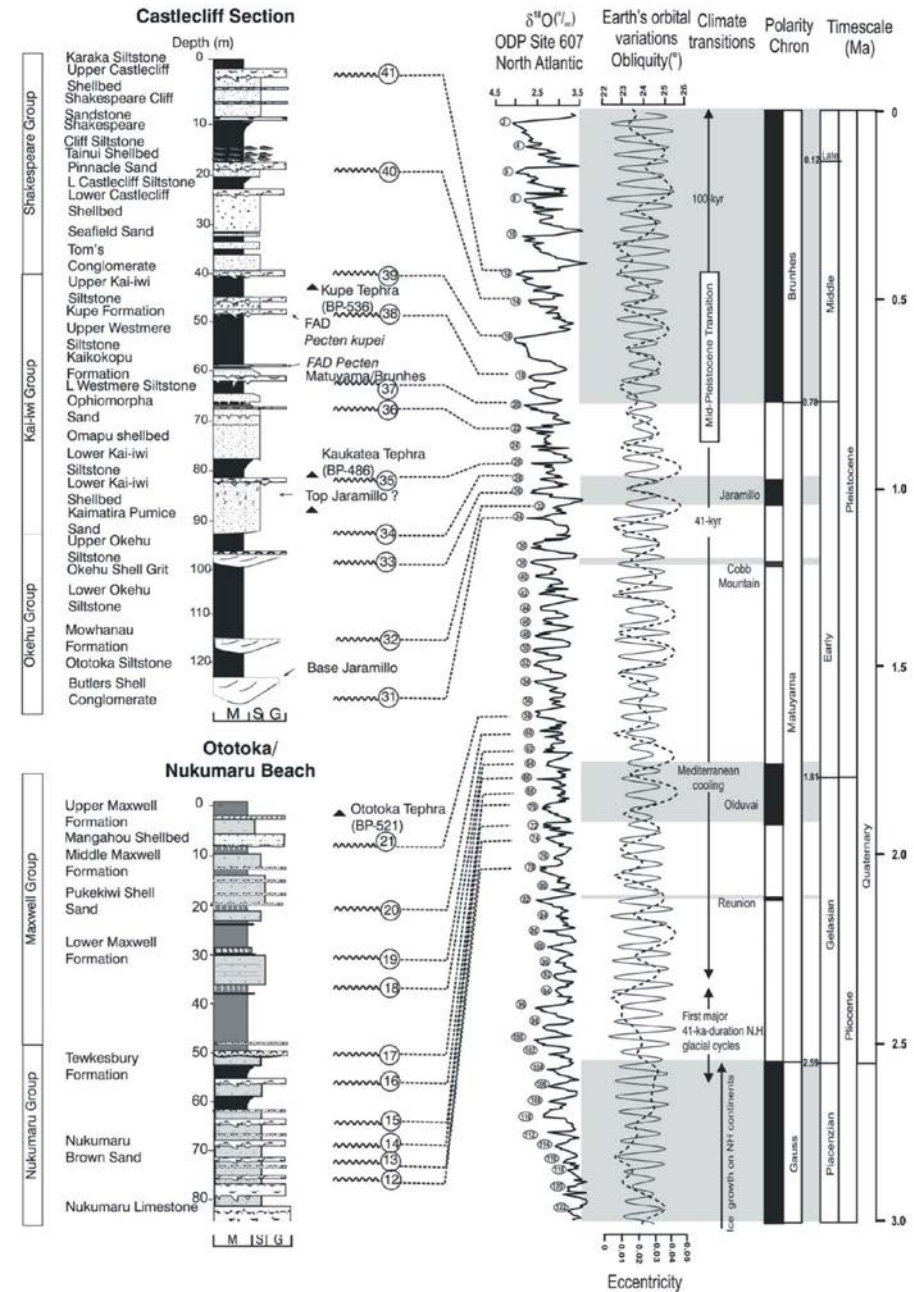


## Orbital forcing and Milankovitch cycles:

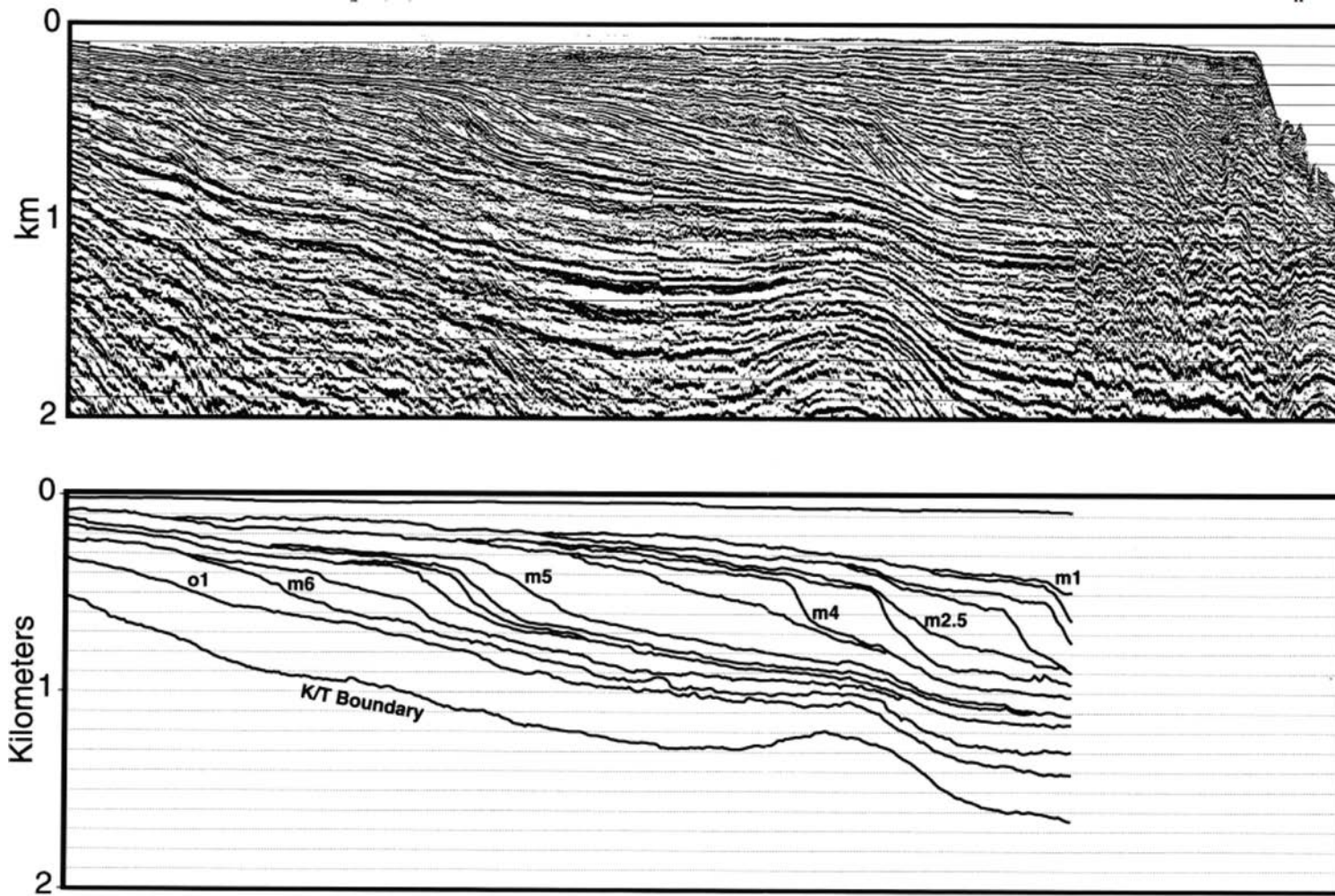
Cycles may be bounded by unconformities indicating Glacioeustatic control.

Left: orbital cycles in pelagic sediments, Sicily (Hilgen et al., 2006)  
 Right: Plio-Pleistocene cycles, Wanganui Basin, New Zealand (Naish et al., 2005).

