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Mesozoic true polar wander: Evidence, uncertainties, and the East Asian record

XIAO-KAI YANG[1, 2], JUN-YUAN ZHOU[1, 2], XIAN-QING JING[3] & YONG ZHANG[1, *]
[1]*State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China*
[2]*University of Chinese Academy of Sciences, Beijing 100049, China*
[3]*Capital Normal University, Beijing 100048, China*
xkyang@nigpas.ac.cn; https://orcid.org/0009-0000-8886-4310
jingxq@cnu.edu.cn; https://orcid.org/0000-0002-2927-5062
jyzhou@nigpas.ac.cn; https://orcid.org/0000-0002-9691-3765
yzhang@nigpas.ac.cn; https://orcid.org/0000-0001-8237-6498
**Corresponding author*

Abstract

True polar wander reorients the solid Earth relative to the spin axis when mass redistribution changes the planetary inertia tensor. Rather than repeating a general history of true polar wander, this review assesses the confidence of proposed Mesozoic true polar wander events and explores their potential links with independent surface records. Specifically, we evaluate post-Pangaea rotations at *ca.* 250–200 and 200–150 Ma, the disputed Late Jurassic monster polar shift, smaller Late Jurassic–Early Cretaceous rotations and loops, and the Late Cretaceous 86–78 Ma oscillation. Their support varies widely because palaeomagnetic records differ in age control, remanence reliability, and reference-frame dependence, and are susceptible to local rotation, inclination shallowing, remagnetization, and unresolved plate motion. We therefore rank candidates using five criteria: multi-region coherence after plate restoration, robust age control, reliable palaeomagnetic data, geodynamically reasonable amplitude and rate, and surface records that match the predicted geographical pattern. East Asia provides a useful case because competing Jurassic–Early Cretaceous palaeolatitude models can be compared with regional aridification, basin evolution, volcanic-lacustrine deposits, and the Yanliao-Jehol fossil record. True polar wander is unlikely to be a single cause of environmental or biological change; its diagnostic value is spatial, because equatorward, poleward, and return motions should produce different climatic, stratigraphic, and biogeographic patterns. Progress will require tighter chronology, stronger tests of primary remanence, improved plate reconstructions, and explicit comparison of predicted true polar wander sectors with sedimentary, geochemical, palaeoclimate, and fossil archives.

Keywords: true polar wander, Mesozoic, East Asia, Pangaea breakup, Jurassic monster shift

True polar wander (TPW) is simple to describe but difficult to demonstrate. Redistribution of mass changes Earth's inertia tensor, and the solid exterior may rotate relative to the spin axis toward a more stable orientation (Gold, 1955; Goldreich & Toomre, 1969; Evans, 1998; Wang & Mitchell, 2023). Palaeomagnetic directions, however, contain several superimposed signals: plate motion by plate tectonics (plate motion hereafter), whole-lithosphere reorientation, regional vertical-axis rotation, and the later alteration, *e.g.*, inclination shallowing and remagnetization (*e.g.*, Elmore *et al.*, 2012; Zhang *et al.*, 2016, 2018, 2019, 2020; Zhang & Zhou, 2026). The key challenge is to separate TPW from plate motion and later alterations, not simply to identify a large apparent polar shift.

Wang & Mitchell (2023) reviewed TPW across the Earth system and geological time. Here, we focus specifically on the Mesozoic, an interval in which several TPW events have been proposed but their timing, amplitude, rate, and geological significance remain debated. The Mesozoic combines Pangaea breakup, Atlantic and Indian Ocean opening, Tethyan and Pacific plate reorganization, large igneous provinces, greenhouse climate, oceanic anoxic events, sea-level change, and major ecosystem turnover (Takashima *et al.*, 2006; Benton, 2010; Seton *et al.*, 2012; Müller *et al.*, 2016). These processes altered both surface and mantle mass distributions, while their geological effects varied strongly among regions. This makes the Mesozoic an important interval for reassessing the evidence, uncertainties, and possible Earth-system implications of TPW.

This review has three aims. First, we define criteria for separating TPW from plate motion and local alterations.

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Second, we rank the principal Mesozoic TPW candidates by strength of evidence. Third, we discuss East Asia as a case study region where competing palaeolatitude models, climate-sensitive sediments, basin histories, volcanic-lacustrine deposits, and fossil assemblages can be considered together. The objective is not to treat TPW as a universal explanation for Mesozoic environmental or biotic change, but to clarify which proposed TPW events are robust, which remain uncertain, and how regional geological records may help constrain their broader significance.

From general true polar wander to a Mesozoic testing framework

True polar wander, apparent polar wander, and the signal-separation problem

In this review, TPW denotes coherent rotation of the lithosphere-mantle shell with respect to the planetary spin axis. It differs from plate motion and local block rotation. Under the geocentric axial dipole assumption, time-averaged palaeomagnetic directions provide a reference linked to the spin axis. An apparent polar wander (APW) path therefore is at least a combination of plate motion, TPW, and local rotation (Gordon, 1987; Besse & Courtillot, 1991; Evans, 2003; Torsvik *et al*., 2012).

This distinction is critical in the Mesozoic, when continental breakup, terrane motion, and margin deformation produced large regional displacements. A direction change in one APW path cannot by itself establish TPW. A stronger test seeks a shared rotational component in independent regions after relative plate motions are restored. Local plate motion may also amplify or partly cancel the global vector, an important complication in East Asia where convergence and subduction affected Jurassic palaeomagnetic paths (Gao *et al*., 2021).

