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The Cenozoic Evolution of Earth's Strongest Geoid Low: Insights into Mantle Dynamics below Antarctica

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Constraining the long-term evolution of geoid anomalies is essential for unraveling Earth's internal dynamics. While most studies focus on present-day geoid snapshots, we reconstruct the time-dependent evolution of Earth's strongest geoid depression, the Antarctic Geoid Low (AGL), over the Cenozoic. Unlike geodetic reference frames that place the deepest geoid low in the Indian Ocean, a geodynamic perspective (relative to a hydrostatic ellipsoid) reveals the strongest nonhydrostatic geoid depression actually resides over Antarctica. Using a back-and-forth nudging technique for time-reversed mantle convection modeling, we leverage 3-D mantle density structures derived from seismic tomography and geodynamic constraints. Our results show that the AGL has persisted for at least ~70 Myr, undergoing a major transition in amplitude and position between 50 and 30 Ma. This coincides with abrupt lateral shifts in Earth's rotation axis at ~50 Ma, validated through paleomagnetic constraints on True Polar Wander. Initially, stable lower mantle contributions dominated the AGL, but over the past ~40 Myr, increasing upper-mantle buoyancy, particularly above ~1300 km depth, amplified the AGL magnitude. This shift stems from the interplay between long-term deep subduction beneath the Antarctic Peninsula and a buoyant, thermally driven upwelling of hot, low-density material from the lowermost mantle. These new results contrast with earlier interpretations, clarifying the crucial role of evolving mantle buoyancy in shaping global geoid anomalies. By incorporating seismic, geodynamic, and mineral-physics data, our reconstructions provide a more comprehensive understanding of mantle flow beneath Antarctica and offer new insights into the dynamic coupling between lower and upper mantle processes that govern Earth's long-wavelength geoid evolution.