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Missing geomagnetic reversals in the geomagnetic reversal history

Researchers may have found the ages that hide undiscovered geomagnetic reversals using statistical analysis

In everyday life, we can easily tell whether objects are packed tightly (high density) or spread out sparsely (low density) just by looking at them. But when dealing with time-series event data, scattering along a timeline, it is not as straightforward to objectively identify when the density is high or low. In this situation, a statistical method called kernel density estimation is useful. By assigning a probability to each data point and overlaying these distributions, the method provides a smooth estimate of how event density changes over time. It is particularly effective for analyzing the timing of geomagnetic reversals.

In geophysics, researchers have compiled records of when geomagnetic polarity reversals occurred, and have examined how densely these reversals are distributed over time. It is known that geomagnetic reversals cluster during certain intervals ("dense" periods) and become very rare during others ("sparse" periods). These differences are thought to reflect variations in heat flow across the core–mantle boundary, which influence the geodynamo that generates Earth's magnetic field.

Periods with high reversal density allow us to more precisely estimate past plate positions, fossil ages, and the timing of environmental changes, using magnetic signatures preserved in the subaerial/submarine rocks or sediments. In contrast, periods with very low reversal density provide fewer dating markers, making reconstructions of the ancient Earth more challenging. However, this scarcity itself can still offer important information, as it may indicate changes in the state of Earth's interior.

Missing short-time-interval geomagnetic reversals may appear as dips in the new reversal frequency model

Earth's magnetic field has undergone many polarity reversals, during which the north and south magnetic poles switch places. These events are reconstructed from geological materials such as volcanic rocks, marine sediments, and marine magnetic anomalies, and they are compiled into the Geomagnetic Polarity Time Scale (GPTS). However, some short-time-interval reversals may not appear in the GPTS because they are difficult to observe due to the time resolution limits.

An international research team from Japan (Kyushu University/National Institute of Polar Research/The Graduate University for Advanced Studies, SOKENDAI/The Institute of Statistical Mathematics/Geological Survey of Japan, AIST/Japan Agency for Marine-Earth Science and Technology (JAMSTEC)/Atmosphere and Ocean Research Institute, The University of Tokyo/Kochi University/Institute of GeoHistory, Japan Geochronology Network/Kobe University), the Republic of Korea (Korea Institute of Geoscience and Mineral Resources (KIGAM)/University of Science and Technology), and the United States (Wayne State University) analyzed the latest reversal timing dataset (GPTS2020) to investigate how reversal frequency has changed over time. They applied an adaptive-bandwidth kernel density estimation (AKDE) method, which estimates reversal frequency while accounting for uneven spacing of reversal events.

Previous studies using the AKDE suggested that the frequency of geomagnetic reversals decreased steadily from approximately 155 million years ago toward the onset of the Cretaceous Normal Superchron (approximately 121 to 83 million years ago), and then increased steadily from the end of the superchron to the present (Constable, 2000, https://doi.org/10.1016/S0031-9201(99)00139-9). AKDE can capture broad trends in the density of events in one-dimensional time-series data.

Numerical geodynamo simulations show that reversal frequency changes depending on the magnitude and spatial pattern of heat flow across the core-mantle boundary. Mantle convection and true polar wander modify this heat flow gradually over tens to hundreds of millions of years. For this reason, a steadily changing reversal frequency has been considered the most reasonable interpretation. However, the conventional AKDE approach was unable to show when geomagnetic reversals that are missing from the GPTS might have occurred during the past approximately 155 million years.

The researchers applied an AKDE method with improved parameter selection to GPTS2020. This method allowed us to estimate variations in reversal frequency with higher temporal resolution. Specifically, the researchers used a cross-validation method to determine the initial bandwidth, which corresponds to the initial resolution of the analysis. A previous study had chosen this initial bandwidth based on empirical rules, but our approach determines it more stably. As a result, the researchers identified four distinct dips in the new reversal frequency model following the Cretaceous Normal Superchron.

Additionally, when researchers added the newly reported Lima–Limo reversals at approximately 31 million years ago, identified through recent high-precision paleomagnetic and geochronological studies of Ethiopian flood basalts (Ahn et al., 2021, https://doi.org/10.1093/gji/ggaa557; Yoshimura et al., 2023, https://doi.org/10.1029/2022GL102560), and performed the AKDE analysis again, the dip in frequency around approximately 32 million years ago became smoother. This finding supports the interpretation that smoother, long-term variations more closely represent the underlying behavior of the geodynamo. It also indicates that the four periods showing dips in reversal frequency may contain missing reversals.

The researchers conclude that dips in geomagnetic reversal frequency are promising candidates for future investigations aimed at identifying potentially missing reversals. The findings highlight specific time intervals that merit high-resolution paleomagnetic investigation using deep-sea magnetic anomaly surveys, lava sequences, and ocean drilling cores. Additionally, this research contributes to improved understanding of the long-term behavior of Earth's magnetic field and the dynamics of the deep Earth.