Surface records as independent geological constraints

Surface records provide an additional way to evaluate whether a proposed TPW reconstruction has geological significance beyond a palaeomagnetic curve. TPW should not be expected to produce a uniform global environmental crisis; its expected signature is spatial contrast. Regions moving equatorward, poleward, or across subtropical belts may experience different changes in climate belts and rotational sea-level forcing, and basins located in different positions relative to a TPW axis may record contrasting transgressive-regressive trends, facies shifts, or biotic responses (Sabadini *et al*., 1990; Mound & Mitrovica, 1998; Mound *et al*., 1999; Raub *et al*., 2007). Therefore, temporal overlap between proposed TPW intervals and major Mesozoic events, such as Pangaea fragmentation, oceanic anoxic events, Pacific plate reorganization, large igneous province emplacement, or greenhouse climate, is not sufficient evidence by itself. The more useful question is whether the reconstructed TPW geometry is consistent with the regional distribution, timing, and sequence of geological change.

Working criteria and confidence levels

Based on this logic, we evaluate Mesozoic TPW candidates using five criteria (Table 1). First, comparable motion should be recoverable from more than one plate, terrane, or reference frame. Second, palaeomagnetic records need secure and sufficiently precise age constraints. For event-scale TPW tests, the most useful records are those tied to

TABLE 1. Working confidence criteria for evaluating Mesozoic true polar wander candidates.

Criterion	Stronger evidence	Weaker evidence	Why it matters
Spatial coherence	Similar motion on two or more independent plates after restoring relative plate motion	Signal from only one locality or one plate	TPW should be global, not local
Age control	Timing constrained by continuous sections, magnetostratigraphy, or precise isotopic ages, *e.g.*, < 2 Ma	Discontinuous sections, large dating uncertainties, *e.g.*, > 10 Ma	Needed to test rate and synchronicity
Remanence reliability	Primary remanence with R-value > 4 (Meert *et al*., 2020)	Remagnetization, inclination shallowing, or local rotation not excluded, or R-value < 4	False APW can mimic TPW
Geodynamic plausibility	Magnitude, rate (< 2.4°/Ma), and axis fit mantle/lithosphere dynamics and plausible mass anomalies	Dynamic mechanisms absent from TPW models, motion requires unrealistic rates or lacks a plausible inertia source	TPW must be physically realistic
Surface prediction	Climate, sedimentary, sea-level, or fossil records match predicted spatial patterns	Only broad temporal coincidence	TPW is valuable because it makes spatial predictions

continuous stratigraphic sections, magnetostratigraphy, or precise isotopic ages, ideally with uncertainties of < 2 Ma where possible. Finer age bounds yield tighter controls on plate palaeogeography and more accurate estimates of plate motion rates, thereby improving the robustness of TPW identification. Third, the record needs appropriate tests of remanence, including demagnetization behaviour, rock magnetism, field tests, and explicit assessment of remagnetization. As a practical benchmark, we follow the R-value framework of Meert *et al.* (2020) and regard records with R > 4 as stronger evidence. Fourth, the amplitude and rate must be compatible with plausible mantle viscosity, lithospheric strength, and inertia anomalies, for example, rates of less than 2.4°/Ma have been suggested (Tsai & Stevenson, 2007; Creveling *et al.*, 2012; Mitchell, 2014). Fifth, the model must predict a geographic pattern that can be tested independently.

These criteria define a confidence scale. High-confidence events combine good chronology, remanence reliability, and multi-region coherence. Medium-confidence events are physically plausible but remain sensitive to pole selection, reference frames, or local rotation. Low-confidence events are better treated as regional APW anomalies until new data resolve the alternatives. The ranking is deliberately updateable: it identifies which observations would most change an interpretation.

The reference frames

The interpretation of proposed TPW events depends partly on the reference frame used. In a palaeomagnetic reference frame, apparent polar wander records plate motion relative to the spin axis; coherent motion among several plates may suggest TPW, but cannot by itself exclude a common component of plate motion (Gordon, 1987; Torsvik *et al.*, 2012). Hotspot reference frames attempt to estimate motion relative to mantle plumes (Steinberger & Torsvik, 2008), but depend on assumptions about hotspot fixity. Mantle-based or geodynamic reference frames combine plate reconstructions with mantle-flow or mantle-structure models, providing a more dynamic framework but relying on assumptions about plate circuits, mantle viscosity, density structure, and absolute plate motion (Steinberger & Torsvik, 2008; Torsvik *et al.*, 2012; Müller *et al.*, 2016). Thus, the same palaeomagnetic data may yield different estimates of TPW amplitude, rate, or timing within different reference frames.

Candidate Mesozoic true polar wander events: evidence, controversy, and confidence levels

Candidate events cluster into five groups (Fig. 1): broad rotations at *ca.* 250–200 and 200–150 Ma, the Late Jurassic monster shift, smaller Late Jurassic–Early Cretaceous rotations or loops, a *ca.* 110–100 Ma signal, and the 86–78 Ma Late Cretaceous oscillation. Because their evidence is uneven, they are best compared as ranked hypotheses rather than combined into a single continuous TPW history.

