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10 MY Evolutionary stasis of earliest Cambrian (Terreneuvian" mollusk-rich communities and Cambrian Evolutionary Radiation correlations

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Slide 1: The "Cambrian Evolutionary Explosion" brackets the most dramatic interval in the origin of metazoans and modernization of marine community history. This talk regards this interval as not a single "explosion" but a series of evolutionary radiations.

Slide 2: Explosions are single, sometimes continuing, events. When the Cambrian Evolutionary **Radiation,** or CER as we will call it, took place, it is bracketed by the stratigraphic ranges of fossils that indicate a succession of biotic radiations, and not a short or continuous evolutionary explosion.

Slide 3: I have proposed three stages of the long Cambrian Evolutionary Radiation, or CER.

Ediacaran taxa, the petalonae, soft problematica, and a few biomineralized taxa as *Cloudina* and *Namacalathus*, are overlapped in Stage 1 of the CER by a few deep burrowers and phosphatic and aragonitic metazoans.

The basal Cambrian global stratotype is in Stage 1 of the CER and defined by Ediacaran extinctions and diversification of deep burrowers.

Stage 2 of the CER is the focus of this talk. It includes a diversification of biomineralized benthic taxa, particularly molluscs and hyoliths, and the later appearance of tropical archaeocyaths and coeval "worm" mud-mound build-ups in cool-water facies and altitudes.

The lower level taxa of Stages 1 and 2 persist into the remarkably diachronous onset of Stage 3 of the CER, with the appearance of trilobites and other arthropods.

Slide 4: A Cambrian base at about 542 million years and the oldest calcified trilobites at about 520 million mean the CER brackets 40% of the Cambrian and roughly corresponds to the global Terreneuvian Series. CER Stage 2 comprises the middle and upper parts of the Terreneuvian.

Slide 5: CER Stage 2 featured a benthic community with the oldest diverse "small shelly fossils," or SSFs, with biomineralized, aragonitic mollusks and hyoliths labeled "c"; phosphatic conodont element-like sclerites, tommitiiids, and tubes, "p"; and agglutinated conoidal remains, "a".

Slide 6: CER Stage 2 featured largely tropical paleocontinents. As an aside, how most paleogeographic reconstructions show the earliest Cambrian evaporitic carbonate platforms of west and southern Africa near the South Pole is beyond me. The primary field regions of this talk are tropical Siberia and South China and the south temperate Avalonia continent.

Slide 7: Traditional lowest Cambrian correlations of tropical Siberia and South China emphasize low diversity faunas with the *Anabarites* triradiate conchs and the protoconodont *Protohertzina*. These are followed by early CER Stage 2 faunas with low diversity mollusks as *Purella* and *Anabarella* in the Siberian upper Nemakit-Daldynian Stage and what has been called lower China B in the middle Meishucunian Stage.
It seemed to follow, that overlying, more diverse faunas with the apparent rostroconch *Watsonella* and the snail *Aldanella attleborensis* are correlative and marked the end of CER Stage 2.

Slide 8: We illustrate *Watsonella crosbyi* and *Aldanella attleborensis* again as the FADs of these taxa have been repeated endlessly as (1) guides to CER Stage 2, (2) as Tommotian Stage indicators, and (3) as alternative bases to define the upper stage of the Terreneunian Series. These conclusions are all wrong. These are merely long-surviving taxa that appeared well before the Siberian Tommotian.

Slide 9: Important regions of the Siberian Platform in understanding earliest Cambrian biostrat include the SE where the type section of the Tommotian at "Dvortsey" and a nearby section at Ulakhan Sulugar show a spectacular unconformity at the Tommotian base. We will also summarize old and new results on the west side of the Anabar Uplift, area 2, where this unconformity is filled in.

Slide 10: 'Dvostsey" and Ulukhan-Sulugar show the Tommotian base at a break from sparsely fossiliferous, yellow Yudoma Formation dolostone to varicolored mudstones and carbonates of the Pestrotsvet Formation. This is not a facies break but a type 1 sequence boundary with channeling and fissure fills. The Russian literature typically says that diverse Tommotian faunas appear in the upper Yudoma. Well, no, and only in channel and fissure fills with Tommotian onlap.

Slide 11: Two Tommotian concepts developed from the SE Siberia work. One is chronostratigraphic, that the Tommotian base is defined by the *Nogoriocyathus aldanicus* archaeocyath Zone base at 'Dvortsey.' The second is a belief that diverse earliest Cambrian faunas below the oldest trilobites in Siberia and elsewhere are Tommotian.
In SE Siberia, as many as 170 taxa, including the oldest archaeocyaths, hyolithid hyoliths, and lingulate brachiopods appear above the sequence boundary. Let's call these "ahb" taxa, for the Tommotian archaeocyaths, hyolithids, tommotiids, and brachiopods. Note that the supposed index fossils *Watsonella crosbyi* and *Aldanella attleborensis* appear in Tommotian fissure and channel fills or higher, and their lowest global ranges are not represented at the sub-Tommotian unconformity.
Slide 12: Earliest Cambrian biostrat was complimented by carbon isotope work in the 1980s. Work summarized here by Kirschvink and others showed isotope excursions in SE Siberia, with a strong negative peak at the sequence boundary and base of the Tommotian. Peaks N, Z and I are sub-Tommotian.
Slide 13: A second area of great importance in understanding the earliest Cambrian is the west margin of the Aldan Uplift, the circled number 2.
Slide 14: In this area, the biostrat was well known by the 1960s and was complimented by carbon isotope work summarized by Knoll and others at Kotujkan River. We compliment this with work at nearby Ary-Mas Yuryakh ridge.