Time Scale:  $10^4$ - $10^5$  years





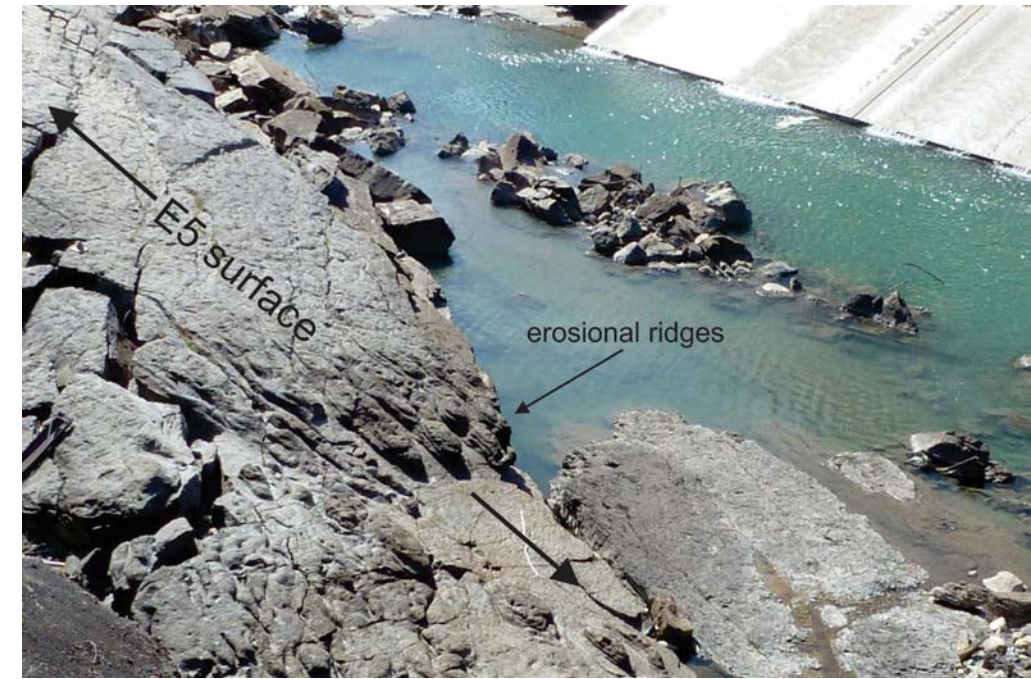
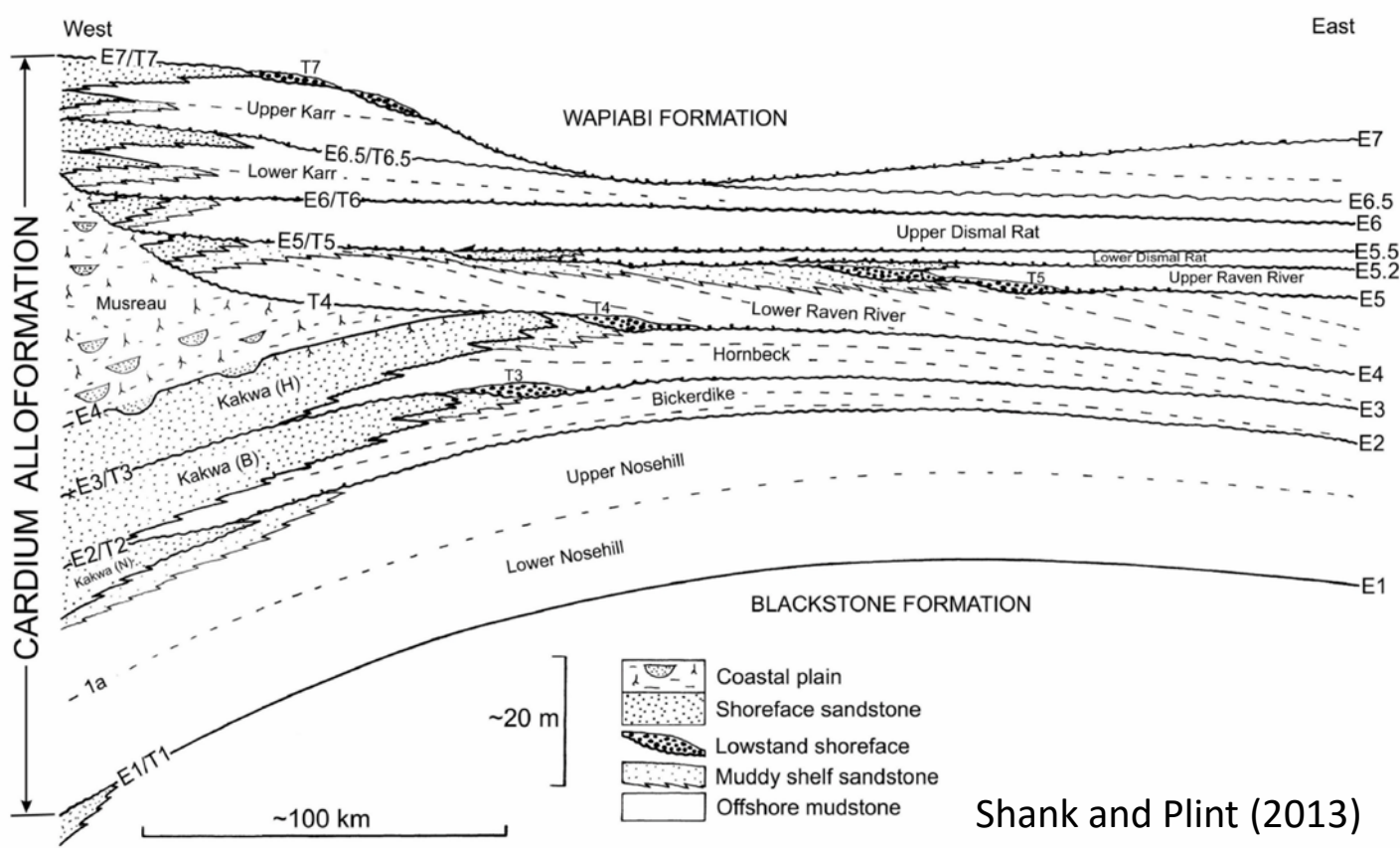


