AGSO

NORTH WEST SHELF PROJECT
Palaeomagnetic Framework

Phanerozoic configurations of Greater Australia: Evolution of the North West Shelf

Part Two
Palaeomagnetic and geologic constraints on reconstructions

by

Chris Klootwijk

AGSO Record 1996/52

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PALAEOMAGNETIC AND GEOLOGIC CONSTRAINTS ON RECONSTRUCTIONS

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Chris Klootwijk

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

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CONTENTS

ABSTRACT

Palaeomagnetic constraints on the Phanerozoic evolution of Australia's North West Shelf indicate successive dispersions of continental fragments. Such dispersions are characteristic for the evolution of the northeastern margin of Gondwana. Palaeomagnetic constraints are reviewed, therefore, within a wide spatial setting. A mainly graphic overview is presented of relevant Phanerozoic palaeomagnetic data, with discussion of their implications on northeast Gondwana's dispersive and Laurasia's accretionary evolution. Regions covered are Australia and India as the main dispersive cratons of northeast Gondwana, the Siberian Platform as the main accretionary craton, and continental fragments and terranes of established or presumed Gondwanan origin that are now accreted to the Siberian cratonic nucleus or to the North American craton, amongst others the Cathaysian continents, northeast Russian terranes east of the Verkhoyansk Mountains, and terranes in the North American Cordillera.

The Australian Phanerozoic APWP is discussed in detail with emphasis on two widely different propositions for the Late Palaeozoic trajectory and their implications for Gondwana-Laurasia interaction at the time of the Variscan Orogeny. Loops and cusps on the Australian and Indian APWPs are identified for further analysis of potential relationships with fundamental tectonic events.

Palaeolatitude plots are presented for continental blocks and terranes of probable Gondwanan origin that are now situated east of the Urals and south of the Central Asian Fold Belt, in the eastern and northern periphery of the Siberian craton, and within the North American Cordillera. The plots indicate, amongst others, four northward movement phases of potential global tectonic relevance, namely in the Early Devonian (Kazakhstan), in the latest Devonian-middle Carboniferous (northeast Gondwana), in the middle to Late Permian (northeast Gondwana), and in the Triassic (Cathaysian continents, northeast Gondwana, Gondwanan fragments in Southeast Asia and the North American Cordillera).

Palaeomagnetic reconstructions of the Palaeozoic configuration of northeast Gondwana have concentrated on relationships of the Cathaysian continents and Australia. Fitting of "spline" approximations of Cambro-Ordovician to Late Devonian APWP trajectories for the North China block and Australia result in an unique lock of North China off northwestern Australia and western Irian Jaya, in very good agreement with a recently proposed reconstruction based on biostratigraphic and lithostratigraphic evidence (Metcalfe and Nicoll,1994). Comparison of individual pole positions of mainly Devonian age for other Cathyasian blocks - i.e. South China, Indochina and Tarim - with Australia show reconstructions that are also in good agreement with the Metcalf and Nicoll model. Comparison of Early Devonian palaeomagnetic data for the Alexander terrane of the North American Cordillera and Australia allows relocation of the Alexander terrane off southeastern Australia, in good agreement with lithostratigraphic arguments for such a former relationship.

Finally, the identified loops and cusps on the Australian and Indian APWPs are tentatively correlated with and interpreted in terms of significant events in the Phanerozoic evolution of the North West Shelf and, to a lesser extent, eastern Australia.

INTRODUCTION

The Phanerozoic evolution of Australia's North West Shelf is characterised by successive dispersions of continental fragments from the northeastern margin of Gondwana. Reconstruction models related to evolution of this margin have been reviewed in the accompanying Record (Klootwijk,1996a). Palaeomagnetic constraints on evolution of this margin are reviewed here.

The palaeomagnetic review has wide coverage in time. Requirements of the North West Shelf project have expanded well beyond the originally suggested coverage of Late Palaeozoic and Early Mesozoic breakup phases to include the Ordovician to Cretaceous Periods. On palaeomagnetic grounds such coverage has been further extended to cover the Phanerozoic in full. Cambrian data from the Cathaysian continents, which represent a substantial part of the pre-breakup database, are thus included in the palaeomagnetic reconstructions. With this approach, palaeolatitude plots from the major continental blocks and dispersed terranes can be anchored to their present position, rather than remain floating, and the plots represent full Phanerozoic coverage.

The review's coverage in space is also extensive. The project's original requirement was for palaeomagnetic reconstruction, versus Australia, of the pre-breakup configuration of the major fragments of southeastern and eastern Asia, i.e. North China, South China, Indochina and Shan-Thai-Malay. Regional geological considerations, however, reviewed in the accompanying Record (Klootwijk,1996a), suggest that the stripping of Gondwana's northeastern margin occurred through separation and relocation of extensive ribbon-continents rather than through separation of individual fragments. Such ribbon continents and fragments of Gondwanan origin have been identified within a wide zone throughout Asia peripheral to the Siberian Platform. For this reason the spatial coverage includes: the whole of southern Asia, eastward from the Urals and southward from the Central Asian Fold Belt; northeastern Russia to the east of the Verkhoyansk Fold Belt; the North Taimyr block and associated regions north of the Siberian Platform. The search for terranes of Gondwanan origin has been further extended to include the North American Cordillera. Late Palaeozoic latitudinal evolution of these terranes, as part of a hypothetical "Pacifica" continent, seems related to latitudinal movements of the Cathaysian continents, whereas their subsequent Mesozoic and Cenozoic movements along the northeastern Pacific rim are related to evolution of the northwestern Pacific. Finally, palaeomagnetic coverage for Siberia was judged necessary as it is the main accretionary craton, and palaeomagnetic coverage for eastern Gondwana as the main dispersive source craton has been extended beyond Australia with complementary data from India and New Zealand.

PALAEOMAGNETIC DATA: ACQUISITION, MANIPULATION, PRESENTATION

Palaeomagnetic data for relevant continents and terranes have been extracted from the Global Palaeomagnetic Database (GPMDB Version 3.1: Lock and McElhinny,1991; McElhinny and Lock, 1993,1994,1996), through careful scrutiny of individual results. The ACCESS version of the database covers all palaeomagnetic data published in established international journals up to the end of 1994. Further results of 1995 and 1996 have been extracted directly from relevant publications as available. Datasets for Australia and India have been complemented with relevant data published in the "grey" literature and with as yet unpublished data obtained from studies on the Indian Gondwana succession, carried out at the Research School of Earth Sciences (Agarwal,1980; Klootwijk and Agarwal,unpublished), and from studies on Australian cratonic basins, the Tasman Orogenic System and

Table 1: Time intervals (Ma) for mean pole calculation

Early Cambrian	Cb1	545-509		
Middle Cambrian	Cb2	509-498		
Late Cambrian	Cb3	508-490		
Tremadoc-Arenig	O1	490-465		
Llanvirn (Llandeilo)	O2	465-459		
Caradoc-Ashgill	O3	459-434		
Llandovery	S1	434-425	S1-2	434-420
Wenlock	S2	425-420		
Ludlow	S3	420-414	S3-4	420-410
Pridoli	S4	414-410		
Early Devonian	D1	410-384		
Middle Devonian	D2	384-369		
Late Devonian	D3	369-354		
Early Carboniferous	C1	354-314		
Late Carboniferous	C2	314-298		
Tournaisian/Visean		354-325		
Namurian-Stephanian		325-298		
Tournaisian		354-344		
Visean		344-325		
Namurian		325-313		
Pennsylvanian		314-298		
Early Permian	P1	298-270		
Late Permian	P2	270-251		
Early Triassic	Tr1	251-241		
Middle Triassic	Tr2	241-230		
Late Triassic	Tr3	230-205		
Early Jurassic	J1	205-184		
Middle Jurassic	J2	184-159		
Late Jurassic	J3	159-141		
Early Cretaceous	K1	141-97.5		
Late Cretaceous	K2	97.5-65		
Neocomian		141-123		
Gallic?		123-89		
Senonian		89-65		
Palaeogene		65-24		
Neogene		24-0		
Palaeocene		65-55		
Eocene		55-34		
Oligocene		34-24		
Miocene		24-5		
Pliocene		5-0		

