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The late Katian Elkhorn event: precursor to the Late Ordovician mass extinction

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ABSTRACT

The late Katian Elkhorn event is a biogeochemical perturbation preceding the Late Ordovician mass extinction (LOME) with an exceptional record in the United States (U.S.). Results of our recent studies in this interval allow revised temporal ordering to strata across multiple basins providing insights into the magnitude of environmental disturbance and associated processes and feedbacks. The record of the Elkhorn event spans portions of the Appalachian and Midcontinent basins in the eastern U.S. and the Williston Basin and Cordilleran margin in the west. Our work focuses heavily on the Midcontinent Basin in particular, as it shares many characteristics of size, tectonic setting, and lithofacies with the Baltic Basin, providing the potential for resolving global signatures of the event.

In its type-area, the Cincinnatian Series ends with the Elkhorn event. The succession is marked by shallowing from subtidal to marginal marine facies, capped by a karstic sequence boundary. Our new conodont data demonstrate that an overlying white to pink crinoidal grainstone package, previously assigned to the basal Silurian "white" Brassfield Formation near the Ohio-Indiana state line, is in fact Upper Ordovician. Further, $\delta^{13}C_{carb}$ values in this unit are elevated, in line with later phases of the Elkhorn event (2‰ more positive than reported Rhuddanian values). These findings support a correlation of the grainstone interval with the Fernvale Formation of central Tennessee. To the east, much of the northern Appalachian Basin was overfilled with widespread marginal marine to terrestrial red beds by the onset of the Elkhorn event, while the Midcontinent Basin to the west remained relatively sediment starved. In the southern Midcontinent, the mid-Elkhorn event sequence boundary was onlapped by ironstone deposition (lower Fernvale Formation). The ironstones are overlain by sparry and hematitic grainstones with localized bioherms. In Arkansas, where the Fernvale is thickest (>30 m), the sparry phase gives way upward to manganese carbonates and bioherms. Across the region, the Fernvale is, in turn, cut by a sequence boundary, suggesting a yet higher Katian sequence, and is perforated by paleokarst pockets that are filled and overlain by upper Katian (Ka4) sediments. This sequence boundary is onlapped by black shales and the thickest (>10 m) phosphorite of the Ordovician at the end of the Elkhorn event.

Previous studies have suggested age equivalence of the Elkhorn and Paroveja $\delta^{13}C_{carb}$ excursions in Laurentia and Baltica. Despite the attraction of aligning the latest Richmondian and Pirgu regional stages, our data sets demonstrate that this is a miscorrelation. Critical to this revision are new integrated biostratigraphic and chemostratigraphic data sets in a transect from the margin of the Appalachian Basin into the Midcontinent Basin. The new data reveal that the Elkhorn Shale and Fernvale Formation are overlain by the Brainard and laterally equivalent Sylvan, and Mannie shales. These shale successions contain graptolites of the *complanatus* and *pacificus* zones. Thus, the Elkhorn event occurred in the latest *manitoulinensis* Zone, suggesting correlation with the Baltic Moe $\delta^{13}C_{carb}$ excursion.

Our extensive new data sets provide regional chronostratigraphic correlation of strata deposited during the Elkhorn event. When temporally ordered, these records provide evidence for high amplitude sea level oscillations, major redox fluctuations, and reef pulses that demonstrate the waxing and waning of continental ice sheets on Gondwana and the spread of oceanic anoxia only a few million years before the LOME. These findings further call into question traditional models of rapid glaciation during a long-lived greenhouse state as the sole driver of the LOME and emphasize the need for new integrated Upper Ordovician research initiatives to better characterize Katian events.

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