The Atlantic continental margin off New Jersey. A classic continental-slope clinoform complex. Sequences (sequence boundaries defined by heavy lines in the lower diagram) average a few million years in duration.

What caused the accommodation changes that led to their development?

Subtle tectonism driven by intraplate-stress changes? Glacioeustasy? Or some combination of causes.

Time scale:  $10^5$ - $10^6$  years.



Erosional “fingers” on the E5 surface at Seebee  
(see Shank and Plint, 2013)

The Upper Cretaceous Cardium Alloformation of Alberta.

Widespread allomembers bounded by E/T surfaces display abrupt facies changes,  
Sheet-like geometry of allomembers show no obvious correlation to basin tectonics.

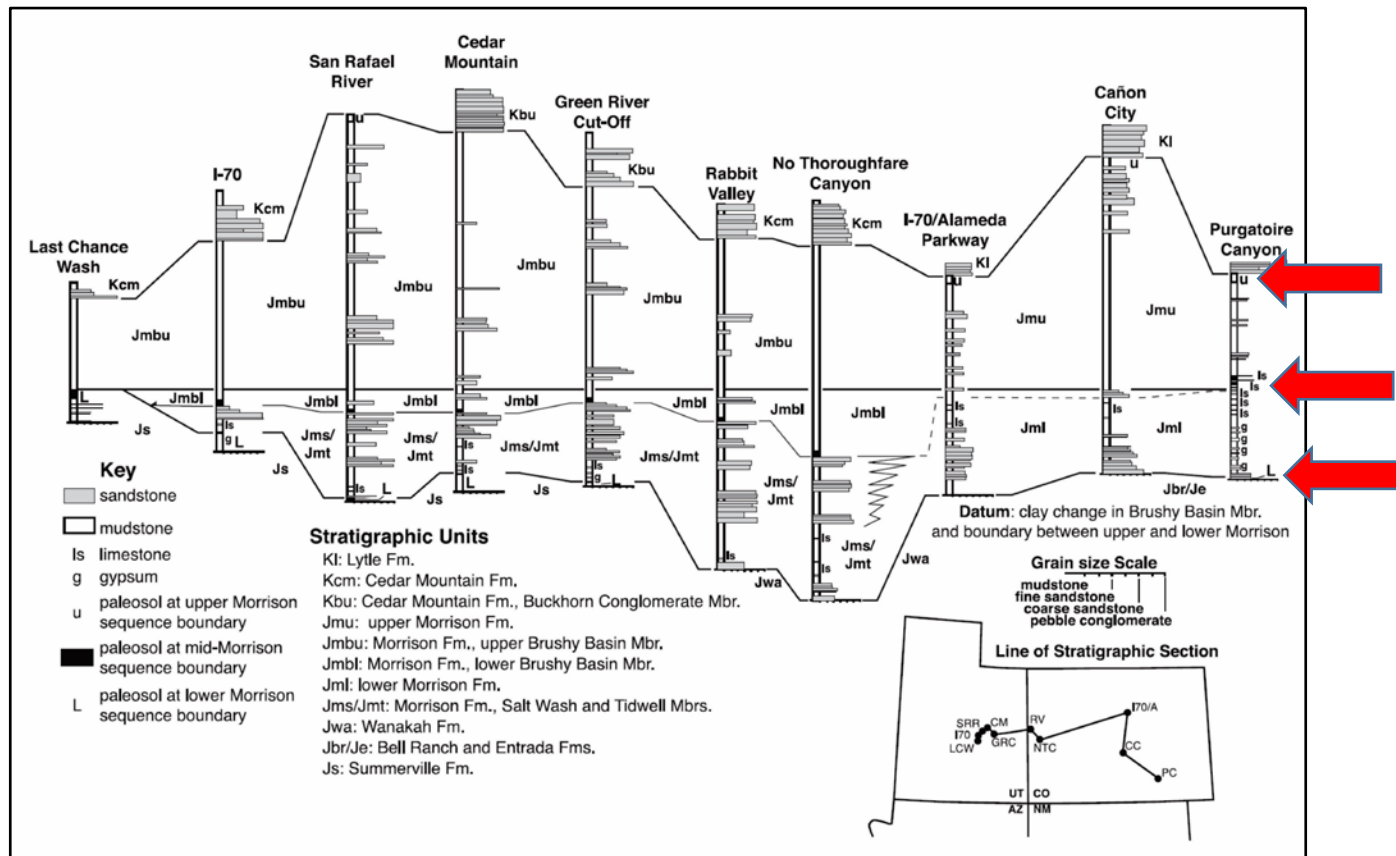
Allomember durations:  $10^4$  years.