Slide 15: The Kotuikan River, with Artem Kouchinsky for scale, extends from the possible terminal Ediacaran through Stage 1 CER fossils in mudstone and carbonate of the Manykay Formation, or Nemakit-Daldynian, to a thrombolitic cap called the Koril Member. The Medvezhaya Formation, with a Stage 2 CER fauna was called "Tommotian" by the Russians because of its abundant SSFs, but it lacks the key Tommotian ahb taxa (or archaeos, hyolithids, and lingulate brachiopods).
Knoll and Kauffman et alia in 1995 and 1996 interpreted what was really recorded. They recognized the N, Z, and I excursions of the Yudoma Formation in SE Siberia in the Staryaya Rechka through Manykay formations, but noted a positive carbon excursion I' not present in SE Siberia. Thus, the Anabar Uplift preserves sub-Tommotian strata absent in SE Siberia at the Yudoma–Pestrotsvet contact.

Slide 16: This figure from Knoll and Kaufman et alia is fundamental for lowest Cambrian correlation and understanding CER Stage 2. Older Soviet sources referred the prolific faunas at Kotuikan River to the Tommotian as they include taxa first described from the Tommotian in SE Siberia.. However, carbon isotope study showed that most supposed Tommotian SSFs appear below the I' excursion, shown as a red bar here, and do not provide a robust basis for biostrat correlation. Are these supposed Tommotian index taxa sub-Tommotian?—yes, as none of the characteristic Tommotian ahb taxa are present, and the upper Medvezhaya taxa occur below the widespread I' excursion. Again, Kotujkan River records the lower ranges of taxa first described in SE Siberia but cut out at the sub-Tommotian unconformity . Indeed, the snail *Aldanella attleborensis*, still regarded in a 2014 report as a basal global Tommotian Stage index appears well below the I' excursion—and its lowest presence above the sequence boundary at the top of the Manykay Fm. further indicates that we don't know the timing of its evolutionary origin in CER Stage 2.

Slide 17: The Ary-Mas-Yuryakh section compliments Knoll & Kauffman's work. It is only 14 km away from the Kotujkan River mouth.

Slide 18: The stratigraphy and fossils of this section were documented by the 1960s, and the Soviet and most current Russian literature would call the Medvezhya Formation Tommotian based on SSF diversity.

Ary-Mas-Yuryakh and Kotujkan River have the same carbon isotope stratigraphy, and the I' excursion occurs in the upper Medvezhya Formation. Not only does the "index species" *Aldanella attleborensis"* again occur below the I' excursion, but the other supposed global index species to the Tommotian *Watsonella crosbyi* occurs below I'. These taxa are known from hundreds of specimens, and the limitations on their FADs at Ary-Mas-Yuryach resulting from incomplete preservation, collecting, and likely habitat control mean we really do not have and cannot be certain about the record and timing of their earlier evolutionary origin which could be used in chronostratigraphic definition of the base of a global Stage 2.

Slide 19: The "First Appearance Datum" or FAD of a fossil is a seemingly ponderous and precise scientific term. However, other criteria must be used to determine whether or not an expression as the "FAD of *Watsonella crosbyi* or *Aldanella attleborensis"* really has any time significance beyond a local field area, or merely reflects facies changes or unconformities or collection failure.
Indeed, an examination of the ranges of these two species shows that their lowest appearances are below a globally correlatable carbon excursion, I' in Siberia or L4 in China, that we have dealt with elsewhere (that will be in the last slide in the talk). And indeed, that both species have a long range that essentially corresponds to Stage 2 of the CER.

Slide 20: As discussed in our 2004 and 2013 papers, *Watsonella crosbyi* and *Aldanella attleborensis* have early appearances in high diversity, near-shore, likely intertidal Stage 2 CER faunas about 530 my. Once they appear in Avalonia, they and associated species persist for at least 10 my, and only disappear with community change and the locally late appearance of trilobites in Stage 3 of the CER.

Slide 21: Elements of this talk are in our 2013 report, and Artem and I have submitted a manuscript on the remarkable duration and stratigraphic range of Stage 2 mollusc-rich faunas and the benthic community they are part of.
Thank you.
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The presentation was followed by a question by Brian Pratt who wondered about the intertidal origination of lowest Cambrian SSF taxa in Avalonia. Landing inadequately answered the question by noting that the shallowest SSF faunas in SE Newfoundland occur in wave deposited limestone beds deposited on unconformities as low as the Ediacaran Holyrood Granite.

A more complete answer is that we have published a number of reports on offshore–onshore, litho- and biofacies transitions in the terminal Ediacaran–Lower Cambrian of Avalonian Matitime Canada, SE Newfoundland, and southern Britain.

Briefly, this offshore–onshore facies spectrum in Avalonia includes (1) offshore grayish green siliciclastic mudstone with methanogenic carbonate nodules and without burrows; (2) burrow-mottled green mudstone with small carbonate nodules and rare conoidal fossils; (3) purple to shallower purplish red mudstone with carbonate nodules to thin carbonate lenses and burrow mottling; (4) red siliciclastic mudstones, burrow homogenized, with small carbonate nodules that form thin (to 10 cm) lenticular nodular, fossil wackestones in increasingly proximal facies; (5) red siliciclastic mudstones, burrow homogenized, with thin fossil packstones; and (6) condensed, thin fossil packstones, locally with hematitic small SH-V stromatolites within red mudstones or directly deposited on older units as low as the Holyrood Granite. It is impossible to think that these condensed limestones represent an immediately deep lithofacies when deposited with transgression across unconformity surfaces. (see Landing and Westrop, 2004, Paleontological Society Short Course).