Pangaea-related early Mesozoic rotations

The largest early Mesozoic TPW hypotheses are associated

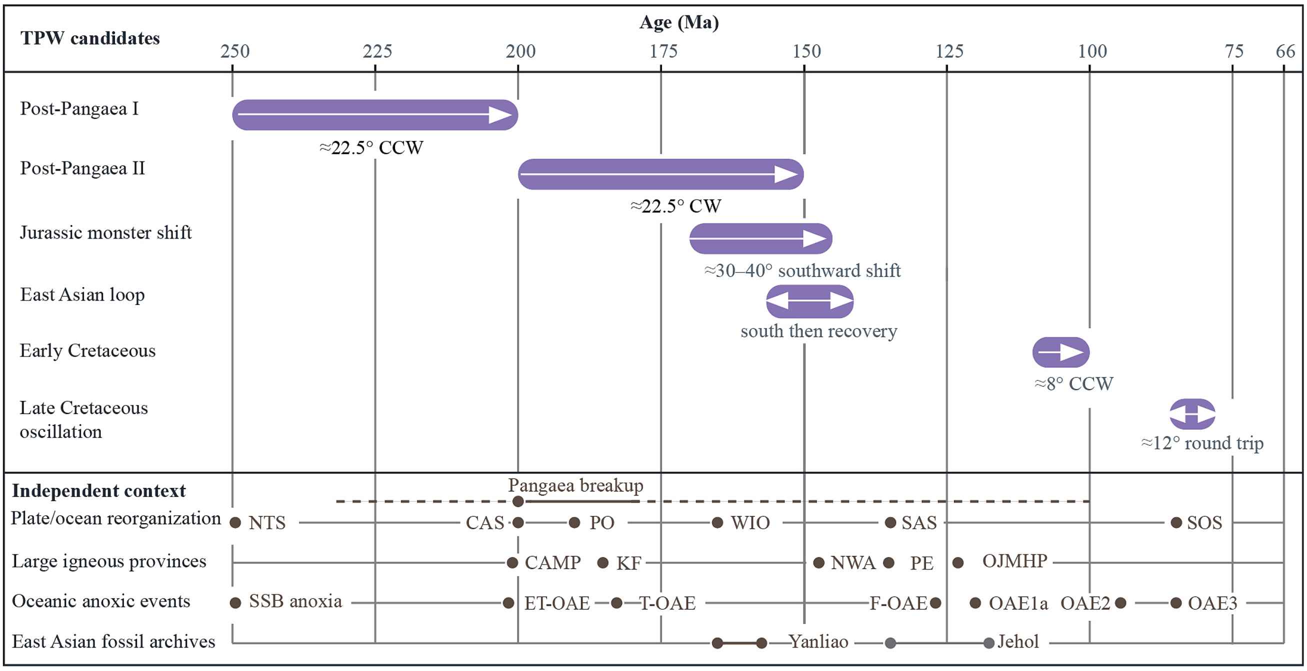

FIGURE 1. Candidate Mesozoic true polar wander events and independent geological context. Full definitions of abbreviations are listed in Tables 2, 3, and 5. Circles mark key temporal nodes of events, and line segments indicate event durations.

with Pangaea and its early breakup. Steinberger & Torsvik (2008) separated mean continental motion from independent plate motion in a palaeomagnetic reference frame and inferred a *ca.* 18° anticlockwise (CCW) rotation during *ca.* 250–220 Ma, followed by a *ca.* 18° clockwise (CW) rotation during *ca.* 195–145 Ma. Torsvik *et al.* (2012) later revised the framework to two broader rotations: *ca.* 22.5° anticlockwise during *ca.* 250–200 Ma and *ca.* 22.5° clockwise during *ca.* 200–150 Ma. These events are credible candidates because they are slow enough to be geodynamically plausible and are embedded in a relatively well-defined plate-tectonic context: the aftermath of Pangaea assembly and the beginning of fragmentation.

These rotations are inferred from global APW compilations and reference-frame comparisons rather than from a single densely sampled stratigraphic record. Their environmental relevance depends on reconstructed motion for each region; a uniform global response is neither required nor expected. We classify these Pangaea-related early Mesozoic rotations as medium-confidence, model-dependent TPW components. They are geodynamically reasonable and broadly consistent with global APW patterns, but their timing and amplitude are less tightly resolved than event-scale records. They are useful for framing long-wavelength palaeogeographic change, but specific climatic or biotic links require independent regional tests.

The Jurassic monster polar shift

The Jurassic monster polar shift is the most conspicuous and contentious Mesozoic TPW hypothesis. It commonly refers to a large, relatively rapid polar shift during *ca.* 170–145 Ma or *ca.* 160–145 Ma. Supporting evidence has been drawn from U-Pb-dated kimberlites in cratonic North America (Kent *et al*., 2015; R = 4 based on the evaluation criteria of Meert *et al*., 2020; Table 2), sequential palaeopoles from Adria-Africa (Muttoni & Kent, 2019; R = 5), Pacific Plate records (Fu & Kent, 2018; R = 4), and tests using La Negra volcanic rocks (Fu *et al*., 2020; R = 5; Meert *et al*., 2020). If interpreted as TPW, this would represent a large and rapid reorientation of the solid Earth during a period of major Jurassic plate-boundary and ocean-basin reorganization. The controversy centres on the inferred speed and size of the shift. Wang & Mitchell (2023) summarized estimates of roughly 30° for North America and the Pacific Plate and about 40° for Adria-Africa, but those values depend on APW construction and

TABLE 2. R-value evaluation of the main cited palaeomagnetic data (Meert *et al*., 2020).