Was this allomember stratigraphy generated by glacioeustasy? (Plint et al., 2012)



# A classification of unconformities

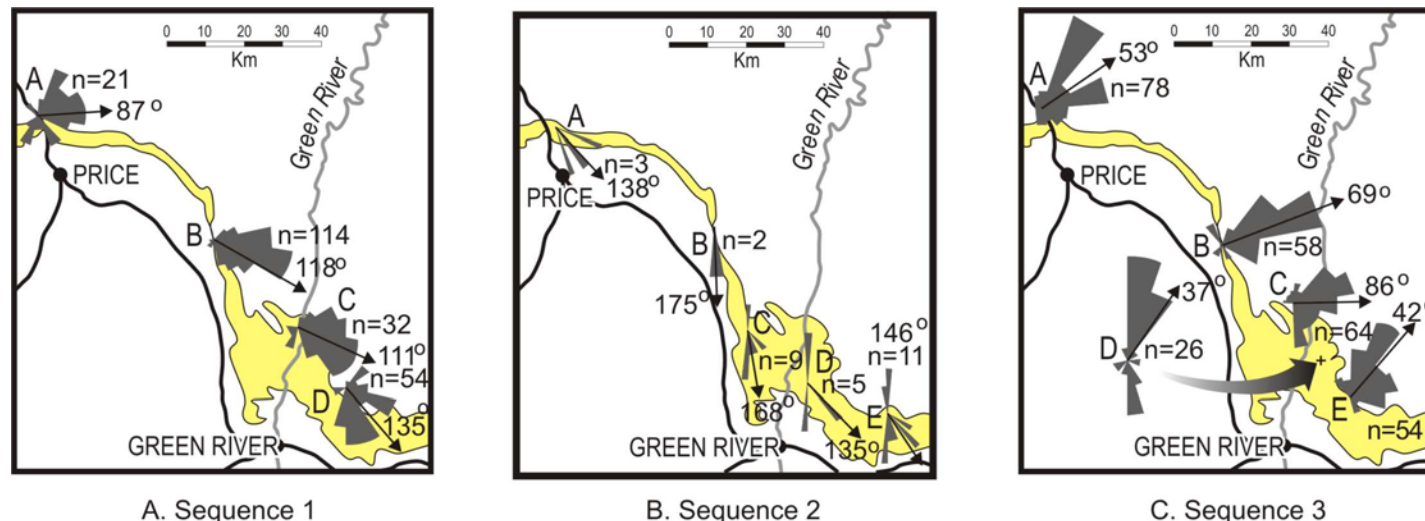
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Large-scale shifts in dispersal patterns  
 Interpreted to have been caused by  
 subtle intrabasinal tectonism.  
 Underlying process: changes in intra-plate  
 Stress regime.  
 Time scale:  $10^4$ - $10^5$  years

