Phanerozoic polepath loops, and their correlation with basin development and resource accumulation

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Five major loops are apparent on the Phanerozoic Australian apparent polar-wander path (polepath). They coincide with the initiation of major basin systems, indicating that a consistent and simple relationship unifies these events. Polepath loops reflect interplate movement reversals, which activate intraplate deformation and basin development. The polepath provides the only verifiable insight into Australian plate dynamics before seafloor spreading. Its potential to detail the evolution of stress patterns and fluid-flow pathways, and thereby resource accumulation, can be realised by further detailing the loops.

Interplate movements provide the mechanism driving the intraplate deformation that leads to basin development and mineralisation (e.g., Loutit et al. 1994: in Australasian Institute of Mining & Metallurgy, Annual Conference, Darwin, 5–9 August 1994, technical program proceedings, 123–128). Seafloor-spreading data detail the movements of the Australian plate, but only as far back as the oldest break-up event recorded on the North West Shelf — Callovian–Oxfordian. Earlier movements can be traced from the polepath, but the record is less precise for latitudinal and rotational movement, and there is no control over longitudinal movement.

Australia's Palaeoproterozoic polepath has been successfully interpreted in terms of regional basin development and mineralising events (e.g., Wyborn et al. 1993: AGSO Research Newsletter, 19, 1–2; Wyborn et al. 1998: AGSO Research Newsletter, 28, 1–6; Idnurm & Wyborn 1998: AGSO Research Newsletter, 28, 6–7). The Phanerozoic polepath, however, has been less systematically explored (e.g., Klootwijk 1995: AGSO Research Newsletter, 22, 14–17; Klootwijk 1997: AGSO Research Newsletter, 26, 22–24), because attention has focused mainly on defining it. Even so, the Palaeozoic segment of the polepath is under dispute (owing to two different interpretations proposed for the middle–late Palaeozoic); the Mesozoic part is poorly defined; and the precise shape of the better established Cainozoic path has been questioned. Recent definition of the late Palaeozoic polepath for New England, however, has provided new insights into links between Phanerozoic polepath features, basin development, and mineralising events (Klootwijk 1998: in AGSO Record 1998/2, 105–110).

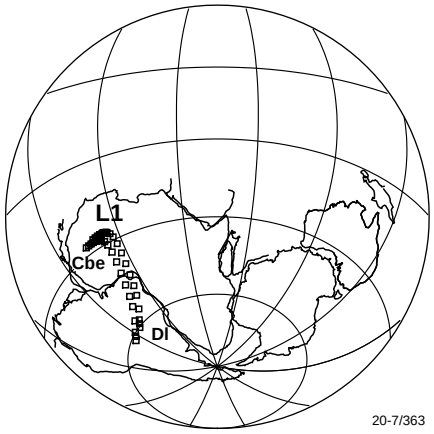

Fig. 6. Australian early–middle Palaeozoic (Early Cambrian–Late Devonian) 'spline' polepath (see Klootwijk 1996a: op. cit., fig. 2) shown on a Gondwana reconstruction anchored to Australia in its present position.

It is now clear that the Australian Phanerozoic polepath contains five major loops (Klootwijk 1996a: in AGSO Record 1996/52; Figs. 6–8; Table 1) whose apexes coincide with the initiation of major basin systems.

These correlations link polepath loops to major basin development in a consistent but simple geodynamic relationship (though the inverse relationship does not apply universally because the polepath does not define longitudinal movements). The loops reflect interplate movement reversals; consequent intraplate deformation, mainly extensional, triggers basin development and facilitates the fluid flows that drive hydrocarbon accumulation and mineralisation.

Loop L1: Late Cambrian–Early Ordovician

The L1 apex (Fig.6) coincides with the Cambro-Ordovician Delamerian Orogeny and with the earliest Ordovician Samphire Marsh Extensional Movement (Shaw et al. 1994: AGSO Record 1994/48), the onset of the Canning Basin.

Loop L2: Middle Carboniferous

L2 on the New England polepath (Fig.7), believed to be representative for cratonic Australia and eastern Gondwana (Klootwijk 1996a: op. cit.), indicates large-scale latitudinal movements (Klootwijk 1995: op. cit., figs. 26, 27): latest Devonian to middle Visean northward movement over more than 30 degrees from low southern to low northern latitudes (Armidale reference), followed by late Visean very fast southward movement to about south polar latitudes. The southward movement created an extensional regime which led to the (latest Visean–) Namurian initiation of the Westralian Superbasin.

