Sequence Stratigraphy of the Great American Carbonate Bank*

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Search and Discovery Article #50821 (2013)**
Posted July 29, 2013

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013

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Abstract

The Cambrian-Ordovician Sauk megasequence of the great American carbonate bank (GACB) comprises a succession of mixed lithologies, but dominantly carbonate rocks, whose thickness, stratigraphy, and lithofacies distribution reflect the presence of a complex of intrabank platforms and basins, aulacogens, and tectonically active margins that together make up the major part of the paleocontinent Laurentia. The stratigraphy of the Sauk megasequence can be subdivided and correlated across the GACB through the recognition of major unconformities, marine flooding events, and stratigraphic stacking patterns, documented within a robust biostratigraphic framework.

The base of the Sauk megasequence is typically defined as the contact of Cambrian, or sub-Tippecanoe-megasequence Ordovician rocks, with Precambrian, mostly igneous, basement. The Sauk megasequence is overlain (commonly unconformably) by the Middle Ordovician Tippecanoe megasequence, the age of which varies across the GACB. Where subsequent erosion has occurred, the Sauk megasequence may be overlain by rocks younger than the Tippecanoe megasequence. Palmer's (1981) subdivision of the Sauk megasequence into Sauk I, II, and III subsequences (now referred to as supersequences) is widely, but not universally, recognized.

Across many areas of the GACB, the Sauk III supersequence of Palmer can be subdivided into two supersequences (herein defined as ‘‘Sauk IIIA" and ‘‘Sauk IIIB"), based on an unconformity and/or biostratigraphic changes near the Cambrian-Ordovician boundary. Additional significant unconformities and marine flooding events also can be correlated across much of the GACB.

The recognition of correlatable surfaces across the GACB has been challenging because of local syndepositional tectonics and paleotopography, and lithofacies heterogeneity. However, confidence in correlation across the GACB has been greatly enhanced by an increasingly refined biostratigraphic framework.

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Sequence Stratigraphy of the Great American Carbonate Bank

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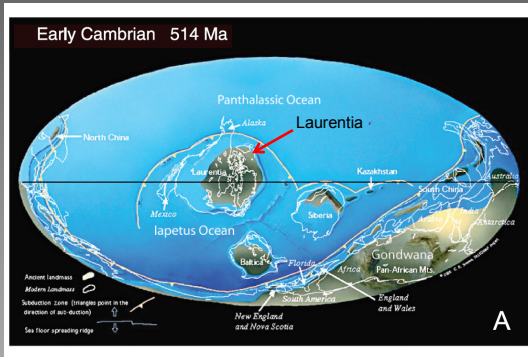
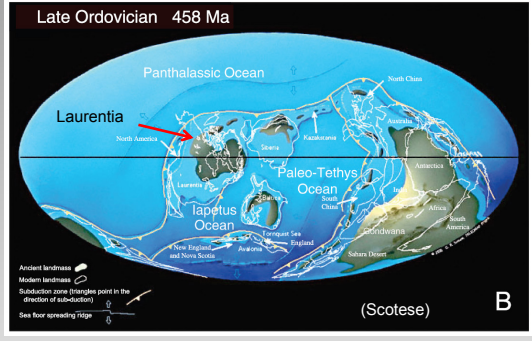
Outline

- The GACB
  - Definition
- The Sauk Sequence - Historical Perspective
  - Sloss' sequences and the foundation of sequence stratigraphy
  - Sloss' original Sauk sequence
  - Palmer's subsequences
- The Sauk Succession Across the GACB
  - Bank-wide unconformities and flooding "events"

Great American Carbonate Bank - Definition

- The term “Great American Bank” was coined by Bob Ginsburg (1980) to embrace Cambrian to lower Middle Ordovician carbonates and related siliciclastics ***[Sauk Sequence]*** deposited on and around the Laurentian continent.
- Later amended to Great American Carbonate Bank by James Lee Wilson while consulting on Cambro-Ordovician carbonate reservoirs in late 1980’s to emphasize the extent of the carbonate platform.