Study area / dataset	R-value	Main caveats	Reference
Scaglia Rossa limestones, Italy	6	Requires structural and inclination-shallowing considerations; formal reversal-test reporting is not the central strength.	Mitchell *et al*. (2021)
Kimberlites, Superior Province, Canada	4	Limited number of independent igneous bodies; PSV averaging and formal reversal-test constraints remain conservative.	Kent *et al*. (2015)
ODP Site 801B, Pacific Plate	4	Mainly provides palaeolatitude constraints rather than a fully oriented palaeomagnetic pole; field-test and reversal-test constraints are limited.	Fu & Kent (2018)
Adria sedimentary sections, Italy	5	Based largely on reanalyzed sedimentary records; carrier tests and independent field tests are less complete than in ideal primary igneous datasets.	Muttoni & Kent (2019)
La Negra volcanics, northern Chile	5	Good igneous dataset, but rock-magnetic carrier identification and independent field tests are limited; the younger pole has less decisive reversal-test support.	Fu *et al*. (2020)
Southwest Greenland coast-parallel dykes	6	Very strong dataset, but the dyke swarm may represent a protracted emplacement interval rather than a single instantaneous pole.	Kulakov *et al*. (2021)
Nandaling and Tiaojishan/Lanqi volcanics, North China	5	Important volcanic constraints, but the older age assignment is relatively broad and the shift is defined by a limited number of key poles.	Yi *et al*. (2019)
Haifanggou and Lanqi/Tiaojishan volcanics, North China	5	Strong volcanic sampling and field tests, but reversal-test statistics are not fully explicit and one pole is based on relatively few sites.	Gao *et al*. (2021)
Tiaojishan and Tuchengzi volcanics, North China	5	Uncorrected local vertical-axis rotations and overlapping palaeopole confidence intervals without remagnetization constraints	Hou *et al*. (2024)

plate restoration. A new high-quality pole from southwest Greenland instead supports slower Jurassic motion and argues against a discrete rapid shift (Kulakov *et al*., 2021; R = 6).

We classify the monster shift as a medium-confidence but high-priority hypothesis. It may explain several Jurassic palaeomagnetic and palaeolatitude anomalies, yet it is not secure enough to serve as an assumed cause of climate or biotic change. The decisive test is whether independent regions and surface archives reproduce its predicted geometry and timing.

Smaller Late Jurassic–Early Cretaceous rotations and round-trip models

After the broad early Mesozoic rotations, reconstructions suggest smaller clockwise motion at *ca.* 150–140 Ma and anticlockwise motion at *ca.* 110–100 Ma, with amplitudes of *ca.* 8–10° (Steinberger & Torsvik, 2008; Wang & Mitchell, 2023). Such paired motion could reflect continuing adjustment of long-lived mantle structure as slab and plume loads changed. Hou *et al.* (2024) proposed a more specific East Asian loop: southward motion from *ca.* 155–147 Ma followed by northward recovery to *ca.* 147–141 Ma (R = 5).

Signals of this size are close to common uncertainties in palaeomagnetic poles and plate circuits. Inclination shallowing, local rotation, imprecise ages, or remagnetization can obscure or imitate them. We therefore classify these smaller proposed TPW events as low- to medium-confidence hypotheses. Future continuous magnetostratigraphic, sedimentary, geochemical, and fossil records should be able to test whether the predicted transient displacement and partial recovery are real.

The Late Cretaceous 86–78 Ma oscillation

The 86–78 Ma oscillation is a well-resolved individual Mesozoic candidate. Mitchell *et al.* (2021) inferred *ca.* 12° of round-trip motion, with an excursion near 84 Ma followed by recovery. The interpretation rests on more than 1000 samples from overlapping Scaglia Rossa sections, consistent inclination and declination changes, magnetostratigraphic control, and magnetic-mineral evidence for a stable signal (R = 6). A palaeomagnetic study of a single section within a global TPW framework provides a useful test.

Late Cretaceous TPW had earlier been proposed from Pacific seamount data (Gordon, 1983; Sager & Koppers, 2000) and questioned using lower-resolution Italian records (Lowrie & Alvarez, 1977; Alvarez & Lowrie, 1978; Cottrell & Tarduno, 2000). Mitchell *et al.* (2021) argued that the older sampling was too sparse to resolve a short oscillation. The case therefore also illustrates how sampling density can control whether brief TPW is detected.

The outstanding test for this TPW event is to replicate its signal beyond Italy. Planetary reorientation should appear, within age uncertainty, on other plates. We therefore assign the event medium–high confidence relative to other Mesozoic candidates, while retaining multi-plate confirmation as a key requirement. Its round-trip path offers an unusually clear target for transient climate and relative sea-level tests.

A confidence hierarchy for Mesozoic true polar wander

The Mesozoic record is best expressed as a confidence hierarchy. The 86–78 Ma oscillation is resolved at medium to high resolution. The Pangaea-related early Mesozoic rotations are physically plausible but reference-frame dependent. The monster shift is consequential yet disputed, and the smaller Jurassic–Cretaceous rotations remain near the resolution limit of many datasets.

This hierarchy should guide interpretation of surface records. Better-supported events can be used to make explicit predictions; weaker events should be tested by those records rather than assumed to explain them.