Loop L3: Late Carboniferous–Early Permian

The initiation of the Sydney, Gunnedah, and Bowen Basins is fundamental to the development of the eastern Australian basins. Recent $^{40}Ar/^{39}Ar$ dates narrow the onset of significant crustal extension in the (northern New England) region to ca 305 Ma (Holcombe et al. 1997: Geological Society of Australia, Special Publication 19, 66–79). This date is similar to U–Pb dates constraining the L3 apex: between 309 ± 3 Ma (Gulson et al. 1990: Australian Journal of Earth Sciences, 37, 459–469) and 297.3 ± 2.5 Ma (Black 1994: AGSO Record

Table 1. Australian Phanerozoic polepath loops

Loop	*Period*	*Basin initiation*
L1	Late Cambrian–Early Ordovician	Canning Basin
L2	middle Carboniferous	Westralian Superbasin
L3	Late Carboniferous–Early Permian	Sydney, Gunnedah, Bowen Basins; oroclinal bending S. New England
L4	Late Triassic–Early Jurassic	Ipswich, Tarong, Clarence–Moreton, Maryborough, Surat, Eromanga Basins; rifting along New Guinea margin
L5	Late Jurassic–Early Cretaceous	Rifting along the northeastern and southern margin of the Australian plate

1994/34) — i.e., Westphalian to Asselian on the AGSO Phanerozoic Timescale (Young & Laurie 1996: 'An Australian Phanerozoic timescale', Oxford University Press). The similarity of these dates underlines the causal relationship between plate movement reversal and extensional (less so compressional) tectonism.

The latest Carboniferous–?earliest Permian apex represents a reversal in Gondwana's rotational movement from counterclockwise in the Late Carboniferous and possibly earliest Permian to clockwise for the major part of the Permian and Triassic. These contrasting rotations greatly influenced the late Palaeozoic–early Mesozoic tectonic development of Gondwana's Laurentian and Protopacific margins. The counterclockwise rotation can be associated along the Laurentian margin with large-scale dextral shear systems in the Ural–Variscan–Mauritanides–Appalachian orogenic system (Arthaud & Matte 1977: Geological Society of America, Bulletin 88, 1305–1320) and probably also with changeover from Pangea–B (Irving 1977: Nature, 270, 304–309) to Pangea–A2 (Van der Voo & French 1974: Earth Science Reviews, 10, 99–119). Along the Protopacific margin, the rotation was associated with extensional basin development along a dextral megashear stretching from the Bowen Basin to the Parana basin in southern South America (Visser & Praekelt 1998: Tectonophysics, 287, 201–212). The succeeding clockwise rotation of Gondwana led to compressional deformation along this zone of extensional basins — i.e., the Gondwanide Orogenies (e.g., Veevers et al. 1994: Geological Society of America, Memoir 184, 331–353), specifically the Hunter–Bowen Orogeny in eastern Australia.

The successive counterclockwise and clockwise rotations of Gondwana most likely induced dextral and sinistral displacements of New England with respect to the Lachlan–Thompson neocraton (Harrington & Korsch 1985: Australian Journal of Earth Sciences, 32, 163–179; Offler & Williams 1987: Geodynamics Series, 19, 141–151) and mega-drag-folding of the Texas, Coffs Harbour, and Manning oroclines.

Loop L4: Late Triassic–Early Jurassic

L4 coincides with a fundamental period in the development of the hydrocarbon-bearing basins of the North West Shelf. The loop is underdefined on the Australian Mesozoic polepath, but the better defined Indian polepath provides additional constraints within Gondwana (Klootwijk 1996a: op.cit., figs. 19, 20). The two polepaths constrain the loop's apex to between 185+ Ma (Australia) and 210–200 Ma (India).