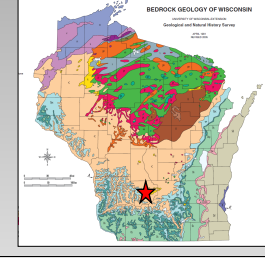


Paleogeography

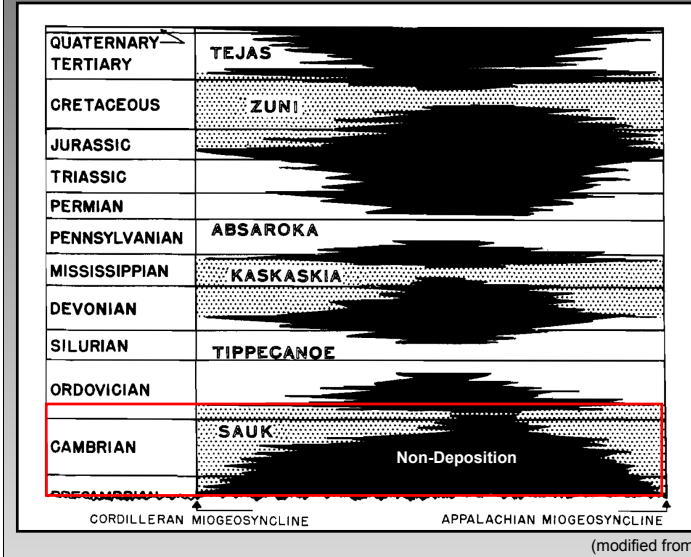
- Situated Astride Equator
- Greenhouse Conditions
- Ideal for Carbonate Sedimentation

The Sauk Sequence

- Named for Cambrian and Ordovician exposures in Sauk County, Wisconsin
- 'The sequence comprises "those strata that overlie an interregional unconformity cut on late Precambrian and older rocks and underlie an interregional unconformity at the base of the succeeding Tippecanoe sequence. The Sauk sequence ranges in age from latest Precambrian to Early Ordovician (Canadian), possibly including early Middle Ordovician (early Chazyan) strata in some areas." (Sloss, 1963, based on Sloss et al., 1949)



Sloss' Original Cratonic Sequences

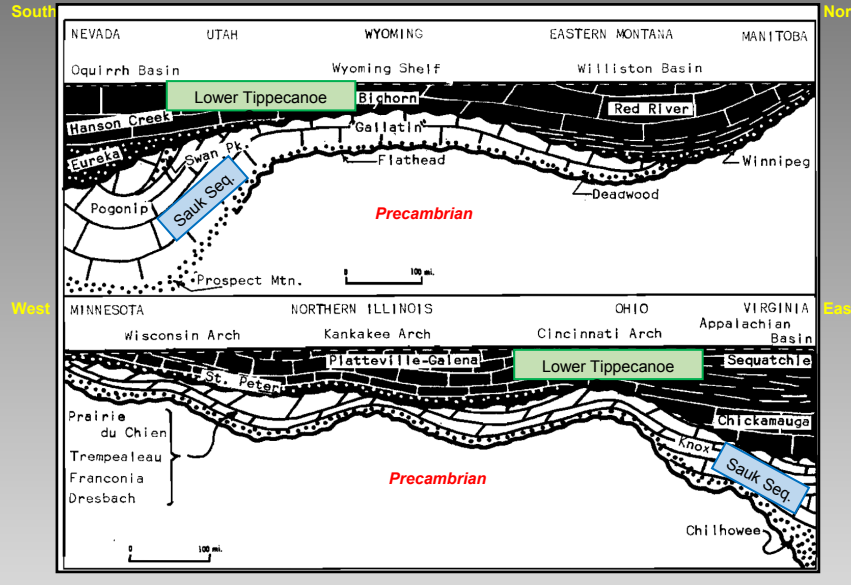


- Megasequence – >50 m.y.
- Supersequence – 3-50 m.y.
- Sequence – 1-3 m.y.

(modified from Sloss,1963)

Presenter's notes: Vail (1991) sequence definition. >Up to 5000 m of Sauk in Great Basin, 3500 m in Appalachians.

