Inhalte „Events in Earth History“

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- Late Devonian Events (F/F-, Kacak-, Hangenberg Event)
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Secular Trends in Global Glaciation – External Drivers

Blue bars = cool climates (icehouses), white bars = warm modes (greenhouses). Blue for Jurassic-Cretaceous icehouse = no polar ice caps for this time interval. $pCO_2(0) =$ present-day atmospheric CO$_2$ concentration.

PIRD = paleo-latitude of ice rafted debris

OGD = other glacial deposits.

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The onlap curve is a local to regional measure of relative land- or basinward movement of a baseline estimated in reference district sections. Onlap curves are now mostly obtained by interpretation of seismic sections.

*sequences with known prominent condensed sections

Periods with known higher-frequency eustatic cycles and documented condensed sections are indicated by vertical bars.
Cambrian-Ordovician sea-level changes

Global sea level: long-term envelope (4<sup>th</sup> order) and short-term curve of (3<sup>rd</sup> order) sea level fluctuations.

Order of sea level change (duration):
- 2<sup>nd</sup> = 10 – 100 Ma (megasequence)
- 3<sup>rd</sup> = 1-10 Ma (sequence)
- 4<sup>th</sup> = 200 – 500 ka (parasequence)
- 5<sup>th</sup> = 10 – 500 ka (parasequence)

A semiquantitative measure of the relative magnitude of short-term events [minor, 1 (<25); medium, 2 (25 to 75 m); and major, 3 (>75)].

The dashed vertical line approximates PD sea level to which long- and short-term sea-level curves are.

A first sharp drop in sea level occurs prior to the Silurian/Ordovician boundary, where a second sea level drop is seen. Both are due to a build up of continental ice masses.
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Ordovician Paleogeography

Late Ordovician
(450 Myr)
Late Katian

Late Ordovician
(460 Myr)
Middle Katian
Late Ordovician palaeogeography (450 Myr) showing preferential location of land masses in southern hemisphere with broad equatorial band of land masses, favouring extension of ice masses from south pole to low latitudes.

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Late Ordovician palaeogeography (450 Myr) showing location of key locations for paleoenvironmental reconstruction:
1. South China; Wangjiawan North section (Hirnantian GSSP) and Wangjiawan Riverside section. 2. North Gondwana; Anti-Atlas, Morocco. 3. Baltica; Estonia, Valga and Karla drill cores. 4. Eastern Laurentia; Anticosti Island, Canada.
At least 6 transgressive-regressive cycles can be differentiated with an intermittent high sea level noted for the Boda event or warming phase, where ice shield collapsed. The Hirnantian may thus be considered as being a set of two adjacent events.
Polar view of Gondwana paleogeography: ice sheets reconstruction for the Katian/Hirnantian. Age is old on right and young on left hand side. Boda impact site is located in Baltica, out of view.
Boda Warming Event: Bolide or equatorial LIP?

Generalised time chart of climatic, geodynamic and geochemical events.
Dap.: Dapingian  BODA: Boda event  CFBP: Continental Flood Basalt Province.
Alternatively to a bolide impact, LIPs have been postulated as warming triggers.

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The consequences of basaltic flooding would result in a carbon cycle perturbation with:

1) atmospheric emission of large amounts of CO$_2$ and subsequent climate warming, and
2) decline of atmospheric CO$_2$ by weathering accompanied by cooling.

Evolution of atmospheric CO$_2$ and surface oceanic $\delta^{13}C$ as a function of the time for the modeled reference run (black line) and $P_{off}$ run (dashed line) corresponding to the simulation with a steady-state phosphorus cycle.

Note conceptual similarity to “Snowball Earth Scenarios”
Chemical index of alteration (CIA) variation across Ordovician-Silurian boundary at sections on Yangtze Block. CIAcorr indicates CIA values (solid circles) corrected for K-metasomatism. Vertical dashed lines show the CIA range of average shale. Shaded interval indicates Hirnantian climate cooling period. Arrows mark two major biotic crises (I, II) during the latest Ordovician.