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For more information about this research, see " Evidence for missing geomagnetic reversals from geomagnetic reversal frequency model using adaptive kernel density estimation," Yutaka Yoshimura, Masakazu Fujii,Hidemitsu Hino, Shotaro Akaho, Satoshi Kuriki, Osamu Ishizuka, Toshitsugu Yamazaki, Hyeon-Seon Ahn, Tesfaye Kidane, Yuhji Yamamoto, Yo-ichiro Otofuji, *Geophysical Research Letters,* https://doi.org/10.1029/2025GL120557

About National Institute of Polar Research, Japan

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conducting cutting-edge research on polar ecosystems, polar climate science, geology, sustainability in polar regions, and more.
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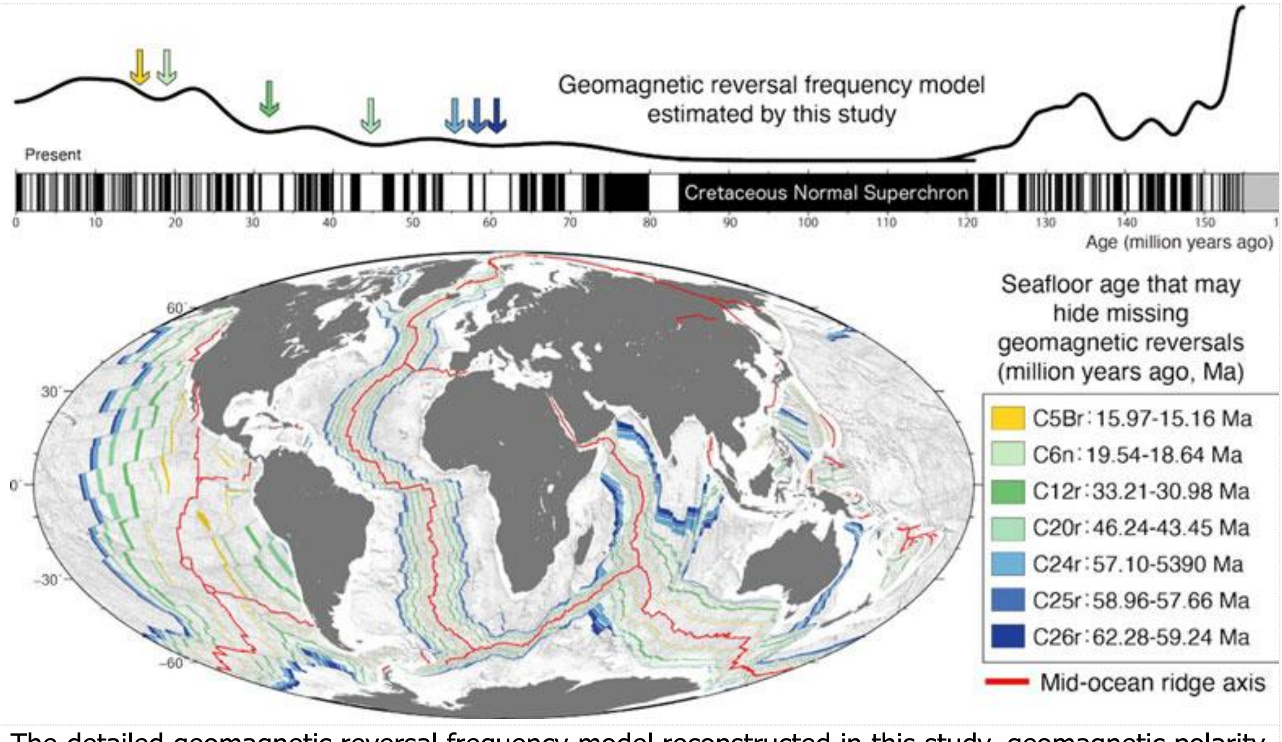
About Kyushu University
Founded in 1911, Kyushu University is one of Japan's leading research-oriented institutions of higher education, consistently ranking as one of the top ten Japanese universities in the Times Higher Education World University Rankings and the QS World Rankings. Located in Fukuoka, on the island of Kyushu—the most southwestern of Japan's four main islands—Kyushu U sits in a coastal metropolis frequently ranked among the world's most livable cities and historically known as Japan's gateway to Asia. Its multiple campuses are home to around 19,000 students and 8,000 faculty and staff. Through its VISION 2030, Kyushu U will "drive social change with integrative knowledge." By fusing the spectrum of knowledge, from the humanities and arts to engineering and medical sciences, Kyushu U will strengthen its research in the key areas of decarbonization, medicine and health, and environment and food, to tackle society's most pressing issues.



The detailed geomagnetic reversal frequency model reconstructed in this study, geomagnetic polarity time scale (drawn using data from Ogg, 2020, Geologic Time Scale 2020, Elsevier), and the Earth's ocean floor structure map with ages of missing reversals (drawn using data from Müller et al., 2019, Tectonics). The colored bands indicate the ocean floor at times when high-resolution surveys are needed to detect missing geomagnetic reversals. ©Yutaka Yoshimura

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