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# Multi-step increase of atmospheric oxygen between ~2.5-2.4 Ga

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The Transvaal Supergroup is a very well preserved paleoproterozoic sedimentary sequence located in soutern Africa that hosts key markers indicating the prevailing redox conditions during sedimentation, such as the Kalahari Manganese Field. However, scarcity of temporal control in the Transvaal Supergroup hinders our understanding and ability to link the mechanisms that dictate planetary processes, such as the rise of atmospheric oxygen and global glaciations. Thus, we report results from a high-precision geochronology study, which improves the regional chronostratigraphic chart. Additionally, redox-sensitive proxies in the ~2.47 Ga old Kuruman Formation, including trace elements alongside triple-sulfur and molybdenum isotope compositions, provide evidence for the presence of an interval with ephemeral oxic conditions that existed prior to the Paleoproterozoic glaciations.

By combining our new data with previous studies, we provide a tentative summary of the evolution of environmental oxygen in the Griqualand West Basin. The lower Ghaap Group is generally dominated by anoxic conditions, although oxygen oases restricted in space and time develop for several millions of years, as observed in the ~2.48-2.46 Ga old Kuruman Formation. These oxygen oases eventually become unstable and collapse for reasons that are not yet understood, since strong anoxic conditions are observed again in the ~2.45-2.44 Ga old siliciclastic Koegas Subgroup. Although we do not know the exact beginning of the period of regional glaciation that follows stratigraphically upwards, we do know that it ends at ~2.42, depositing thick diamictite, known as the Makganyene Formation. The end of the glaciation may have been triggered by the emplacement of a Large Igneous Province, known as the Ongeluk Formation. The redox state during this period is hard to constrain with the available rock record, nevertheless thick Mn-horizons that undoubtedly deposited under fully oxic conditions follow stratigraphically upwards in the ~2.41 Ga old Hotazel Formation. Summarizing, our updated framework challenges the idea that the first rise in oxygen was a single synchronous and uni-directional event. Instead, we conceive it as a complex process varying in spatial and temporal scales, which occurred in a multi-step manner after various individual events in aqueous environments with varying amounts of dissolved oxygen.