Geodynamic associations: Pangaea breakup, mantle structure, and plate-boundary reorganization

No single rift, subduction episode, or large igneous province is likely to trigger TPW in isolation. Pangaea breakup, redistribution of subduction zones, ocean-basin growth, and mantle upwelling are therefore relevant as parts of a changing global mass pattern (Fig. 1), not as one-to-one causes.

Pangaea provides the broadest context. The *ca.* 250–200 Ma rotation occurred after final Pangaea assembly, whereas the *ca.* 200–150 Ma counter-rotation overlaps early fragmentation and Atlantic development. Steinberger & Torsvik (2008) noted that the inferred rotation axes were spatially related to the region of the later North America-South America-Africa triple junction. This spatial coincidence does not prove causality, but it suggests that the inertia structure inherited from supercontinent assembly and its surrounding subduction systems may have influenced early Mesozoic TPW.

Central and South Atlantic development, Indian Ocean opening, Tethyan evolution, Southern Ocean and Pacific-Izanagi-Farallon-Phoenix reorganization overlap several proposed TPW intervals (Seton *et al*., 2012; Müller *et al*., 2016; Table 3). These changes redistributed ridges, slabs, and oceanic lithosphere. They establish a plausible dynamical setting, but temporal overlap does not identify which component, if any, drove a particular rotation.

The Central Atlantic Magmatic Province, Karoo-Ferrar, Paraná-Etendeka, and the Ontong Java-Manihiki-Hikurangi plateau system also overlap candidate intervals (Marzoli *et al*., 1999; Jourdan *et al*., 2005, 2007; Taylor, 2006; Hoernle *et al*., 2010; Blackburn *et al*., 2013; Table 4).

TABLE 3. Timing of Mesozoic seafloor spreading initiation. Asterisks indicate data used in Fig. 1.

Ocean	Abbreviations	Oceanic seafloor spreading	Reference
Neo-Tethys *	NTS	260–240 Ma	Jafari *et al*., 2023
Central Atlantic *	CAS	200–190 Ma	Seton *et al*., 2012
Pacific Ocean *	PO	190–170 Ma	Seton *et al*., 2012
Western Indian Ocean *	WIO	165–154 Ma	Seton *et al*., 2012
Eastern Indian Ocean	EIO	156–132 Ma	Seton *et al*., 2012
North Atlantic	NAA	146–120 Ma	Seton *et al*., 2012
South Atlantic *	SAS	135–130 Ma	Seton *et al*., 2012; Heine *et al*., 2013
Southern Ocean *	SOS	84–80 Ma	Seton *et al*., 2012

TABLE 4. Global large igneous provinces (LIPs) in the Mesozoic. O, ocean; C, continent

No.	Age (Ma)	LIP Name	Type	Locations	Volume	References
1	75–70	Sierra Leone/SL	O	Atlantic Ocean	V=2.5 Mkm^3	Eldholm & Coffin (2000); Ernst & Buchan (2001a)
2	95–88	Caribbean-Colombian/CC	O/C	Central America, South America	V=4.5 Mkm^3	Kerr (2014)
3	90–86	Madagascar	C	Africa	V=4.5 Mkm^3	Ernst & Buchan (2001b)
4	101–97	Hess	O	Pacific Ocean	V=9.1 Mkm^3	Eldholm & Coffin (2000); Ernst & Buchan (2001b)
5	100–94	Maud	O/C	Africa	V=4 Mkm^3	Gohl *et al*. (2011)
6*	124–120	Ontong Java-Manihiki-Hikurangi plateau/OJMHP	O	Pacific Ocean	V=58 Mkm^3	Ingle & Coffin (2004)
7	130–90	High Arctic Large Igneous Province /HALIP	C	Circum-Arctic	V=2.8 Mkm^3	Jowitt *et al*. (2014)
8	125–119	Manihiki	O	Pacific Ocean	V=8.8 Mkm^3	Taylor (2006)
9	120–118	Kerguelen	O	Indian Ocean	V=9.1 Mkm^3	Wallace *et al*. (2002)
10*	135–134	Paraná–Etendeka/PE	C	South America & Africa	V=2.4 Mkm^3	Thiede & Vasconcelos (2010)
11*	152–139	NW Australian margin/NWA	O	Australia	V=2.2 Mkm^3	Pirajno & Hoatson (2012); Rohrman (2013)
13	145–135	Shatsky	O	Pacific Ocean	V=4.3 Mkm^3	Sager *et al*. (2013); Heydolph *et al*. (2014)
14	146–144	Magellan	O	Pacific Ocean	V=1.8 Mkm^3	Eldholm & Coffin (2000); Ernst & Buchan (2001b)
15*	185–175	Karoo–Ferrar/KF	C/S	Africa, South America, Antarctica	V=5 Mkm^3	Svensen *et al*. (2012); Storey *et al*. (2013)
16*	202–200	Central Atlantic Magmatic Province /CAMP	C	North America, South America, Africa, Europe	V=10 Mkm^3	Marzoli *et al*. (2011); Bertrand *et al*. (2014)
17	230–225	Wrangellia	O	Western North America	V=1 Mkm^3	Greene *et al*. (2010)

These provinces record major thermal anomalies, but are better treated as markers of broader mantle reorganization than as isolated TPW triggers.