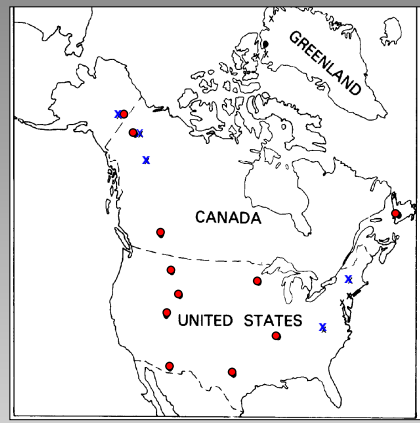
Sauk Sequence Distribution



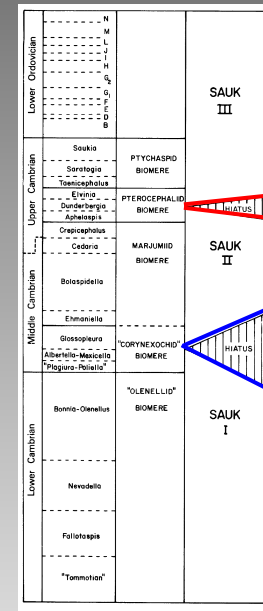
(modified from Sloss,1963)

Palmer's Sauk Subsequences

- Eustatic-Driven Disconformities
- Based on Faunal Discontinuities
- Regressive Siliciclastics



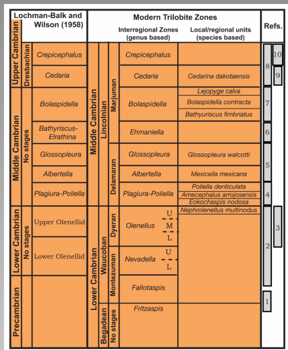
Palmer's localities where the Sauk I-II lower Middle Cambrian (X's) and Sauk II-III lower Upper Cambrian (•) discontinuities were documented (Palmer, 1981).



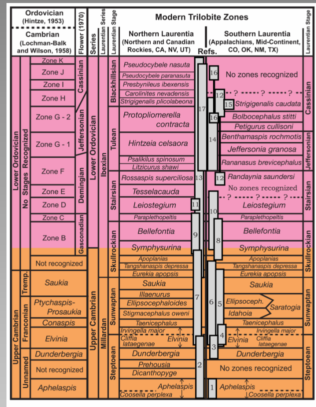
(Palmer, 1981)

Presenter's notes: > Sauk I-II. Typically, *Glossopleura* occurs a few meters above Ollenellids. > Sauk II-III Beds with *Elvinia* above disconformity are separated by only a few meters from faunas of *Prehousia,* or, more typically *Aphelaspis. Dunderbergia* or younger missing. Discontinuity between Lw. and Mid. Cambrian also seen in Baltic and North Africa.

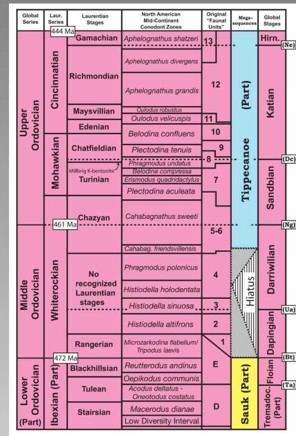
Cambrian-Ordovician Chrono and Biostratigraphy



Lw. –Mid. Cambrian Platform Carbonate Trilobite Zonation for Laurentia



Up. Cambrian – Lw. Ord. Platform Carbonate Trilobite Zonation for Laurentia



Upper Lw. Ord. – Upper Ord Chronostratigraphy and Conodont Zonation

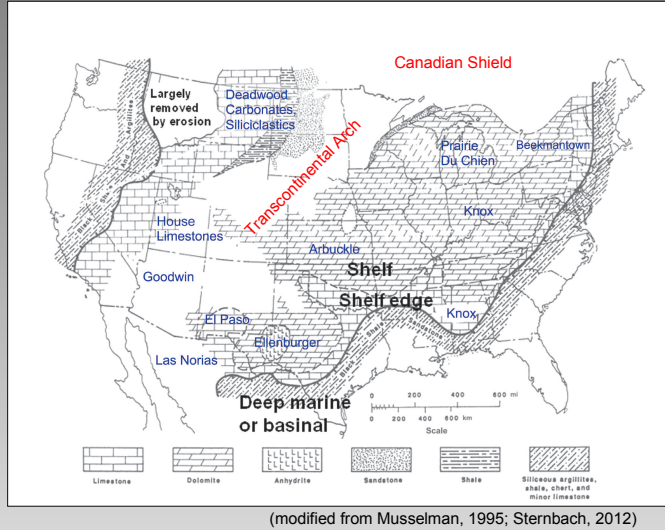
(Taylor et al., 2012)

Presenter's notes: 25 biostrat zones for refined zonation.