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Compilation of carbon isotopic ($\delta^{13}C_{\text{carb}}$) variations in seawater through the Ordovician along with the conodont-apatite based tropical seawater temperature trend.

Note: Conodont apatite SST reconstructions deviate significantly from brachiopod carbonate oxygen isotope based SST reconstructions. The Boda warming event and the extreme SST during the Tremadocian may thus be due to an analytical effect/artefact.
Comparison of $\Delta^{13}C$ three-point running average curves from Anticosti Island and Estonia to sections from Nevada and Yukon Territory, Canada. The grey rectangle indicates where $\delta^{13}C_{\text{carb}}$ values deviate positively from a baseline and later return to baseline values in all sections.

The change in $\Delta^{13}C$ through the Hirnantian Stage in Estonia and Anticosti Island can be interpreted to reflect atmospheric $pCO_2$ levels that were relatively low immediately prior to the $\delta^{13}C_{\text{carb}}$ excursion and then increased as ice sheets expanded. Higher availability of atmospheric CO$_2$ lead to decreased isotope fractionation in organic matter. Ultimately, this period of elevated $pCO_2$ is followed by global deglaciation.

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Ordovician carbonate isotopes and climate

Correlation of Upper Ordovician to Lower Silurian strata, $\delta^{13}$C curves, sea level, inferred ice volume, and $pCO_2$ trends from Estonia to western Anticosti Island, Quebec. Diagnostic chitinozoan species are plotted with important zones.

The dark grey interval from the Kardla drill core (Estonia) represents a zone, that is likely missing at an unconformity (U) in the Point Laframboise section. Lfb and Be => Laframboise and Bernati Mbrs.

Evolutionary stages 1 to 4:

1. sedimentary shallowing upward trends, $\delta^{13}$C$_{\text{carb}}$ and $\delta^{13}$C$_{\text{org}}$ values are low and then begin rising, $pCO_2$ levels are low, development of ice sheets;
2. continuous shallowing upward trends, maximum $\delta^{13}$C$_{\text{carb}}$ and $\delta^{13}$C$_{\text{org}}$ values, $pCO_2$ levels rise and reach maximum, further expansion of ice sheets, and reduction of continental silicates prone to weathering;
3. initial deepening followed by shallowing upward trends, high $\delta^{13}$C$_{\text{carb}}$, $\delta^{13}$C$_{\text{org}}$, and $pCO_2$ levels, interglacial episode followed by renewed expansion of ice sheets;
4. deepening upward trends, low $\delta^{13}$C$_{\text{carb}}$, $\delta^{13}$C$_{\text{org}}$, and $pCO_2$ levels, ice sheets collapse, and continental silicates are available for weathering.
Hypothetical plankton range (B-D) based on GCMs parameterized as indicated (HSL high sea level, LSL low sea level).

(E) Comparing inferred chitinozoan biotopes with the hypothetical plankton models allows to identify Hirnantian Tropical to Polar chitinozoan biotopes, with key boundaries at \(\sim 20, 25, 30, 40^{\circ} \text{S}\). Oceanic climate belts during the major glaciation of the Early Paleozoic can be mapped and compared to the pre-glacial Sandbian climate belts.

The chitinozoan biotopes and their inferred climate belts are most similar to the patterns for the hypothetical planktonic provinces for a SST-model at \(\times 8\ \text{PAL} \ p\text{CO}_2\) and low relative sea levels, but indicate an even steeper faunal and hence latitudinal temperature gradient than the model.

The dots represent localities and the error bars reflects variance with regard to the PALEOMAP reconstructions.
Late Ordovician Polar Front migration

Time line showing a Katian start of Late Ordovician cooling and an opposite view with an earlier onset in the Sandbian (Caradoc).