Persistent lower-mantle anomalies beneath Africa and the Pacific may have supplied a long-lived framework within which changing slabs and plumes generated paired or oscillatory motion (Steinberger & Torsvik, 2008; Wang & Mitchell, 2023). This interpretation is model-dependent, but it explains why successive rotations might share preferred axes rather than occur randomly.

Testable Earth-system consequences of Mesozoic true polar wander

The key test is spatial pattern rather than simple timing. A real TPW event should move different regions toward different latitude belts, so coeval environmental or biotic changes should not be uniform everywhere. This makes independent sedimentary, geochemical, and fossil records essential for testing the geological consequences of proposed TPW events. Equatorward, poleward, and round-trip motions should not produce the same climate, sea-level, sedimentary, or biotic history in every region (Table 5).

Palaeolatitude change, climate belts, and sedimentary facies

Palaeolatitude is the environmental variable most directly changed by TPW. Equatorward motion may move a region into warmer or arid subtropical belts; poleward motion may increase cooling, seasonality, or humidity depending on circulation. Evaporites, aeolian sandstones, red beds, coals, carbonate platforms, palaeosols, lacustrine shales, and fossil assemblages can therefore test the predicted direction of motion.

The test must compare direction as well as age. Muttoni *et al.* (2013) related Jurassic motion of Adria-Africa to zonal Tethyan facies, whereas Yi *et al.* (2019) linked southward displacement of East Asian blocks to regional aridification. Both hypotheses are valuable because they translate a palaeomagnetic reconstruction into a facies prediction; both remain conditional on the underlying TPW model.

True polar wander-related sea-level change and basin records

Reorientation also changes rotational potential. The ocean surface adjusts quickly, whereas the solid Earth responds more slowly, producing a sector-dependent relative sea-level signal. Models predict transgression in some equatorward-moving regions and regression in some poleward-moving regions, with amplitude controlled by path, rate, mantle viscosity, lithospheric thickness, and site geometry (Sabadini *et al*., 1990; Mound & Mitrovica, 1998; Mound *et al*., 1999).

Mesozoic sequence boundaries and flooding events have many causes (Vail *et al*., 1977; Haq *et al*., 1987; Haq, 2014). TPW becomes diagnostic only when coeval basins in predicted sectors show the expected contrast. Basin histories should therefore be tested against reconstructed rotation axes rather than matched to TPW ages alone.

TABLE 5. First-order spatial predictions for testing environmental consequences of a Mesozoic true polar wander event.

Predicted motion	Potential climatic tendency	Potential stratigraphic or oceanographic tendency	Useful tests
Equatorward	Warmer conditions, possible movement into arid subtropical belts, altered monsoon or wind belts.	Relative sea-level rise in favourable sectors; carbonate-platform expansion, evaporites, red beds, aeolian deposits, or restricted basins depending on local setting.	Compare palaeolatitude predictions with facies belts, palaeosols, evaporites, coals, carbonates, and fossil assemblages.
Poleward	Cooler or more seasonal conditions; possible humidification or increased seasonality depending on circulation.	Relative sea-level fall in favourable sectors; regression, exposure surfaces, clastic progradation, or contraction of shallow-marine habitat.	Test against sequence stratigraphy, basin accommodation, climate-sensitive facies, and vegetation/ fossil records.
Across equator or subtropical belts	Nonlinear climate response; possible transient ecological and sedimentary transitions.	Complex sea-level and circulation response; possible shifts in upwelling or redox-sensitive settings.	Requires high-resolution age models and regional comparison across the predicted TPW sectors.
Round-trip motion	Transient response followed by partial recovery; not a simple one-way trend.	Paired transgression-regression or facies change and reversal may be expected in some sectors.	Best tested in continuous stratigraphic sections with magnetostratigraphy and independent geochemistry.

Ocean circulation, redox structure, and carbon cycling

The Toarcian event, OAE1a, and OAE2 are commonly linked to volcanism, greenhouse forcing, nutrient supply, restriction, stratification, and organic-carbon burial (*e.g.*, Schlanger & Jenkyns, 1976; Larson & Erba, 1999; Leckie *et al.*, 2002; Weissert & Erba, 2004; Jenkyns, 2010; Table 6). TPW is not an alternative to those mechanisms, but could alter where shallow seas, upwelling, and restricted basins were positioned relative to latitude.

A useful test asks whether reconstructed motion predicts the geography of black shales, carbonate-platform stress, evaporites, or carbon-isotope expression. Redox records should constrain uncertain TPW models, rather than only being used afterwards as generic confirmation.

Biogeographic and evolutionary consequences

Mesozoic biogeography varied strongly among regions (Westermann, 2000; Upchurch *et al.*, 2002; Benton, 2010; Friis *et al.*, 2011; Zhou, 2014). By shifting continents, shelves, and corridors across climate and circulation belts, TPW could alter habitat area, dispersal routes, seasonality, and marine provinciality.

Such effects would be indirect. Extinction, radiation, and turnover also depend on volcanism, sea level, ecological innovation, habitat fragmentation, preservation, and sampling (*e.g.*, Zhou & Zhang, 2026). A credible TPW-biotic link therefore requires a well-supported event, a mapped environmental prediction, and independent regional fossil or sedimentary evidence (*e.g.*, Jing *et al.*, 2022).