L4 documents the reversal in eastern Gondwana's latitudinal movement from northward during the Triassic to southward during the Jurassic. By the latest Triassic, India had reached tropical latitudes; Australia's North West Shelf, about 30°S. This interplate movement reversal can be correlated with the initiation of major phases of intraplate extension, less so compression, and basin development along the eastern, northern, and northwestern margins of the Australian Gondwana fragment. The eastern margin evolved with the initiation of the Ipswich and Tarong Basins during the Late Triassic (Holcombe et al. 1997: Geological Society of Australia, Special Publication 19, 52–65) and with the probably subduction-related initiation of the Clarence–Moreton, Maryborough, Surat, and Eromanga Basins during the Early Jurassic (Williams & Korsch 1996: Geological Society of Australia, Extended Abstracts, 43, 564–568). The northern, New Guinean, margin is characterised by Late Triassic–Early Jurassic rifting (Symonds et al. 1996: Geological Society of Australia, Special Publication 43, 528–542). Elsewhere, on the North West Shelf, the interplate movement reversal can be correlated with:

- later phases of the Middle Triassic to Early Jurassic Fitzroy Movement — i.e., Late Triassic–earliest Jurassic transpressional movements fundamental to the extensive formation of reservoir and structural traps (AGSO North West Shelf Group 1994: in P.G. Purcell & R.R. Purcell (Eds.), 'The sedimentary basins of Western Australia', Petroleum Exploration Society of Australia (PESA), Perth, 63–76); and
- major Hettangian–Pliensbachian rifting accompanied by heating-enhanced source generation (Arne et al. 1989: Australian Journal of Earth Sciences, 36, 495–513).

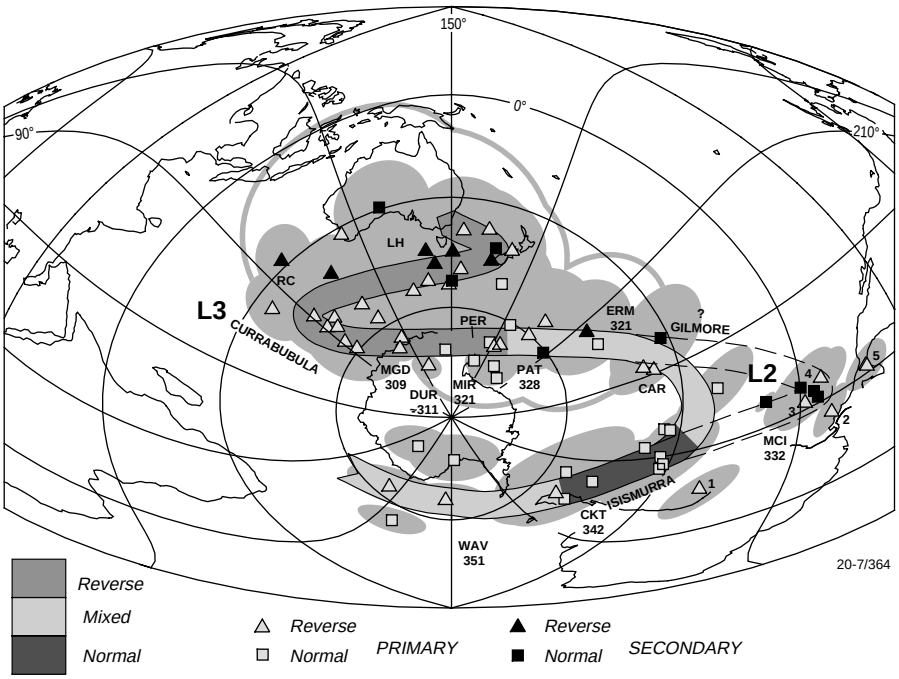

Fig. 7. Australian late Palaeozoic polepath based on Carboniferous and Permian pole positions for volcanic successions of the Tamworth Belt, New England (see Klootwijk 1996b: AGSO Record 1996/53, table 1.3, for pole position data; and Klootwijk 1996a: op. cit. for acronyms). Note that the definition of the apex of loop L2 is under review.

Loop L5: Late Jurassic–Early Cretaceous

L5 is poorly defined on the Australian Mesozoic polepath (Fig.8) and is only marginally better so on the Indian path. The loop reflects another reversal in eastern Gondwana's latitudinal movement from southward during the Jurassic to northward during the Early Cretaceous and Cainozoic.