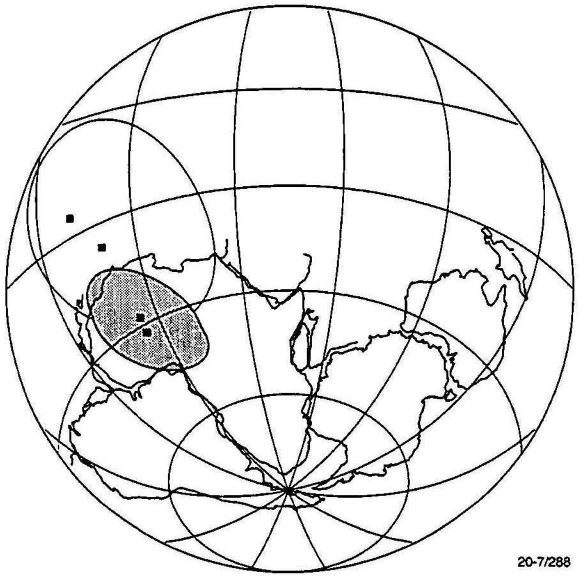


Figure 1 Early Palaeozoic (Cb1 - S1-2) mean pole positions for India-Nepal-Pakistan (Klootwijk,1996e, table 1.6) shown on a Gondwana reconstruction anchored to Australia in its present position. Schmidt equal area projection (center: 30°S, 75°E). Error ellipses have been suppressed for pole positions with EP_{95} values in excess of 30°.

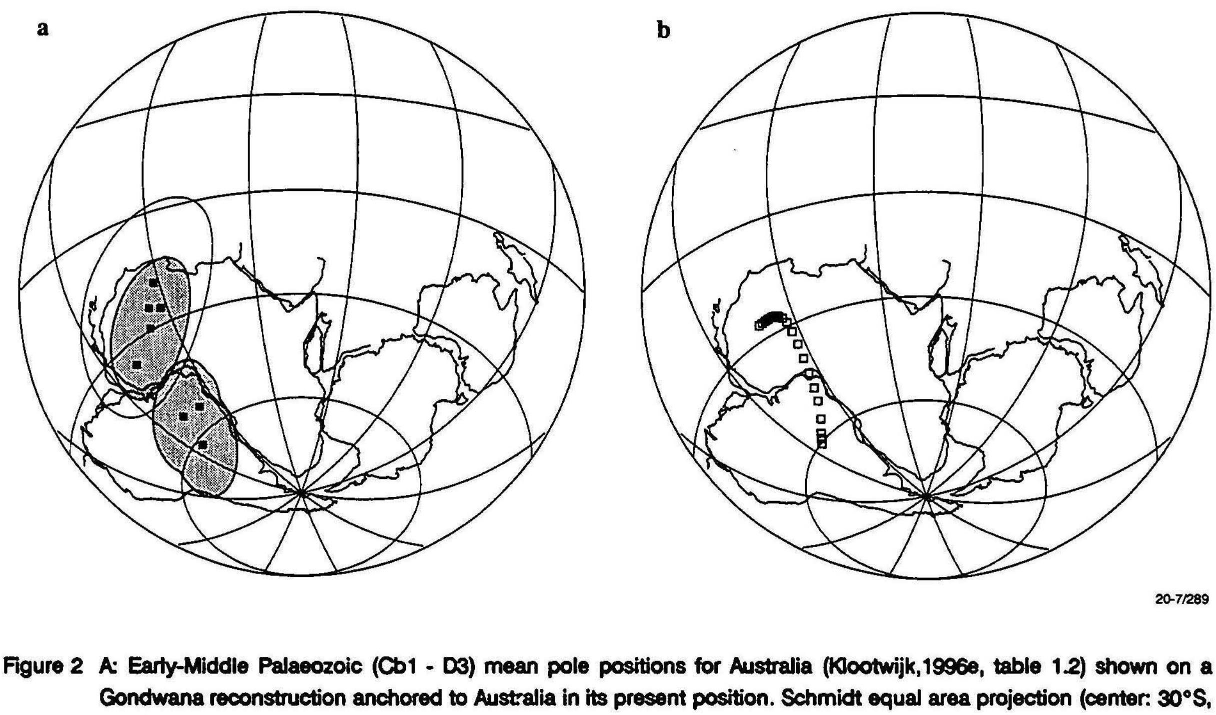


Figure 2 A: Early-Middle Palaeozoic (Cb1 - D3) mean pole positions for Australia (Klootwijk,1996e, table 1.2) shown on a Gondwana reconstruction anchored to Australia in its present position. Schmidt equal area projection (center: 30°S, 75°E). Error ellipses have been suppressed for pole positions with EP_{95} values in excess of 30°. B: "Spline" polepath segment for the pole positions shown in Figure 2A, derived with the GMAP for Windows program (Torsvik and Smethurst,1995) using the Jupp and Kent (1987) method for fitting spherical smoothed splines (10% smoothing) with weighting according to α_{95} values.

the Tamworth Belt of the New England Fold Belt, carried out at AGSO (e.g. Klootwijk and Giddings,1993; Klootwijk et al.,1993; Klootwijk,1995,1996b).

All palaeomagnetic data have been checked for errors, presented as south pole positions, complemented with local palaeolatitude detail, annotated with comments whenever required, and catalogued in younging order. Results from fold belts peripheral to the Indian Shield (Himalayas, Salt Range, Baluchistan) have been corrected for local or regional rotations wherever established, with corrected results added to the datasets for India, Nepal and Pakistan. Mean results have been collated for the major continental blocks, either from published sources (Siberia [Khramov and Rodionov,1980; Khramov et al.,1981; Zonenshain et al.,1990], North China, South China [Enkin et al.,1992; Zhao et al.,1996], Tarim, Ala Shan - Hexi corridor [Zhao et al.,1996]), or have been determined for Australia and India from the tabled data (Klootwijk,1996e: tables 1-6) for time-intervals according to the AGSO Phanerozoic Timescale (Young and Laurie,1996) as specified in Table 1.

For the construction of palaeolatitude plots, individual palaeomagnetic results have been converted to palaeolatitudes at an easily identifiable common site for each continental block or terrane as listed in Table 2, and stratigraphic ages have been converted to absolute ages following the AGSO Phanerozoic Timescale. The GMAP for Windows program (Torsvik and Smethurst,1995) has been used for relocation of several of the Cathaysian continents in pre-break reconstructions within eastern Gondwana, and the ATLAS program (Cambridge Paleomap Services,1992) has been used for construction of some geographical overviews.

EASTERN GONDWANA PHANEROZOIC POLEPATHS

Phanerozoic palaeomagnetic data have been compiled for the major eastern Gondwana fragments, Australia, India and New Zealand (Klootwijk,1996e, table 1), with the initial intention to transfer all data to Australia so as to provide additional detail to a common Australian - eastern Gondwana apparent polar wander path (APWP). It soon became evident that local and/or regional rotation effects reduce the potential of the New Zealand data to add detail to a common APWP. The majority of the Indian data are not affected by regional rotations. The Late Palaeozoic and Mesozoic data from the Indian Gondwana succession and the Late Cretaceous and Tertiary data from Ninetyeast Ridge are taken as representative for the Indian Shield, and the pre-breakup Gondwana results have been transferred to Australia. Indian Early and Middle Palaeozoic data come in part from the Himalayan and Salt Range fold belts. A rotation correction has been applied to all extrapeninsular palaeomagnetic results. A corrected mean pole position for the Middle Cambrian (Fig.1) is in reasonable agreement with the Australian Palaeozoic polepath (Fig.2), but does not add further detail. Early Cambrian data, mainly from the shield region, show good agreement with the Australian APWP in a Gondwana reconstruction (cf. Figs 1 and 2). Whilst supportive for the Australian APWP, the Indian data add little detail to it. Combination of transferred Indian data and Australian data into a combined APWP, therefore, has not been pursued further.

Australian APWPs

The Australian Phanerozoic APWP is not without controversy. The Palaeozoic trajectory is under dispute (the Late Palaeozoic part in particular) the Mesozoic trajectory is ill-defined, and the precise shape of the better-established Cenozoic trajectory is also disputed.