Challenges to Correlation across the GACB

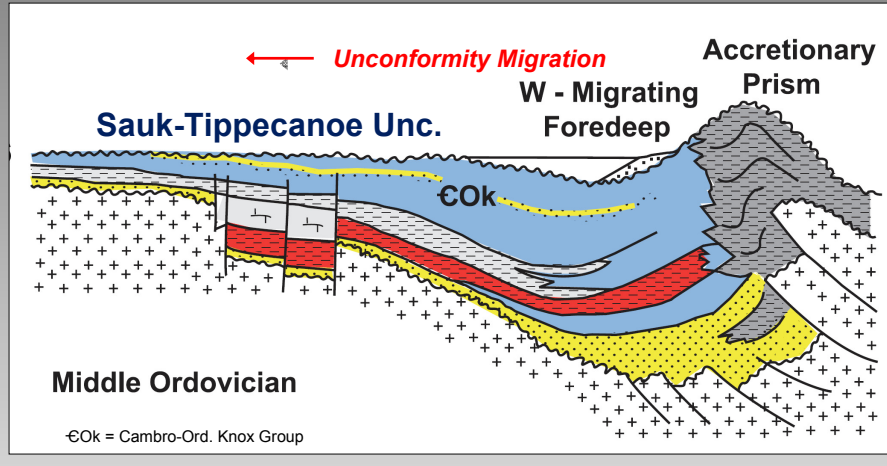
- Post-Sauk (and Post-Tippecanoe) Erosion
  - E.g., Canadian Shield, Transcontinental Arch
- Facies Variations and Local Unconformities as a Result of:
  - Local Tectonics/ Varying Subsidence Rates
    - East to west migration of peripheral bulge (and Sauk-Tippecanoe boundary) during arc-continent collision in Mid. Ordovician
  - Paleotopography
- Lack of Biostratigraphic Control
  - Insufficient sampling in remote areas
  - Diagenesis, especially dolomitization on Bank top
- Workers' Definitions of Sequences and Criteria for Selecting Sequence Boundaries

Post-Sauk Erosion
Lower Ordovician Lithofacies



(modified from Musselman, 1995; Sternbach, 2012)

Migration of Sauk-Tippecanoe Unconformity



(modified from Read and Repetski, 2012)

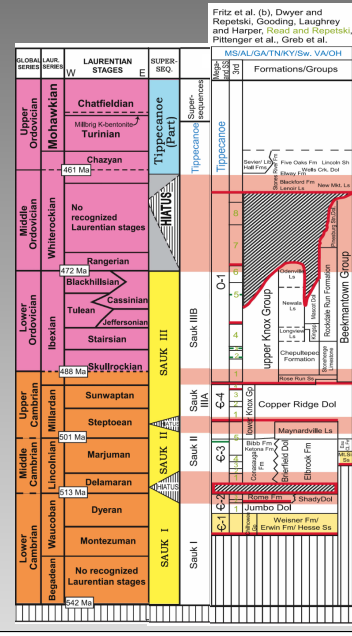
The Big "Events"
(Not Universally Recognized)

- Palmer's Subsequences (Supersequences)
  - Sauk I-II supersequence boundary (Lower Cambrian Delamaran)
    - *Hawke Bay Event*
    - Between middle and upper *Ollenelus* trilobite Zones
    - 511 Ma boundary on global cycle chart (Haq and Schutter, 2008)
  - Sauk II-III supersequence boundary (Upper Cambrian Steptoean)
    - *Dunderbergia* trilobite Zone missing on bank top. Found in LST deposits along the bank margins (Palmer 1965, Taylor et al., 2009)
    - Only a minor boundary on the Haq and Schutter (2008) global cycle chart
- Sauk-Tippecanoe Megasequence Boundary
  - Lower Middle Ordovician *Histiodella holodentata* conodont Zone
  - 464 Ma boundary on global cycle chart (Haq and Schutter, 2008)
- *II Additional Major Unconformities or Flooding Events*

Sauk I & II Supersequence "Events"