The latest Jurassic–earliest Cretaceous movement reversal coincides

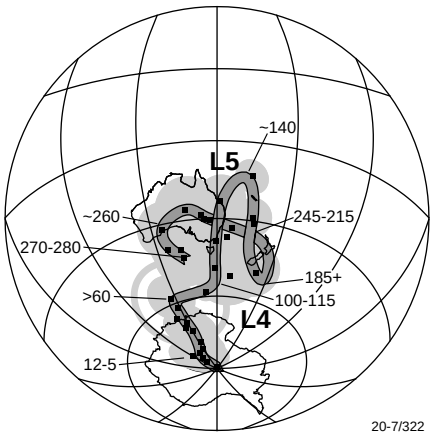

Fig. 8. Latest Palaeozoic–Cainozoic polepath for Australia.

with major rifting phases along Australia's northeastern, southern, and western margins. Along the northeastern and southern margins, the rifting is preserved in the Queensland and Townsville Troughs (Struckmeyer et al. 1994: AGSO Record 1994/50; Symonds et al.1996: op. cit.), the Whitsunday–Proserpine–Graham Creek volcanic belt, and the Southern Rift System (e.g. Symonds et al. 1996: op. cit.). The western margin, in contrast, evinces an initial Tithonian–Berriasian compressional phase, crucial to further development of hydrocarbon traps on the North West Shelf (Etheridge & O'Brien 1994: PESA Journal, 22, 45–63), followed by (Berriasian–) Valanginian extension of the Westralian Superbasin and formation of the Gascoyne, Cuvier, and Perth Basins.

Lesser flexures and their significance

Various smaller bends on the Phanerozoic polepath indicate directional changes, rather than reversals, in interplate movements (see Klootwijk 1996a: op. cit.). The more obvious features are:

- a Late Devonian (to possibly Early Carboniferous) broad bend coinciding with the initial phases of the Alice Springs Orogeny;
- two ill-defined loops of minor dimension coinciding with the Late Permian separation of Cimmerian fragments from northeastern Gondwana;
- a broad Middle–Late Triassic bend correlated with paroxysmal Hunter–Bowen tectonism;
- a latest Early Cretaceous bend preceding the opening of the Tasman Sea;
- a latest Cretaceous–earliest Tertiary bend coinciding with northward propagation of sea-floor spreading into the Capricorn and Coral Sea Basins; and
- a Mio-Pliocene excursion coinciding with the initial contact of continental Australia with the Banda Arc.

Polepath loops, bends, and fluid movements

Several recent Australian and overseas studies have established relationships between polepath loops and bends and mineralising events. Thus, Idnurm et al. (1994: in Australasian Institute of Mining & Metallurgy, Annual Conference, Darwin, 5–9 August 1994, technical program proceedings, 53–156) correlated several inflections on the Palaeoproterozoic polepath for the McArthur Basin with mineralising events. They also linked regional magnetic overprints with pole position groupings which were close to the apexes of the inflections, and which thus could be uniquely identified and dated. Study of the temporal and spatial evolution of these magnetic overprints can provide a low-cost high-resolution facility for unravelling the evolution of fluid movement pathways, hydrocarbon accumulations, and mineral-plumbing systems.

The Phanerozoic polepath has not been explored systematically for such control on fluid movements, but its potential is evident. Its loops and bends reflect changes in movement of the Australian plate. Attendant changes in stress regimes created and reactivated basement fracture systems, increased basement permeability, and thus focused hydrothermal flows with the potential to concentrate hydrocarbon and mineral resources. Pole positions for magnetic overprints acquired in response to fluid-flow systems are expected to lie on the younger limb and/or apex of the loops and bends.

The limited Phanerozoic-overprints data have not so far provided an analogue to the late Palaeoproterozoic association between well-grouped overprint poles and polepath kinks. Few Phanerozoic overprint groupings are directionally confined; a notable exception is the ~90–95-Ma overprints associated with the opening of the Tasman Sea. Most overprints trail polepath inflections in drawn-out suites. This may reflect ongoing remagnetisation during large-scale and fast plate movements, and may thus have the advantage of considerable resolution in the identification and dating of fluid-flow phases. Nevertheless, it is a sobering observation that, so far, only a single overprint pattern can be related to an established mineralisation phase — that is, the Early Carboniferous overprint suite recording the ~350–340-Ma mineralisation phase of the Tasman Orogenic System, which occurred after the Late Devonian (to possibly Early Carboniferous) bend (Klootwijk 1996a: op. cit., fig.5).

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