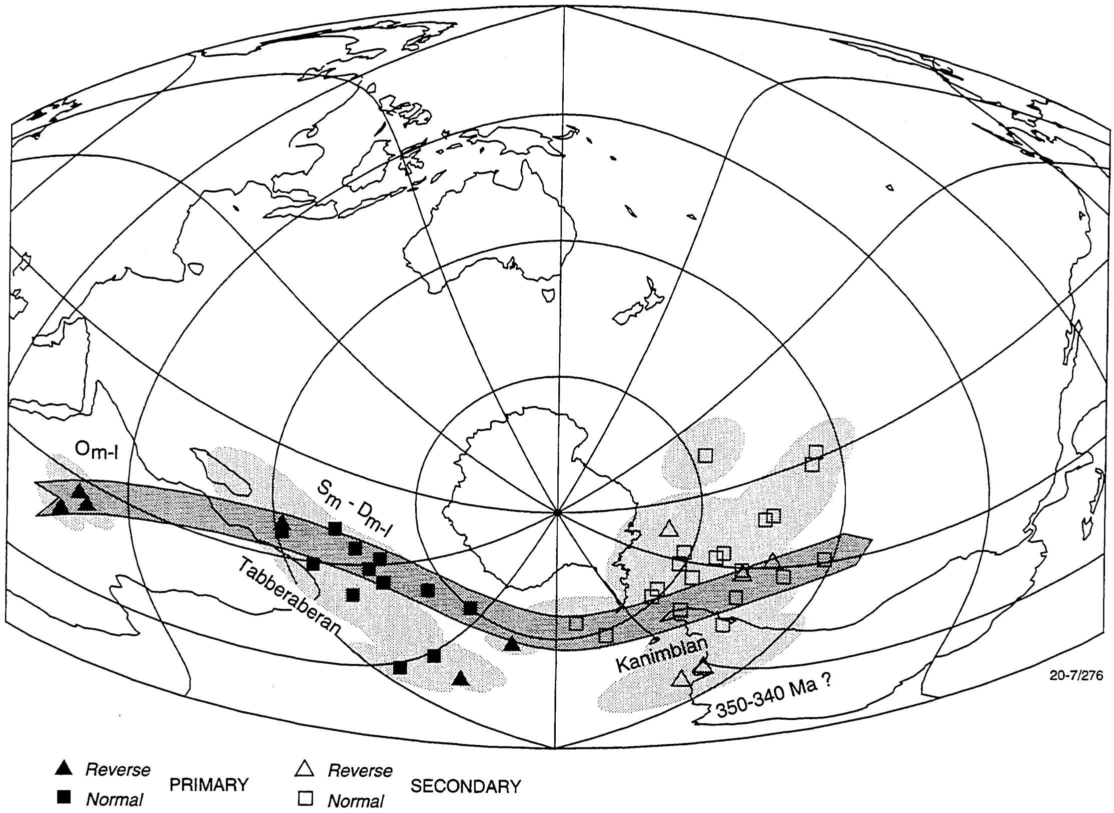


Figure 3 Polepath trajectory for the Molong High and Cowra Trough of the Lachlan Fold Belt, based on Goleby's (1981) results from the Wellington and Canowindra regions and on Klootwijk's unpublished results from Middle Silurian to Middle Devonian volcanics and sediments from the Canberra-Yass region.

Early to Middle Palaeozoic APWP

Schmidt et al. (1993) presented an illustrative overview of the many versions of the Australian Palaeozoic APWP developed over the past four decades. The paths generally agree for the Early and Middle Palaeozoic segments. In a reconstructed Gondwana, the path moves from northwest Africa across central Africa into central and southern South America (Schmidt et al.,1993, fig.1). The Cambrian trajectory is the least contentious. Definition of the remainder of the Palaeozoic path is hampered by uncertain interpretation of the Delamarian overprint (Klootwijk et al.,1980a,b,c), the limited number of published Ordovician and Silurian data, and two opposing interpretations for the Late Palaeozoic trajectory. Possible solutions for these three problems have emerged recently. With regard to the first problem, the recent definition of an extensive eastward loop in the Early-middle Carboniferous polepath for New England (Klootwijk,1995,1996b), discussed hereafter, suggests that the widely-observed overprints in Cambrian successions of the Adelaide Fold Belt and the Amadeus Basin, previously interpreted as developed during the Delamarian Orogeny, may represent a middle Carboniferous Kanimblan event instead. Such an interpretation removes the extensive Cambro-Ordovician loop from the Early Palaeozoic part of the APWP (e.g. Klootwijk,1980c, fig.III.12) and simplifies the path considerably. With regard to the second problem, the scarcity of Middle Palaeozoic data has been

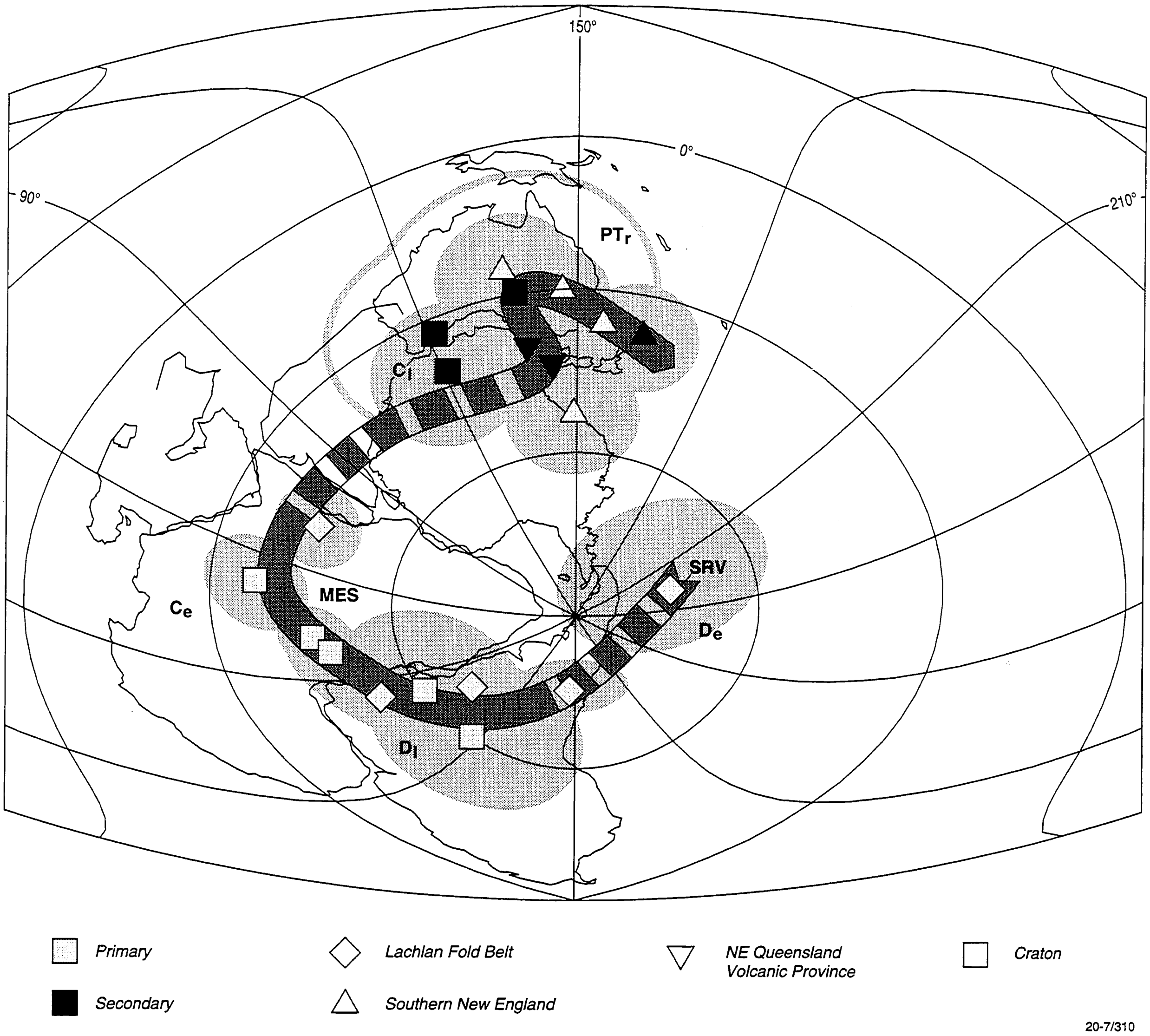


Figure 4 The SLP-path compiled from data detailed in Li et al. (1993: fig.1,table 3), Lackie and Schmidt (1993: fig.1,table 2), Schmidt and Lackie (1993: fig.6), Chen et al. (1993: fig.9; 1994: fig.10, table 6; 1995: fig.9). Acronyms are indicated for several key poles discussed in Klootwijk (1996b): SRV= Snowy River Volcanics; MES= Mount Eclipse Sandstone. All pole position data are listed in Klootwijk (1996e, table 1.1). The shaded outlines indicate ellipses of 95% confidence, or the envelope of ellipses.