Sauk I

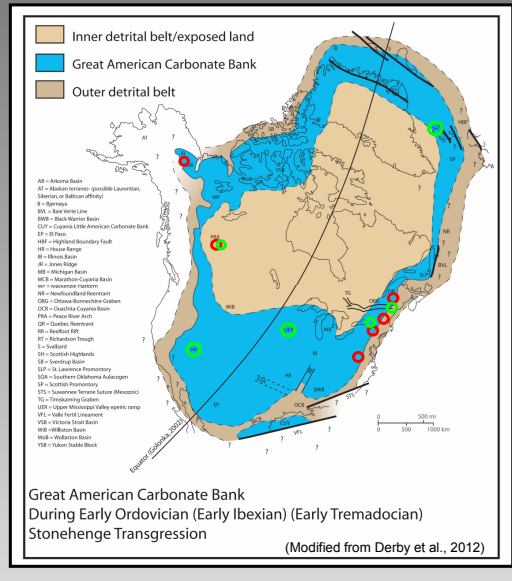
- Lower Cambrian – Beginning of Onlap onto Precambrian Surface
  - Approx. 31 m.y. duration
  - Not as widely distributed as later Sauk supersequences
  - Biostratigraphic subdivision may be limited by
    - Preponderance of siliciclastics
    - Poorer preservation compared to younger supersequences
- Lower Cambrian (Dyeran) sequence boundary – middle *Ollenelus* trilobite Zone



Sauk II

- Approx. 16 m.y. duration
- Middle Cambrian (Marjuman) flooding succession near base of *Crepicephalus* trilobite Zone

Sauk I & II Supersequence "Events"



Great American Carbonate Bank
During Early Ordovician (Early Ibexian) (Early Tremadocian)
Stonehenge Transgression

(Modified from Derby et al., 2012)

- Mid. Camb. (Marjuman) Flooding
- Lw. Camb. (Dyeran) SB

Presenter's notes: Marjuman – Up. Mid. Cambrian; Dyeran –Up.Lw. Cambrian.

Sauk III Supersequence "Events"

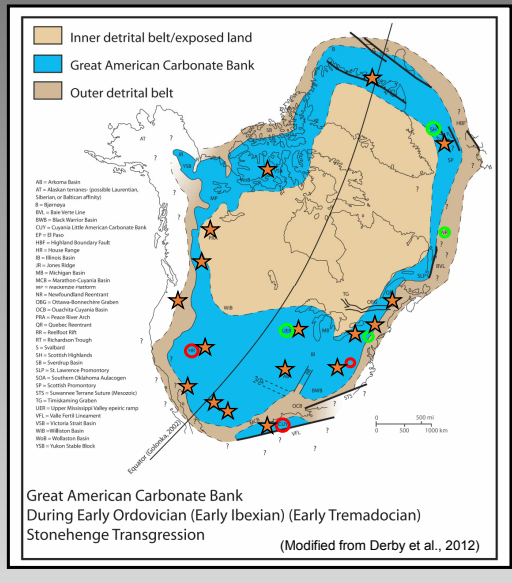
- Depositionally, most Widespread - result of Continued Onlap onto Laurentia
  - Approx. 31 m.y. duration
  - Post-Sauk erosion greatly modified present-day distribution
- Major Sequence Boundary near Cambro-Ord. Boundary (base Skullrockian; base of *Cordylodus proavus* conodont Zone)
  - Major extinction event
  - Divides Sauk III into IIIA and IIIB supersequences
  - Not a perfect match on Haq and Schutter (2008) global sea-level curve
- 8 Additional Major Unc. or Flooding "Events"

Presenter's notes: Continues general onlap since Sauk I. Major extinction affecting conodonts, trilobites, brachiopods, and fauna. IIIA-IIIB – extinction of bracs, conodonts, trilobites.