Top left: depositional units of the Morrison  
 Formation, separated by “unconformity  
 paleosols” (Demko et al., 2004)

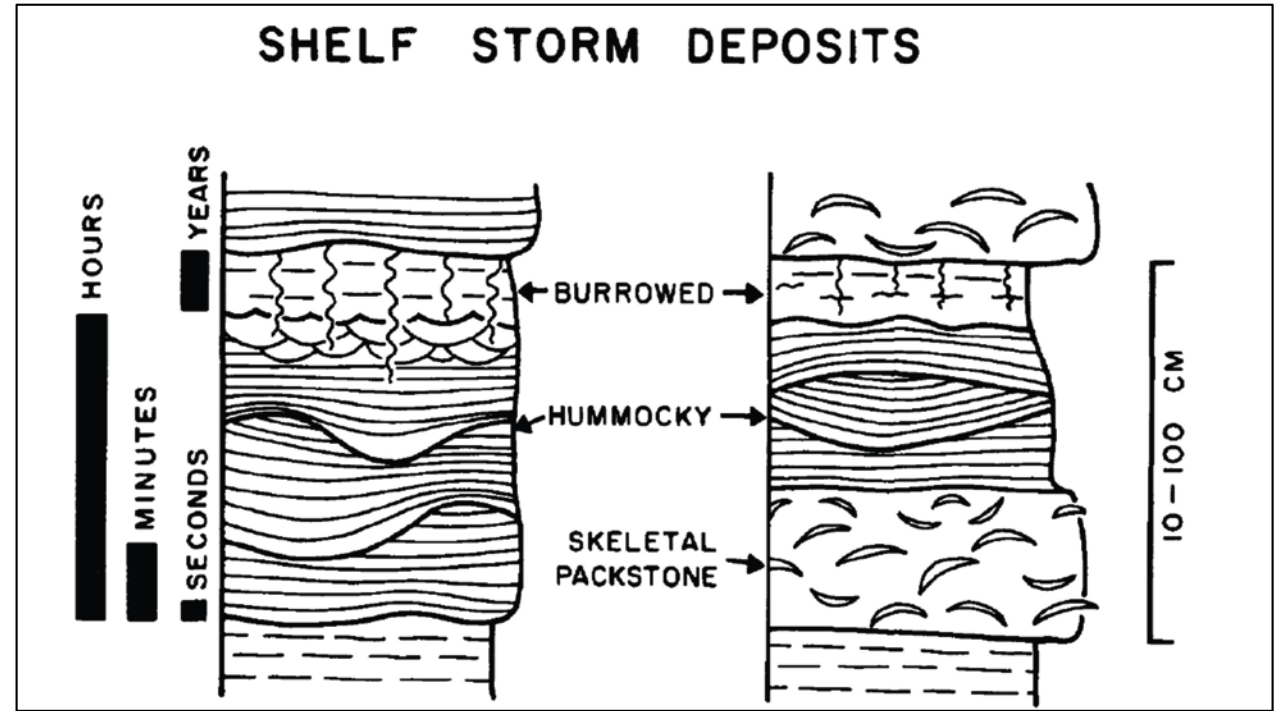
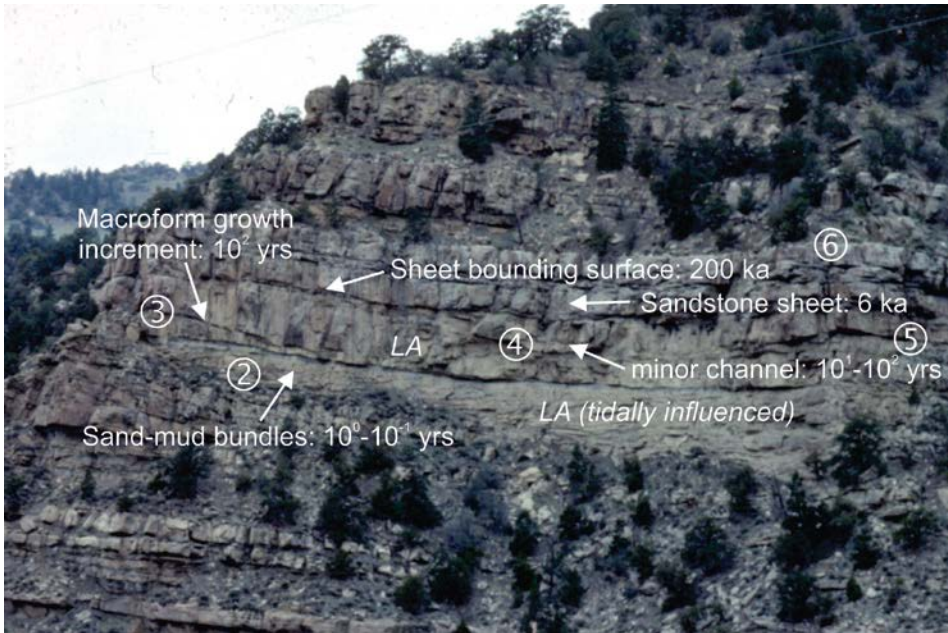
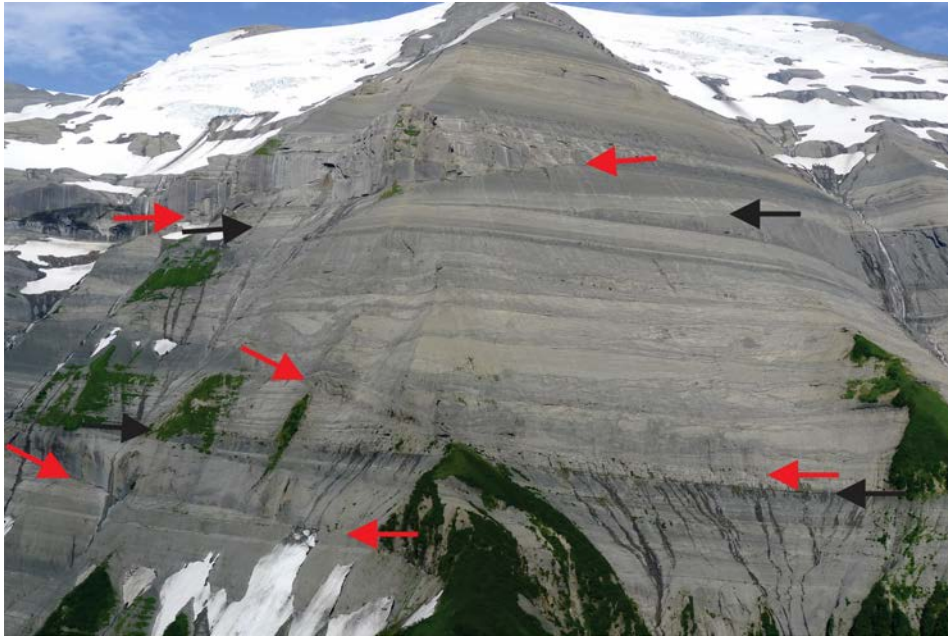
Bottom left: regional shifts in paleocurrent  
 patterns in the three sequences constituting  
 the Castlegate sequences of the Book Cliffs  
 (Willis, 2000).