improved through a study of Middle Silurian to Middle Devonian volcanics and Early to Middle Devonian basin successions from the Molong High and Cowra Trough (Klootwijk, unpublished results) of the Lachlan Fold Belt. These results acknowledge the widespread occurrence of Early Carboniferous (340-350 Ma) - Early Kanimblan - overprints and the probable occurrence of Middle Devonian Tabberabberan overprinting. The polepath defined from this study of the Lachlan Fold Belt (Fig.3) is, for its Silurian-Devonian part, in good agreement with the majority of proposed Gondwana APWPs and is, for its Early Carboniferous part, in good agreement with the recently proposed path for the New England Fold Belt

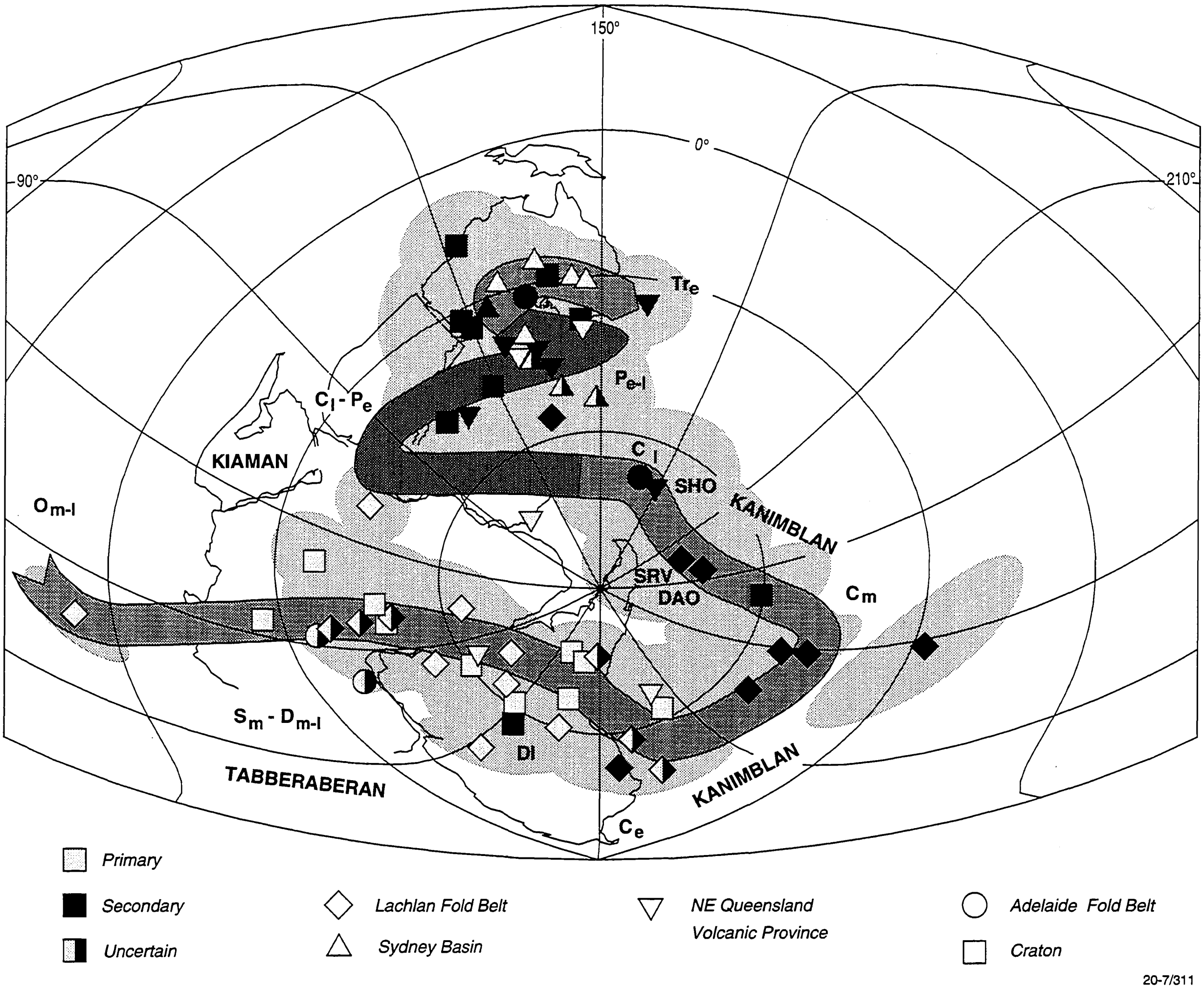
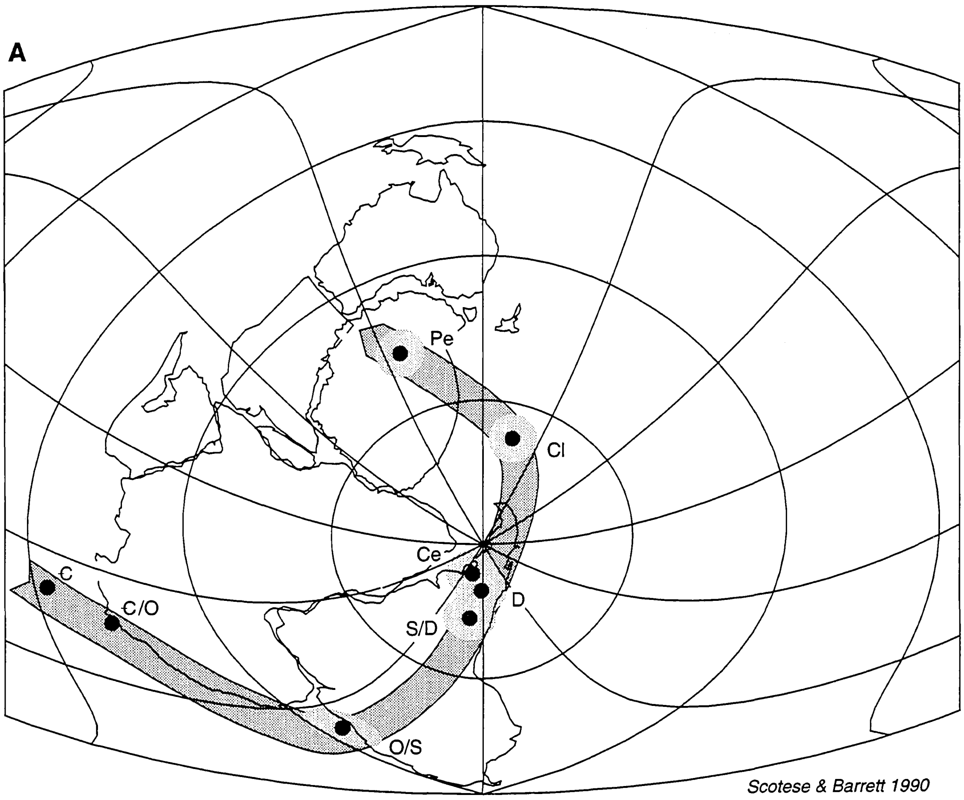


Figure 5 The KG-path based on data detailed in Klootwijk and Giddings (1993: fig.3, table 1), Klootwijk et al. (1993: table 9) and Klootwijk (1996e, table 1.1). Acronyms are indicated for several key poles discussed in Klootwijk (1996b): SRV= Snowy River Volcanics; SHO= Star of Hope Formation volcanics overprint; DAO= Dandenong Volcanics overprint. The shaded outlines indicate indicate ellipses of 95% confidence, or the envelope of ellipses.