Sauk IIIA Supersequence "Events"

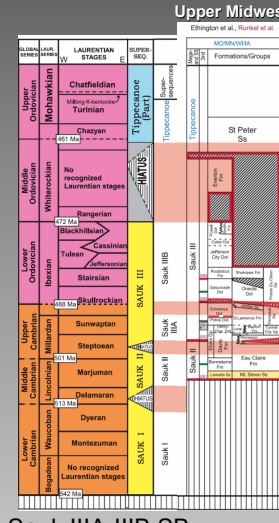
- Adamstown Submergence Event (Up. Cambrain, Sunwaptan) (Taylor et al., 2009)
- Red Tops LST – Up. Cambrian (Sunwaptan) Coincides with Large Negative Carbon Isotope Excursion (HERB Event)
- Major Sequence Boundary near Cambro-Ord. Boundary (base Skullrockian; base of *Cordylodus proavus* conodont Zone

Sauk IIIA "Events"



Great American Carbonate Bank
During Early Ordovician (Early Ibexian) (Early Tremadocian)
Stonehenge Transgression

(Modified from Derby et al., 2012)

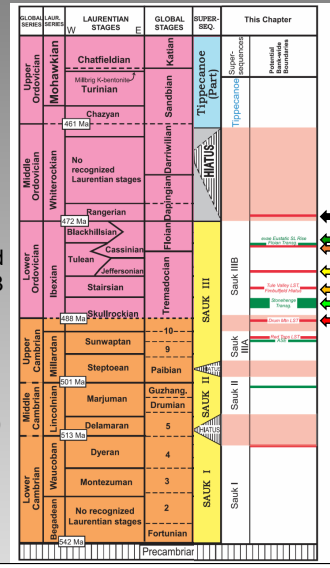


- Sauk IIIA-IIIB SB
  (Lange Ranch Eustatic Event)
- Upper Sunwaptan SB
  (Red Tops Lowstand)
- Upper Sunwaptan Flooding
  (Adamstown Submergence Event)

Sauk IIIB "Events"

- Wide Recognition of Multiple 3rd Order Sequences on GACB
- Post-Sauk Erosion Limits Areal Extent

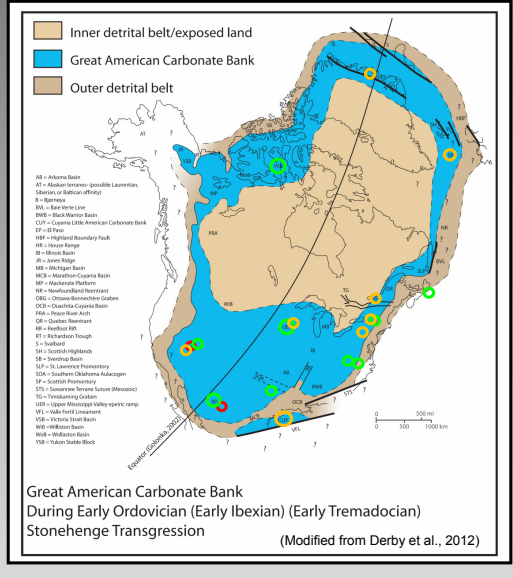
- **Boat Harbour Unc.** In lower Tulean
- **Fimbulfjeld Unc., Tule Valley Lst** - Sequence boundary in lower Stairsian
- **Stonehenge Transgression** (basal Ord. Skullrockian) – one of most widely recognized flooding successions of GACB – maximum flooding during Sauk IIIB, possibly entire Sauk megasequence
- **Drum Mountains LST** correlates to *Acerocare (ARE)* regressive event in Europe at end of Cambrian



- **Sequence boundary during early Rangerian** – start of a series of sea-level falls that culminates in Sauk-Tippecanoe megasequence boundary.
- **Laignet Point HST, *evae* eustatic event** - Major flooding succession during late Tulean
- **Sequence Boundary during late Tulean.** Sauk III-IV boundary of Golonka and Kiessling (2002).

(Biostratigraphic zonation simplified from Taylor et al., 2012)

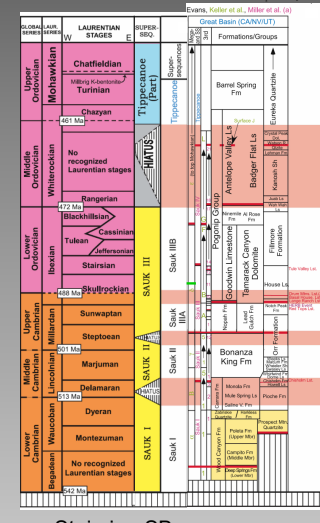
Lower Sauk IIIB Supersequence "Events"



Great American Carbonate Bank
During Early Ordovician (Early Ibexian) (Early Tremadocian)
Stonehenge Transgression

