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Reconstructing the Earth system in deep time (Jean Baptiste Lamarck Lecture)

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Earth system science, the study of our planet as an integrated set of subsystems that drive planetary function, is a modern approach to understanding rapidly evolving issues such as climate change, ecosystem stress, and environmental degradation. That is, the Earth system approach offers a holistic perspective of how our planet functions under a spectrum of external and internal forcings that is not obtained by more traditional disciplinary studies. An Earth system approach is transferable to the geologic past, i.e. the deep time, made possible by the advent of high precision radioisotope dating of volcanics intercalated with sedimentary deposits and the potential for astronomically calibrating broad intervals of the geologic time scale. The application of Earth System (climate) Models and process-based ecosystem models to deep time studies and the ability to build high-fidelity proxy time series with resolutions as high as seasonal- to millenial-scale further facilitate Earth systems studies in deep-time. In this talk, I use our collective research, focused on the late Paleozoic Earth system, to illustrate this approach. The ubiquitous presence of cyclothems, the fundamental stratigraphic unit for the late Carboniferous through early Permian (340 to 275 Ma), throughout paleotropical successions coupled with single-zircon U-Pb CA-TIMS ages has documented eccentricity scale cyclicity and the potential for orbital tuning of stratigraphic and stable and radiogenic proxy records. We use thispaleotropical chronostratigraphic framework to reconstruct onlap-offlap history, to build terrestrial and marine proxy records, and to better understand spatial and temporal variability in paleo-surface seawater composition and climate conditions. Integrated morphologic and isotopic study of well-preserved fossil plants permits evaluation of vegetation climate feedbacks and development of multi-proxy atmospheric pCO_2 and O_2:CO_2 trends. Our efforts to obtain high-precision and accurate U-Pb ages for volaniclastic strata from mid- to high-latitude Gondwanan successions (Paganzo, Paraná, Karoo, Kalahari basins) enables correlation between glaciogenic successions in Southern Hemisphere Gondwana as well as into the paleotropics. These studies provide a new view of the glaciation history of southern Gondwana and new constraints on ice initiation and stability thresholds. Interactive data-model comparisons permit contextural interpretations and reveal counterintuitive process relationships.
These findings for Earth's penultimate icehouse, in the context of other recent studies, have important implications for better understanding the 'sources and sinks' for atmospheric pCO_2 through time and regional climate responses to global forcings under different boundary conditions. They further address the challenges of reconstructing meaningful 'global' surface temperatures and seawater composition from epicontinental-dominated records. Lastly, these findings document the ability of vegetation to physiologically force regional climate and strongly perturb surface hydrology with potential for global-scale impact. On a process-scale, such findings are transferable to other time periods of Earth history, including potentially Earth's future, despite very different time scales of perturbation and boundary conditions.