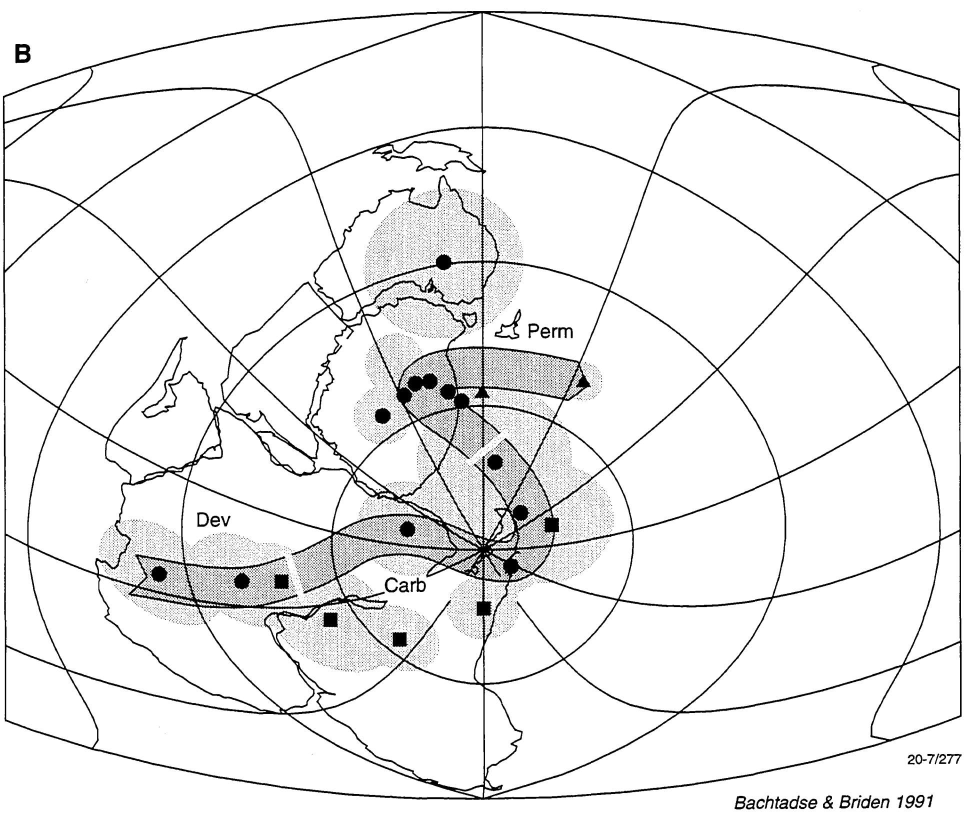
(Klootwijk,1995,1996b).The complex issue of the third problem - the Late Palaeozoic polepath for Australia - will be discussed hereafter. Possible resolution of the first two problems has allowed definition of a simple Early-to-Middle Palaeozoic polepath trajectory for Australia by means of averaging of primary results (see Klootwijk,1996e, table 1.1) over time intervals listed in Table 1. The resultant mean poles (see Klootwijk,1996e, table 1.2) are presented in Figure 2.

Alternatives for the Late Palaeozoic cratonic APWP

The controversy about Australia's Late Palaeozoic polepath has been discussed at some length in Klootwijk and Giddings (1993), Klootwijk et al. (1993) and Klootwijk (1996b). The following discussion on the New England path and its implications is an edited extract of the discussion in Klootwijk (1996b).



Scotese & Barrett 1990



Bachtadse & Briden 1991

Two versions of the Late Palaeozoic APWP with markedly different Devonian and Early Carboniferous trajectories are current. The more established path (Fig.4: SLP-path), originally proposed by Schmidt, Li, Powell and coworkers and adapted over the past decade (e.g. Schmidt et al.,1986,1987,1990; Li et al.,1993; Lackie and Schmidt,1993; Schmidt and Lackie,1993; Chen et al.,1993,1994,1995), shows a pronounced Devonian to Carboniferous "westward" (south-over-west) loop with an apex defined by a mid-Carboniferous Mount Eclipse Sandstone pole position (Chen et al.,1994). The more recently proposed alternative polepath (Fig.5: KG-path: Klootwijk and Giddings,1993; Klootwijk et al.,1993), accommodates all poles accepted in the SLP-path. In addition it includes various poles rejected in the SLP definition which have been re-interpreted as Early Carboniferous overprints, and a considerable number of Middle and Late Palaeozoic pole positions obtained in the course of AGSO studies on the Tasman Orogenic System (TOS) and cratonic basins (Klootwijk and Giddings,1993; Klootwijk et al.,1993; Klootwijk,1996b). The KG-path's database exceeds the SLP-path's base by a factor of three, despite the KG-path not including data from the New England region. The latter data are discussed separately hereafter. The KG-path (Fig.5) features a Middle Ordovician to Devono-Carboniferous west-(over-south)-to-east progressing segment, followed by an "eastward" (south-over-east) Late Devonian to Early Carboniferous loop. This contrasts glaringly with the east-(over-south)-to-west progression and "westward" loop of the Devonian to Early Carboniferous part of the SLP-path. The Late Carboniferous parts of the KG-path and the SLP-path are in general agreement.

The KG-path has several characteristics in common with a Gondwana polepath that was independently derived from lithological indicators for the Late Palaeozoic climate (Fig.6A: Scotese and Barrett,1990) and also with a Gondwana APWP based on reinterpretation of Gondwana data in terms of Carboniferous overprinting (Fig.6B: Bachtadse and Briden,1991). Both versions of Australia's Late Palaeozoic polepath are actively defended by their respective authors and both polepaths continue to be upgraded as the database broadens (e.g. Clark et al.,1996; Klootwijk,1996c,d). Performance of the two Late Palaeozoic APWPs in continent reconstructions ultimately may prove to be the most persuasive test for their appropriateness. For instance, the SLP-path implies existence of a Middle Devonian-Early Carboniferous oceanic basin between northwestern Gondwana and southern Europe, which is not supported by field evidence (Fig.7A). The KG-path, in contrast, implies that this basin, if it ever existed, was already closed by the latest Devonian (Fig.7B). Another, maybe more decisive, test involves reconstruction of the North China block off northwest Australia and western Irian Jaya (Fig.8A), based on superposition of the Cambrian to Late Devonian segment of the KG-path (Klootwijk,1996e, table 1.2) and a North China path (Klootwijk,1996e, table 3.2) based on a recent compilation of pole positions by Zhao et al. (1996). This palaeomagnetic reconstruction is essentially identical to an earlier derived reconstruction (Fig.8B) based on biostratigraphic and lithostratigraphic indicators (Metcalfe and Nicoll,1994). Such a remarkable match of independently derived reconstructions cannot be obtained using the Early Palaeozoic part of the SLP-path which is far too extensive and too complex for matching with the North China path (e.g. Klootwijk and Giddings,1993, fig.3c).

Figure 6 [opposite page] Generalized Late Palaeozoic apparent polar wander paths. A: Gondwana APWP proposed by Scotese and Barrett (1990), based on lithological indicators of climate of the Gondwana continents. B: Gondwana APWP proposed by Bachtadse and Briden (1991), based on palaeomagnetic data from Africa (full dots), Australia (squares) and Madagascar (triangles).