East Asian records and competing Mesozoic true polar wander scenarios

East Asia provides a useful regional case study for discussing Mesozoic TPW because it combines disputed Jurassic–Early Cretaceous palaeomagnetic paths with climate-sensitive continental basins, intense tectono-magmatic activity, and exceptional fossil deposits. It is therefore not simply an illustrative region, but a place where palaeolatitude models, sedimentary records, basin evolution, volcanism, and fossil assemblages can be compared within the same broad geological framework.

Why East Asia is useful

Mesozoic East Asia provides a valuable regional setting for testing the geological implications of proposed TPW events. It was shaped by Mongol-Okhotsk closure, Palaeo-Pacific subduction, intracontinental deformation, lithospheric thinning, magmatism, and widespread

TABLE 6. Global oceanic anoxic events (OAEs) in the Mesozoic. Asterisks indicate data used in Fig. 1.

No.	Age from (Ma)	Age to (Ma)	Duration (Myr)	OAE name	Abbr.	References
1*	250.9	250.3	0.6	Smithian–Spathian Boundary Oceanic Anoxic Event	SSB anoxia	Du *et al*. (2022)
2	234	232.5	1.5	Carnian Humid Episode	CHE	Sun *et al*. (2016)
3	207	204	3	Norian/Rhaetian boundary Oceanic Anoxic Event	NRB	Rigo *et al*. (2024)
4*	201.8	201	0.8	End-Triassic Oceanic Anoxic Event	ET-OAE	He *et al*. (2020)
5*	183.2	182.7	0.5	Toarcian OAE	T-OAE	Jenkyns (2010)
6	136.4	134.1	2.3	Weissert Event	Weissert	Mattioli *et al*. (2014)
7*	126.7	126.6	0.1	Faraoni Event	F-OAE	Matsumoto *et al*. (2021)
8*	120.7	119.5	1.2	Selli Event	OAE-1a	Jenkyns (2018); Matsumoto *et al*. (2022)
9	119	118.75	0.25	Wezel	Wezel	Matsumoto *et al*. (2022)
10	117.3	117.1	0.2	Fallot	Fallot	Matsumoto *et al*. (2022)
11	113	109	4	Paquier Event	OAE-1b	Leckie *et al*. (2002); Millán *et al*. (2014)
12	102	101.7	0.3	Amadeus Event	OAE-1c	Leckie *et al*. (2002); Friedrich *et al*. (2018)
13	101.5	100.5	1	Breistroffer Event	OAE-1d	Matsumoto *et al*. (2022)
14*	94.6	94.3	0.28	Bonarelli Event	OAE-2	Jenkyns (2018)
15*	87.7	85	2.7	Coniacian-Santonian	OAE-3	Kouamelan *et al*. (2020)

basin formation (Huang, 2019; Gao *et al.*, 2021). This tectonically active setting produced a range of basins and volcanic-sedimentary systems across different parts of the region, allowing predicted palaeolatitudinal changes to be evaluated against independent geological records rather than palaeomagnetic data alone.

The independent surface records are unusually diverse: Jurassic aridification, the Yanliao and Daohugou fossil-bearing deposits, Early Cretaceous volcanic-lacustrine basins, and the Jehol biota document major environmental and biological changes in continental East Asia (Zhou *et al.*, 2021). These records should not be used as primary evidence for defining TPW, but they can help evaluate whether different palaeolatitude models imply plausible and geographically consistent environmental consequences.

Competing East Asian palaeomagnetic scenarios

Three models frame the regional problem (Fig. 2). Yi *et al.* (2019) inferred rapid southward motion at *ca.* 174–157 Ma and linked it to East Asian aridification (R = 5; Meert *et al.*, 2020). Gao *et al.* (2021) found no comparable large shift and instead combined TPW with northward convergence during Mongol-Okhotsk closure (R = 5). Hou *et al.* (2024) proposed a later return movement, with southward motion at *ca.* 155–147 Ma followed by recovery at *ca.* 147–141 Ma.

The models predict different histories. A large one-way shift implies sustained climate-belt displacement; a convergence-plus-TPW model implies spatial heterogeneity; a loop predicts a temporary change and partial reversal. Sedimentary and fossil records can therefore discriminate among the scenarios rather than merely illustrate them.

Climate, basins, and volcanic-lacustrine preservation

Middle-Late Jurassic Yanliao and Daohugou successions formed during major regional climate and basin changes. Under the Yi *et al.* (2019) model, southward motion could have promoted aridification. The Gao *et al.* (2021) and Hou *et al.* (2024) models instead predict weaker, more heterogeneous, or transient effects. The practical test is to map red beds, aeolian components, evaporitic indicators, lake deposits, palaeosols, and vegetation against each reconstructed path.

The Jehol archive occurs mainly in volcanic-lacustrine units such as the Yixian and Jiufotang formations (He *et al.*, 2004; Zhou, 2006; Zhang *et al.*, 2008; Cai *et al.*, 2023). Basin tectonics, volcanic input, sedimentation, hydrology, and water redox state governed fossil preservation. Any TPW effect would have operated through the regional climate background, not by directly creating the Lagerstätte.