# A classification of unconformities

SRS	Time scale (yrs)	Inst Sed Rate (m/ka)	Process	Description of break	Field characteristics of sedimentary break and/or of beds above and below
1-4	$10^{-6}$ - $10^{-1}$	$10^4$ - $10^6$	Bedform migration; diurnal to normal meteorological change in runoff; tidal cycles	Local channel scours	Nesting of channels, macroforms and bedforms within a structure of minor bounding surfaces (ranks 1-5 of Miall, 1996).
5-7	$10^0$ - $10^3$	$10^0$ - $10^3$	Autogenic seasonal to long-term geomorphic processes  Rare extreme weather events	Migration and switching of depositional systems  Marked facies change, minor regional erosion	Superimposition of alluvial sheets, deltas and shelf-margin clinoform lobes separated by transgressive ravinement surfaces, rare preservation of falling-stage incised distributary channels, incised valleys  Facies blanket, regional marker horizon
7-9	$10^4$ - $10^5$	$10^{-2}$ - $10^0$	High-frequency tectonism  Regional response to flexural loading/unloading  Far-field intraplate stress changes  Orbital forcing	Syn depositional unconformities  Basin-wide low-angle unconformities  Tilting and warping of sequences and sequence sets  Continental (potentially global) - scale, non-angular break	Strong but very localized angularity, coarse clastic wedges ("growth strata")  Low- to very low-angle clinoform sets Evidence of fluvial or marine erosion, transgressive lag deposits at breaks  Widespread shifts in paleocurrent patterns, shoreline trends  Cyclothemic facies changes, potentially deep erosion of unconformity surface, coastal and shelf-margin clinoform onlap-offlap cycles
9-12	$10^6$ - $10^7$	$10^{-3}$ - $10^{-1}$	Orogenic tectonism  Dynamic unconformities associated with basin fm  Dynamic topography  Global eustasy	Regional angular unconformity  Onlap and offlap caused by basin subsidence  Sub-continental unconformity  Global unconformity	May be associated with deep erosional relief, clastic wedges  Onlap of extensional margins during flexural subsidence Onlap/offlap during motion of foreland-basin forebulge  Low-angularity (units above and below have similar dip). Commonly little field evidence of major time break  Similar to above