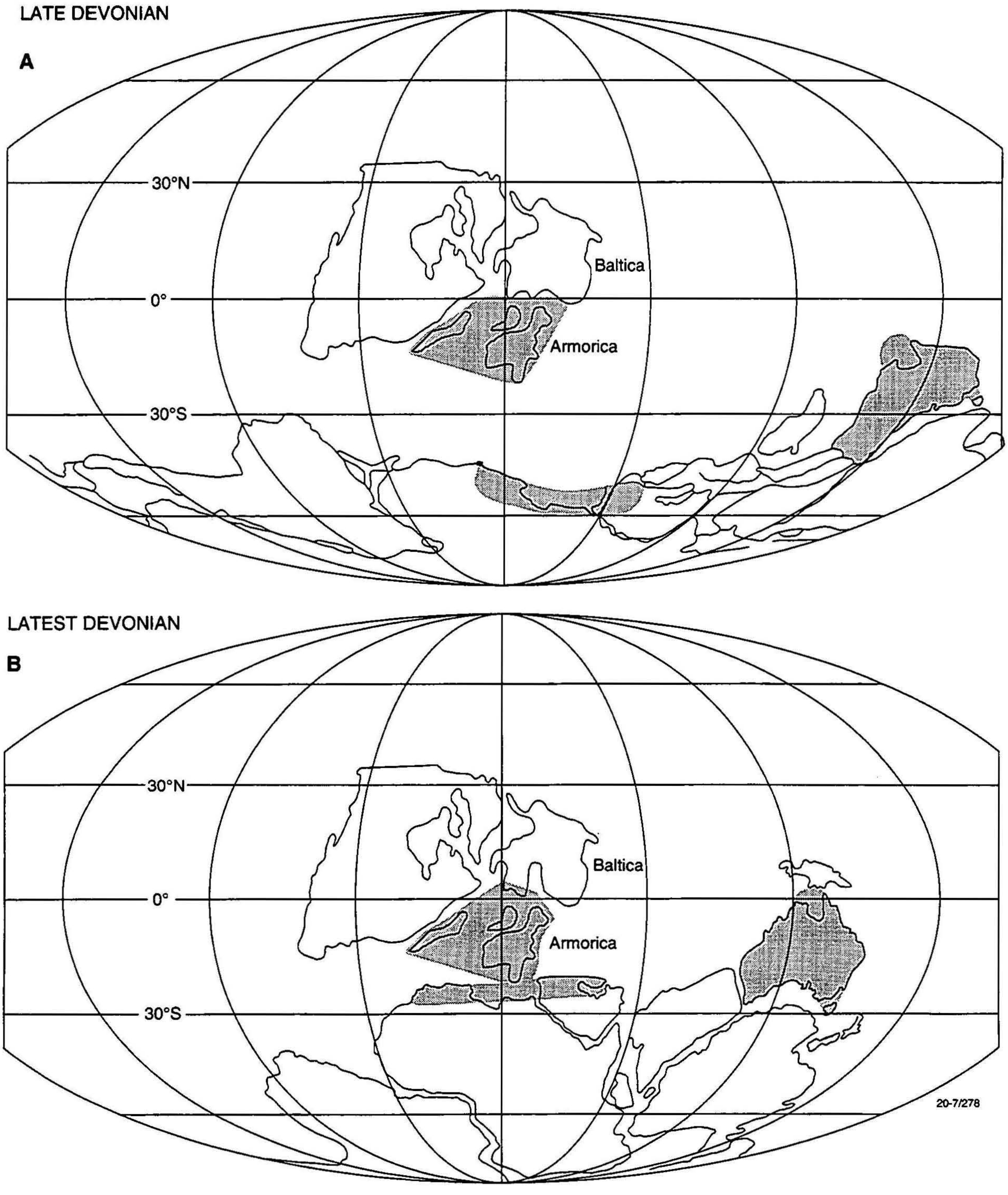


Figure 7 A: Late Devonian reconstruction of Gondwana versus Laurussia, after Scotese (1984). The reconstruction is representative for the SLP-path. B; Latest Devonian reconstruction, based on Scotese (1984) for Laurussia and a latest Devonian pole position for the Mount Eclipse Sandstone of the Ngalia Basin (Klootwijk, unpublished; Klootwijk,1996e, table 1.2). The reconstruction is representative for the KG-path.

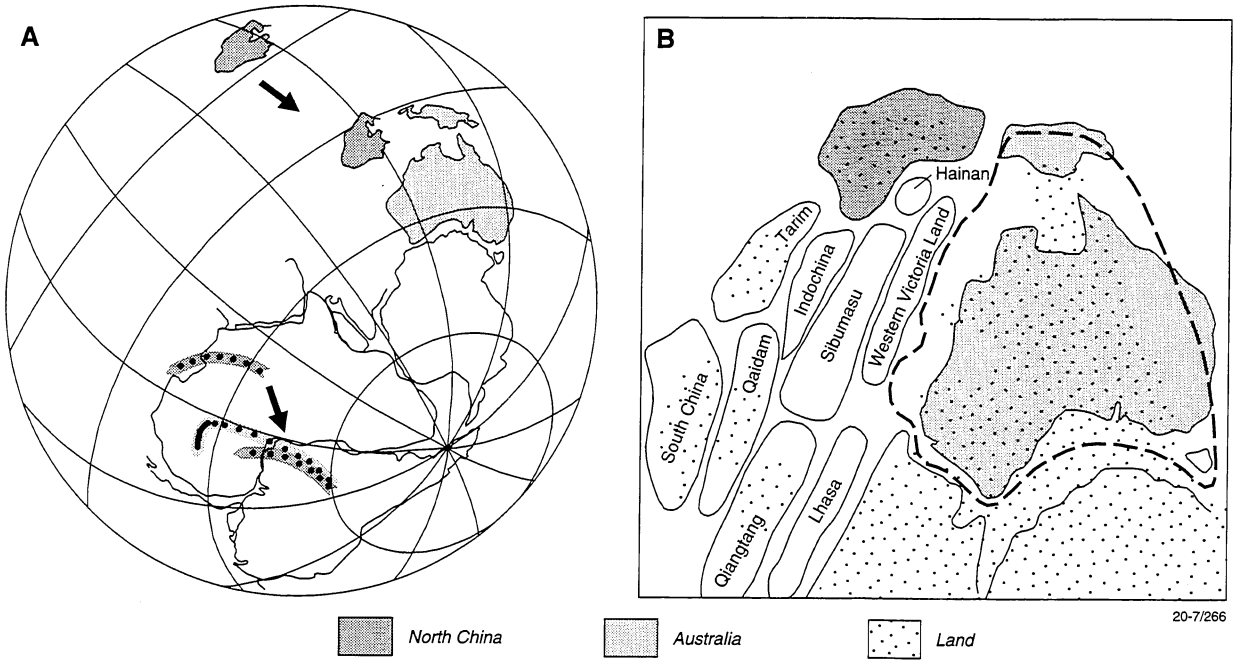


Figure 8 A: Reconstruction of the North China block versus Australia. Euler pole at 9.7°N, 180.3°E, +47.9°. The Australian Cambrian to Late Devonian polepath segment (KG-path) is based on mean poles (8) for sub-Periods detailed in Klootwijk (1996e, tables 1.1,1.2). The North China Middle Cambrian to Late Devonian polepath trajectory is based on selected pole positions detailed in Zhao et al. (1996: table 1). The polepath segments are derived with the GMAP for Windows program (Torsvik and Smethurst, 1995) using the Jupp and Kent (1987) method for fitting spherical smoothed splines (10% smoothing) with weighting according to α_{95} values. The North China block and fitted polepath are shown before and after rotation about the Euler pole. B: Reconstruction of northeastern Gondwana during the Late Silurian based on biostratigraphic and lithostratigraphic evidence, after Metcalfe & Nicoll (1994: fig.3).