Map views compare Sandbian and Hirnantian chitinozoan biotopes, demonstrating an equatorward shift in the position of the Polar Front from 55° to 70° S to likely 40° S, involving an equatorward incursion of Polar water and a compression of the Subpolar belt and faunal (diversity). The subtropical belt then moves slightly northwards.

The shift of the Polar Front maps onto well-known patterns of late Cenozoic glacial-interglacial Polar Front migration.

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Biomarker data show significant responses in algal and cyanobacterial community structures to the stepwise Hirnantian extinction events. Algal disaster species characterized by elevated C₂₈ steranes predominate.
Isotope trends for the two different locations; the high paleolatitude Boda and low paleolatitude Anticosti Island reveal incompatible patterns. The section at Anticosti Island is assumed to reveal a hiatus in the Ellis Bay Formation and thus does not fully record the Boda-Event.
A: Large scale ice flow comparable to the modern Lambert Glacier in eastern Antarctica.
B: Upon ice retreat, meltwater at ice sheet grounding lines carved tunnel valleys, oriented approximately N–S, clustered into E–W oriented belts. Sediments deposited in these valleys upon postglacial transgression provide excellent source rocks for hydrocarbons.

A similar model may also apply for the lesser studied Arabian Peninsula.
A: Following the deposition of glacially-related sediments in the Hirnantian (latest Ordovician), a relic palaeo-topography remained. This palaeotopography was composed of larger depressions cut by fast flowing ice (palaeo-ice streams), with superimposed networks of smaller scale (tunnel) meltwater valleys. Other features, which may have contributed to this relief, included glaciotectonic deformation structures ("push moraines") produced by sediment bulldozing at the ice margin, and fault scarps produced during isostatic rebound reactivation of pre-existing crustal weaknesses.

B: Release of meltwater at the end of the glaciation resulted in transgression. In the initial phase of this transgression, highy productivity stimulated by nutrient release and upwelling led to anoxia characterised some basinal parts of the palaeotopography, hence "hot shales" were deposited exhibiting good type I/II source rock potential (Pre-Devonian = no type III).

C: As transgression continued, shales deposited in late TST phase are organically lean as the anoxic basins became overfilled and full circulation on the shelf resumed.

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Hirnantian event summary

- The Ordovician/Silurian glaciation has been documented on global scale.
- Mechanisms responsible for triggering the event may be associated with extraterrestrial forcing.
- Placement of large igneous provinces in Baltica equatorial regions may have increased weathering rates forcing an atmospheric CO$_2$ drawdown, favored by position of significant land masses in the equatorial belt.
- Sea ice masses expanded from glaciated southern polar landmasses.
- The Hirnantian stage shows the first of the “big five” extinction events and was associated by extinction rate of 85% in the marine realm (Hirnantian prior to terrestrialisation). The extinction event occurred as a two-step event.
- Rapid decline in SST was the probable cause for the first major extinction pulse, with only cold-adapted flora and fauna surviving this pulse. Sea level drawdown and upwelling of “toxic” element and compound (H$_2$S) enriched deepwater contributed to extinction.

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Hirnantian event summary

- The so-called Boda event represents a short-lived warm phase before the recurrence of glaciations and was associated with severe ocean stratification by continental fresh-water run-off.

- Stratified Oceans with warm surface waters proved inhabitable for cold-adapted planktic fauna and flora.

- Stratified Oceans with anoxic bottom waters proved inhabitable aerobic planktic fauna and flora.

- Massive perturbations of the atmospheric and hydrospheric carbon cycle occurred with $\text{CO}_2$ concentration varying between 8-16 x PAL and near PAL over short periods of time.

- Ongoing discussion addresses whether the Hirnantian event was a single but complex multiphased event or represents a series of interlinked but separate events.

- Isotope stratigraphy is applied to correlate Hirnantian event(s) over long distances as faunal provincialism limits biostratigraphic parallelization.

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