Biotic archives from Yanliao to Jehol

The Yanliao and Jehol biotas are separate fossil windows. Yanliao assemblages record diverse Middle-Late Jurassic terrestrial and lacustrine ecosystems in northern China (Huang, 2019). The Early Cretaceous Jehol biota, mainly from the Dabeigou, Yixian, and Jiufotang formations, documents a later and exceptionally preserved terrestrial

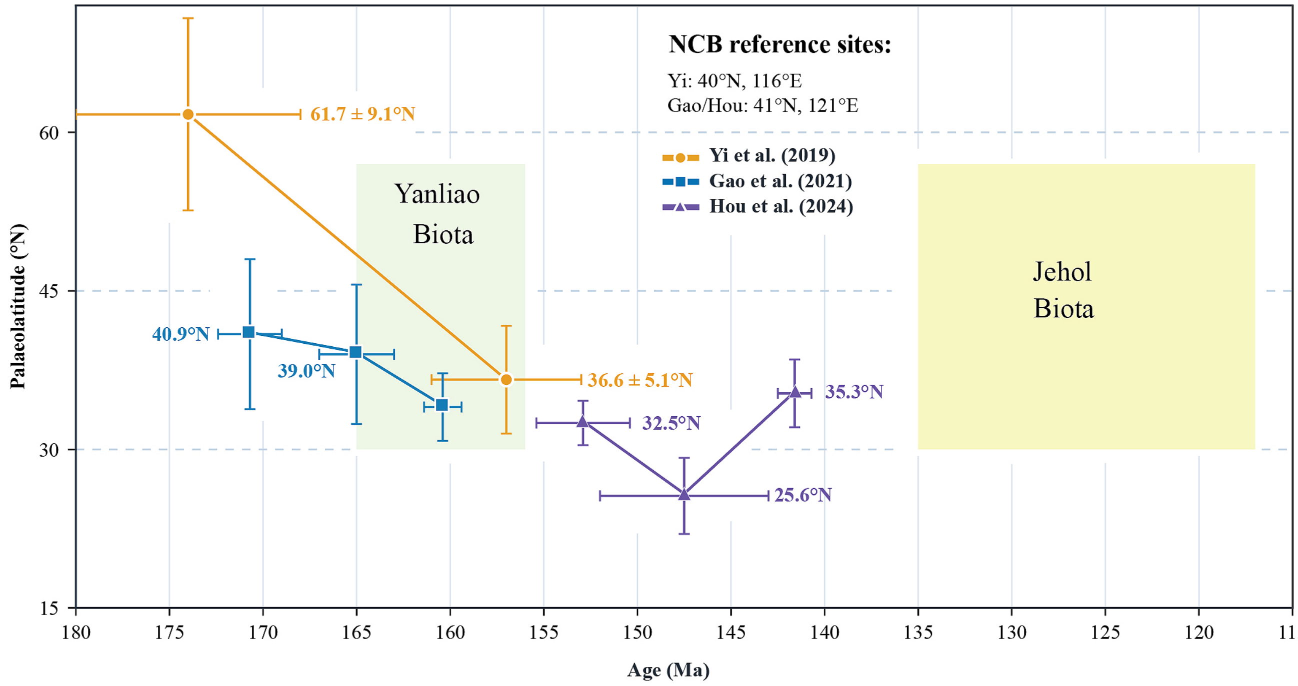

FIGURE 2. Published Jurassic–Early Cretaceous palaeolatitude paths of the North China Block and the age ranges of Yanliao and Jehol biotas.

radiation at *ca.* 135–117 Ma (Zhou, 2006; Benton *et al*., 2008; Huang, 2019). Treating them as a simple replacement obscures their different ages, basins, and preservational settings.

A palaeolatitude shift could have modified temperature, rainfall, seasonality, lake hydrology, vegetation, habitat area, and dispersal. It may therefore have contributed to the background against which Yanliao ecosystems changed and Jehol ecosystems later developed. Regional tectonics, magmatism, ecology, preservation, and sampling remain indispensable explanations; TPW should be tested as one modifier among them.

Future work

Future work should focus on more precisely dated palaeomagnetic poles, stricter rock-magnetic and field tests, improved restoration of regional deformation, and direct comparisons between reconstructed palaeolatitude paths and independently dated sedimentary, climatic, volcanic, and fossil records. East Asia is thus best viewed not as a resolved test of Mesozoic TPW, but as a natural case study region where the geological consequences of competing TPW scenarios can be evaluated.

Outlook

The evidence for Mesozoic TPW remains uneven, and each proposed event should be evaluated by its chronological control, palaeomagnetic reliability, reproducibility, and independent geological predictions. The 86–78 Ma oscillation is comparatively well constrained and illustrates the value of high-resolution stratigraphic tests, but its broader significance still requires comparison with records from other regions. The post-Pangaea rotations are plausible but remain reference-frame dependent; the Jurassic monster shift is still disputed; and the smaller Jurassic–Cretaceous rotations require higher-resolution tests.

Many proposed Mesozoic TPW intervals coincide with major geodynamic and Earth-system changes, including Pangaea breakup, plate reorganization, climatic shifts, oceanic perturbations, and biotic turnover. In the future, regional contrasts in climate, sedimentary, environmental, and biotic responses should therefore be used to constrain and evaluate competing Mesozoic TPW models.

East Asia provides a useful regional case for this approach. Competing Jurassic-Early Cretaceous palaeolatitude models can be tested with aridification, basin histories, volcanic-lacustrine deposits, and the Yanliao-Jehol fossil record. Future progress will depend on precise chronology, demonstrably primary remanence, improved plate and block restorations, and explicit comparisons between predicted palaeogeographic change and independently dated geological records.

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