Newly-derived Carboniferous APWP for New England

The New England polepath is derived from the Carboniferous succession of the Tamworth Belt (Fig.9), a forearc successor basin to the Gamilaroi Terrane that was already accreted to the Lachlan Fold Belt by the latest Devonian as established from provenance linkage (Flood and Aitchison,1992). The Carboniferous succession of the basin is largely made up of volcanogenic sediments and frequent volcanic intercalations, often ignimbritic, derived from a dacitic to andesitic continental arc to the west (Roberts et al.,1995a). The Carboniferous APWP for New England is based on detailed thermal demagnetisation studies of an extensive collection of pilot samples from four tectonic units of the western and southwestern part of the Tamworth Belt. From north-to-south these units are: the Gravesend/Rocky Creek Syncline; the Werrie Syncline; the Rouchel block; and the Gresford block (Fig.9). The study focussed on the volcanic intercalations, which proved far more capable of retaining a presumed primary magnetisation than the volcanogenic sediments in the face of heavy overprinting by a Permian reverse polarity "Kiaman" magnetisation component (Fig.10A,B: Klootwijk and Giddings,1993; Klootwijk et al.,1993; Lackie and Schmidt,1993; Schmidt and Lackie,1993). Focussing on the volcanics has the added advantage that SHRIMP U-Pb zircon ages are becoming increasingly available through an extensive timescale calibration program carried out at AGSO (e.g. Roberts et al.,1991,1995a,b,1996; Claoué-Long et al.,1995).

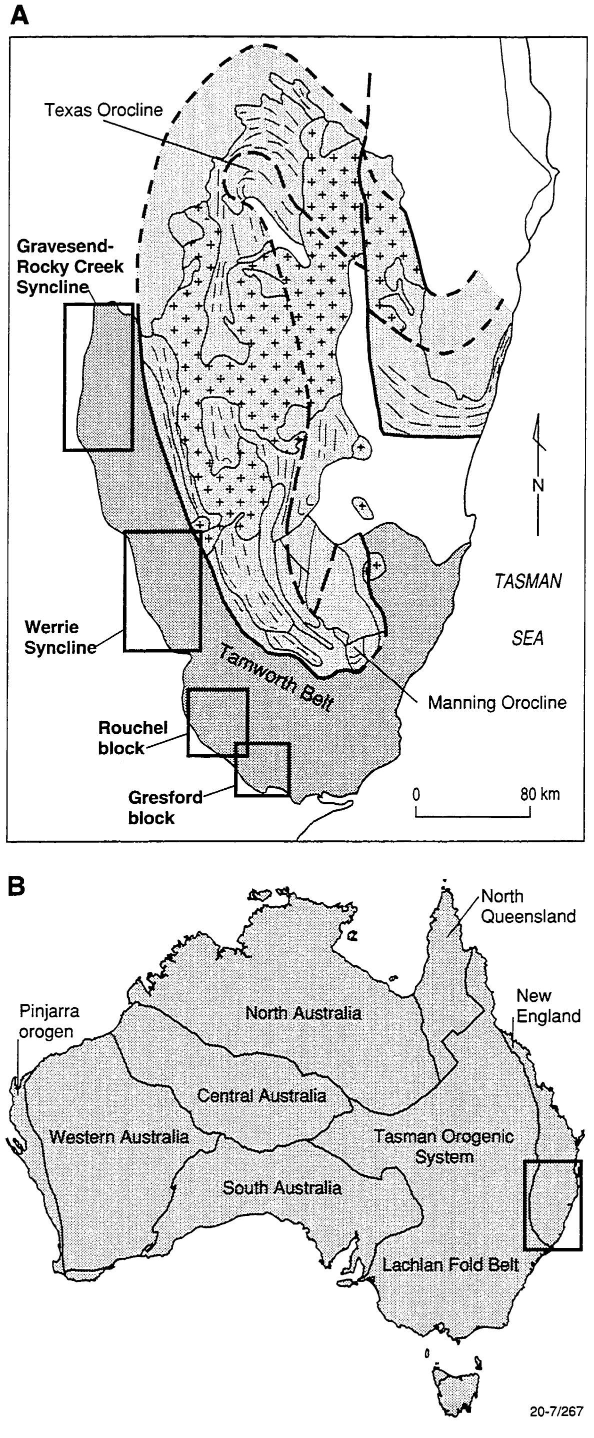
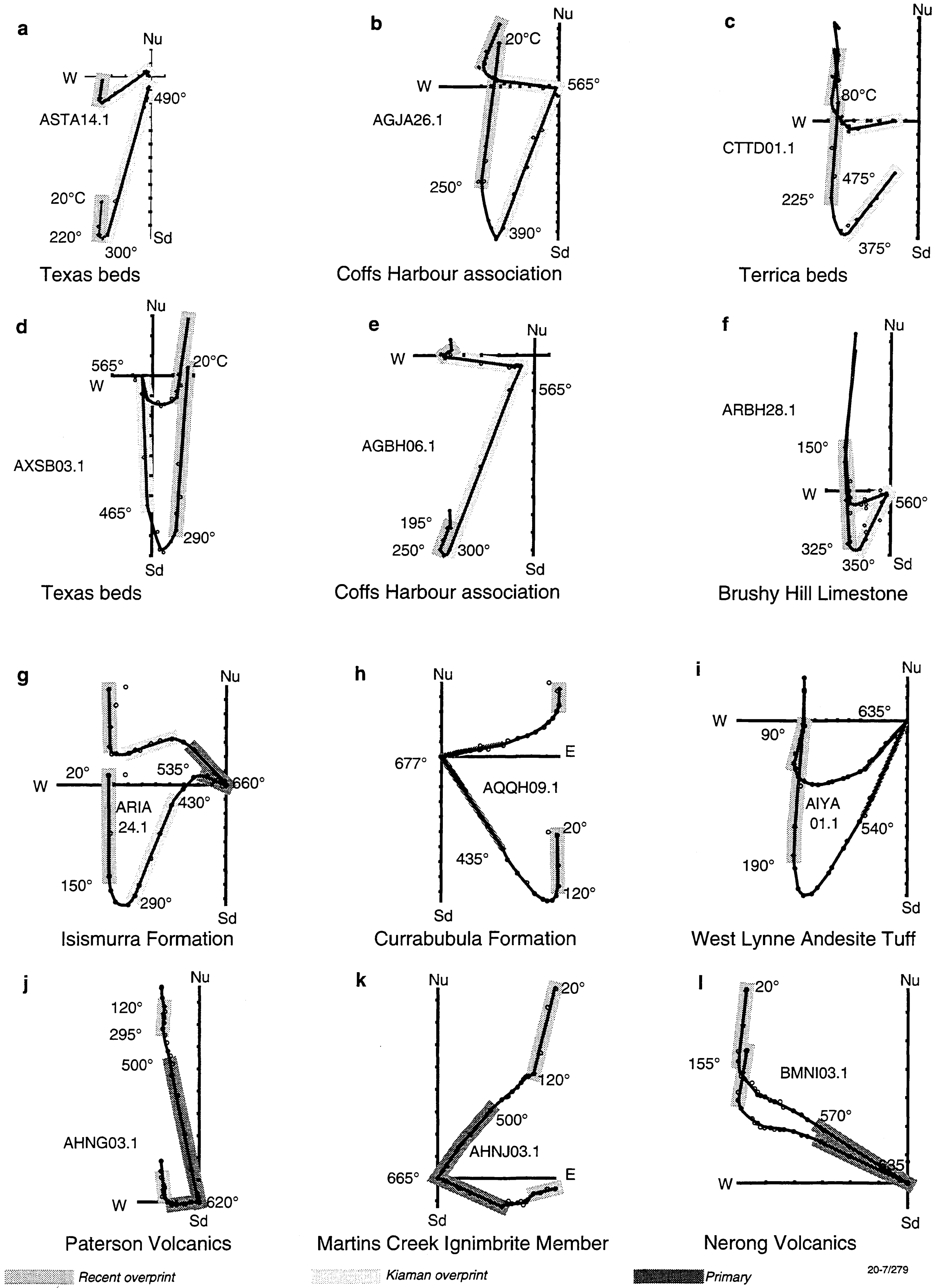


Figure 9 A: Schematic overview of the southern New England Fold Belt after Korsch and Harrington (1987), with outlines of the four studied tectonic units in the Tamworth Belt. The Gamilaroi terrane is a precursor terrane to the Tamworth Belt. The light grey shading represents the Woolomin, Sandon and Coffs Harbour Associations and the dark grey shading the Tamworth Belt. B: Australian mega-elements, representing continent-scale groups of crustal elements after Shaw et al. (1995).