Examples of architectural features that reflect short-to long term sedimentary processes.

Top left: channels and shifting depositional axes, Yakataga Formation (late Cenozoic glaciomarine deposits, southern Alaska). Photo: N. Eyles  
 Bottom left: fluvial architecture of the Castlegate Sandstone, Book Cliffs  
 Top right: Interpretation of storm cycles (Dott, 1983).



## Summary and Conclusions

- This review has provided a categorization and interpretation of sedimentary breaks ranging in duration across the full spectrum of geological time scales, from seconds to hundreds of millions of years.
- Of particular importance to the practice of stratigraphy are structurally conformable or near-conformable disconformities, which include what have variously been described as paraconformities, hiatuses and diastems.
- Those ranging in durations  $\geq 10^4$  years are critical in the definition of sequences. Their extent and relationship to structural features in a sedimentary basin may provide essential information relating to tectonic evolution and other allogenic controls.
- Disconformities that appear structurally conformable at outcrop scale may be angular at a larger scale, as was demonstrated in the original definition of the Sloss sequences within North America.
- Absence of clear evidence of exposure and erosion at a disconformity, such as cut-and-fill erosion, basal breccias, transgressive lags, or paleosoils, may cause the significance of a sharp facies change at a bedding plane to be misinterpreted. This could be particularly significant in the analysis of disconformities generated by high-frequency processes, such as orbital control of a sedimentary unit.
- In channelized deposits, such as in fluvial, deltaic, tidal and submarine-fan settings, there may be nothing to distinguish a channel scour from a sequence boundary at outcrop scale.
- The term cryptic sequence boundary has been suggested for the latter.

**Table 1. A classification of unconformities**

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9-12	$10^6$ - $10^7$	$10^{-3}$ - $10^{-1}$	Orogenic tectonism  Dynamic unconformities associated with basin formation  Dynamic topography  Global eustasy  Long-term environmental change	Regional angular unconformity  Onlap and offlap caused by basin subsidence  Sub-continental unconformity  Global unconformity  Regional disconformities	May be associated with deep erosional relief, clastic wedges  Onlap of extensional margins during flexural subsidence Onlap/offlap during motion of foreland-basin forebulge  Low-angularity (units above and below have similar dip). Commonly little field evidence of major time break  Similar to above  Eolian supersurfaces, drowning unconformities (carbonates)

SRS=Sedimentation Rate Scale (from Miall, 2015a)



Table 2 The relationship between tectonic processes and stratigraphic signatures in foreland basins, at different time scales

Duration m.y.	Scale	Tectonic process	Stratigraphic signature
>50	Entire tectonic belt	Regional flexural loading, imbricate stacking	Regional foredeep basin
10-50	Regional	Terrane docking and accretion	multiple "molasse" pulses
10-50	Regional	Effects of basement heterogeneities during crustal shortening	Local variations in subsidence rate; may lead to local transgressions/regressions
>5	Regional	Fault-propagation anticline and foreland syncline	Sub-basin filled by sequence sets bounded by major enhanced unconformities
5-0.5	Local	Thrust overstep branches developing inside fault -propagation anticline	Enhanced sequence boundaries; structural truncation and rotation; decreasing upward dips; sharp onlaps; thick lowstands, syntectonic facies
<0.5	Local	Movement of individual thrust plates, normal listric faults, minor folds	Depositional systems and bedsets geometrically controlled by tectonism and bounded by unconformable bedding-plane surfaces. Maximum flooding surfaces superimposed on growth-fault scarps. Shelf-perched lowstand deposits.

This table was adapted mainly from Deramond et al. (1993), with additional data from Waschbusch and Royden (1992), Stockmal et al. (1992).