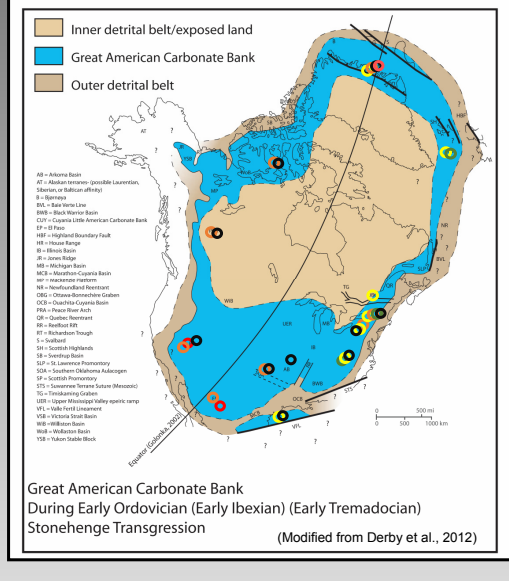
(Modified from Derby et al., 2012)

Great Basin (CA, NV, UT)



Presenter's notes: Upper Skullrockian is Lw. Ord. Lower Skullrockian is Up. Camb.

Upper Sauk IIIB Supersequence "Events



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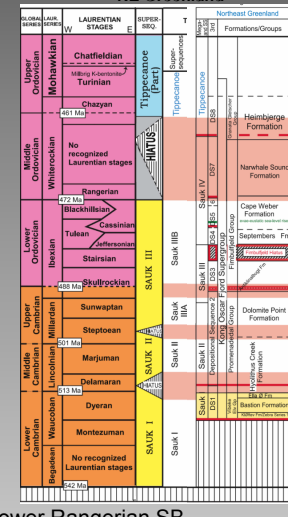
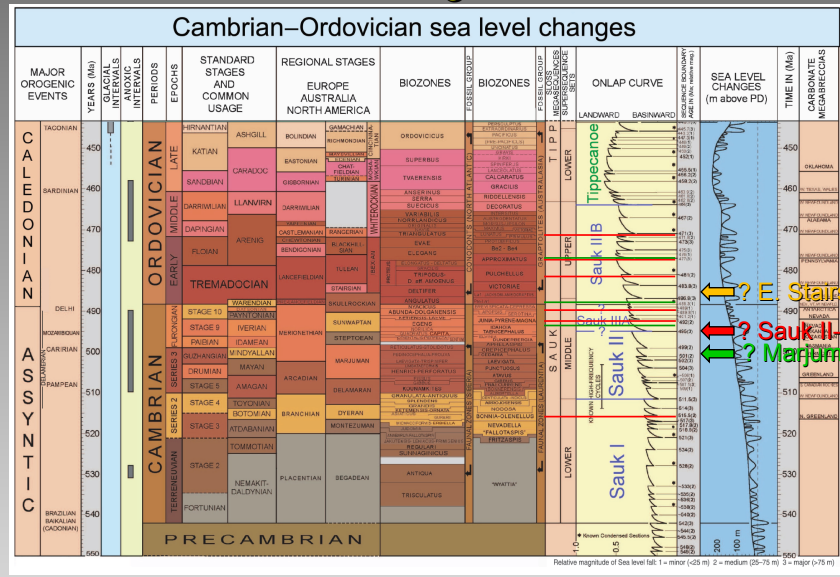
Stonehenge Transgression

(Modified from Derby et al., 2012)



Presenter's notes: Upper Skullrockian is Lw. Ord. Lower Skullrockian is Up. Camb.

Cambrian-Ordovician Global Sea-Level Changes



Presenter's notes: Lw. Stairsian Unc?
Sauk II-III – should be above *Dunderbergia* and below Elvinia, but they place it at top *Taenicephalus*,which is above *Elvinia.* Sauk II-III ?
Mid. Marjuman Flooding ?

Conclusions

- Sloss' Sauk Megasequence and Palmer's Supersequences have Stood the Test of Time
- A Modern Biostratigraphic Framework has Yielded a Better Refined Stratigraphy and Revealed Additional Bank-wide Sequence Boundaries and Flooding Surfaces (possibly 11) including Sauk IIIA-IIIB Sequence Boundary
- Challenges
  - More Refined Sequence Correlation Across GACB at 2nd and 3rd Order Scale
  - Re-examination of Laurentian Sequence Correlation to Global Sea-Level Curve