Figure 10 [opposite page] Zijderveld diagrams of representative samples from various New England regions during thermal demagnetisation, shown in geographic (field) coordinates. The circles indicate successive positions of the end-points of the resultant magnetisation vector during progressive demagnetisation. Open circles indicate projections on the vertical east-west or vertical north-south plane, and dots indicate projections on the horizontal plane. Numbers denote successive peak temperatures in °C of the heating cycles. a-f: Sediments from the Texas beds, the Coffs Harbour Association, and the Tamworth Belt. g-l: Volcanics from the Tamworth Belt.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Sd
Currabubula Formation
i
Nu
W
635°
90°
AIYA
01.1
540°
190°
Sd
West Lynne Andesite Tuff
j
Nu
120°
295°
500°
AHNG03.1
W
620°
Sd
Paterson Volcanics
k
Nu
20°
120°
500°
AHNJ03.1
665°
E
Sd
Martins Creek Ignimbrite Member
l
20°
Nu
155°
BMNI03.1
570°
635°
W
Sd
Nerong Volcanics
Recent overprint
Kiaman overprint
Primary
20-7/279

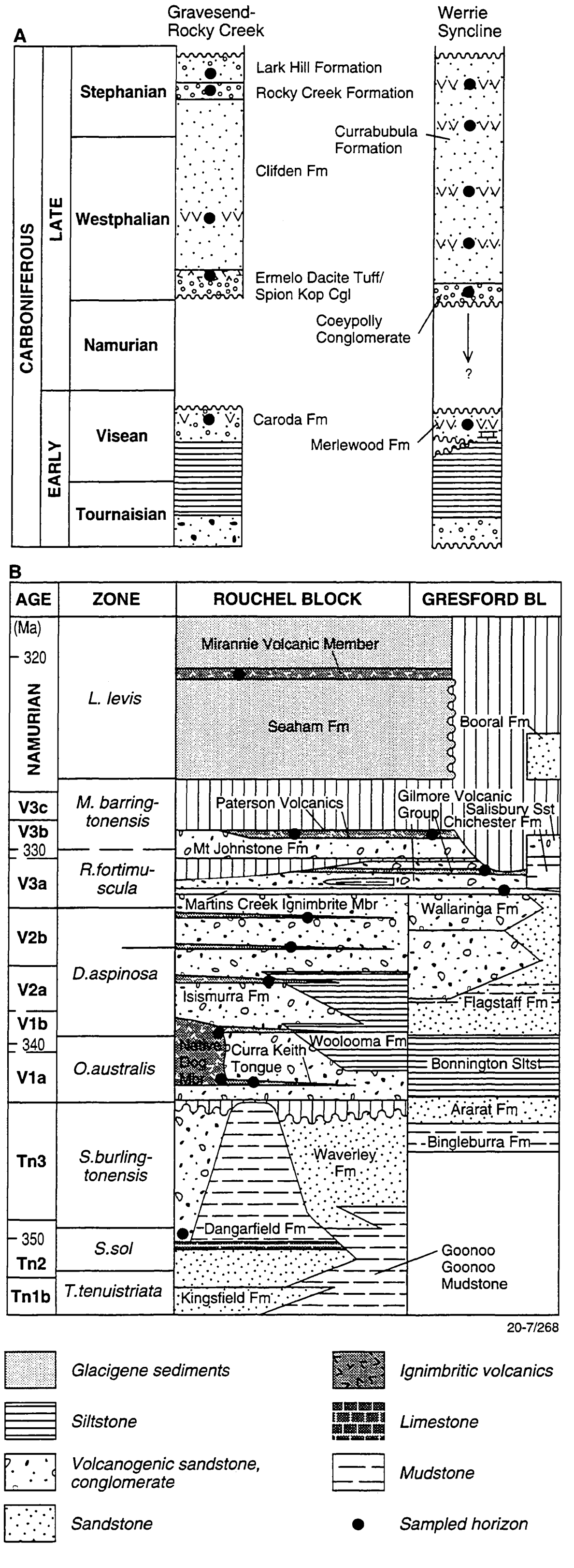


Figure 11 Schematic stratigraphy of the successions sampled in A: the Gravesend/Rocky Creek and Werrie Synclines after the New England 1:500,000 map (Pogson and Hitchins,1973), not updated for new SHRIMP age constraints; B: the Rouchel and Gresford blocks (after Roberts et al. 1995a).

Palaeomagnetic results from the four units are complimentary in time, with mainly Late Carboniferous results obtained from the northern regions (Fig.11A) and mainly Early Carboniferous results from the southern regions (Fig.11B). Comparison of polepath trajectories for the four units (Fig.12A-D) showed no evidence for systematic rotation along the Tamworth Belt, although some rotation may have occurred in the eastern part of the Gresford block, so the individual trajectories have been combined into an overall Carboniferous APWP for New England (Fig.13). Comparison of this Carboniferous APWP with the Middle to Late Palaeozoic KG-path for cratonic Australia (Fig.5) shows good agreement for the earliest Carboniferous and Late Carboniferous parts of the APWP, but a more extensive "eastward" swing for the middle Carboniferous part of the New England APWP. This extensive swing is interpreted as refinement of a common APWP, as is to be expected with latest Devonian accretion of New England, rather than differential movement of New England with respect to the Australian craton. Consequently, the New England APWP is taken to represent the movement of the Greater Australian part of eastern Gondwana.

The Carboniferous APWP (Fig.13) is characterised by an extensive Early Carboniferous "eastward" loop, with an apex defined by ignimbrites in the higher parts of the Isismurra Formation, including, perhaps, the Martins Creek Ignimbrite Member (332.2±2.2 Ma) of the Gresford block as discussed in Klootwijk (1996b). This is followed by a smaller Late Carboniferous "westward" loop, reasonably well-defined by the Currabubula Formation of the Werrie Syncline and the Rocky Creek Conglomerate of the Gravesend/Rocky Creek Syncline. This extensive Carboniferous APWP (Fig.13) is provocative in its radical difference to the SLP-path (Fig.4). Its robustness is supported by a distinctive polarity pattern, which clearly delineates the Permo-Carboniferous Reversed Superchron (PCRS). The base of the PCRS is constrained in the Gresford and Rouchel blocks (Fig.12C,D) between the normal polarity Mirannie Volcanics Member (321.3±4.4 Ma) and a reverse polarity tuff overlying the Paterson Volcanics at the Paterson railway quarry, dated at about 314 Ma (J. Roberts, pers. comm.,1994; Roberts et al.,1995b). In the Gravesend/Rocky Creek and Werrie Synclines (Fig.12A,B) the base of the PCRS is constrained between the normal polarity Ermelo Dacite Tuff (321±3.2 Ma) and the reverse polarity base of the Currabubula Formation (313.6±3.6 Ma). Recently, the base of the PCRS has been located more precisely within the Clifden Formation of the Rocky Creek Syncline, between the normal polarity Eastern Arms Dacite and the reverse polarity Wanganui Andesite (Opdyke et al.,1996a,b), which can be correlated with the Ermelo Dacite Tuff and the Peri Rhyodacite of normal and reverse polarity respectively (Fig.12A). Results from the Isismurra Formation of the Rouchel block show the possible existence of an earlier normal polarity interval whose extent is no better defined than within the lower and middle Visean. Mixed polarity intervals precede and follow this normal polarity interval.

Implications of the New England APWP for Carboniferous tectonism

SHRIMP age control on the New England APWP is, as yet, limited. The palaeolatitudinal information contained in the path (Fig.13) is, therefore, best demonstrated as plots of palaeolatitude versus declination of magnetisation, with the shift in declination along the APWP representing relative rather than absolute age control. The resulting pattern is shown in Figure 14, separately for the earlier, middle and younger parts of the polepath. The middle segment (Fig.14B) details the late Visean-Namurian large-scale, southward movement to South polar latitudes that is expected from biostratigraphic and lithostratigraphic evidence for deterioration of the climate in eastern Australia (Roberts,1981; Roberts et al.,1993). The preceding Early Carboniferous northward movement to moderate northern latitudes (Fig.14A), however, was unexpected and imposes very high movement rates (and unrealistically high if the Martins Creek Ignimbrite Member results are included) on the succeeding southward movement.

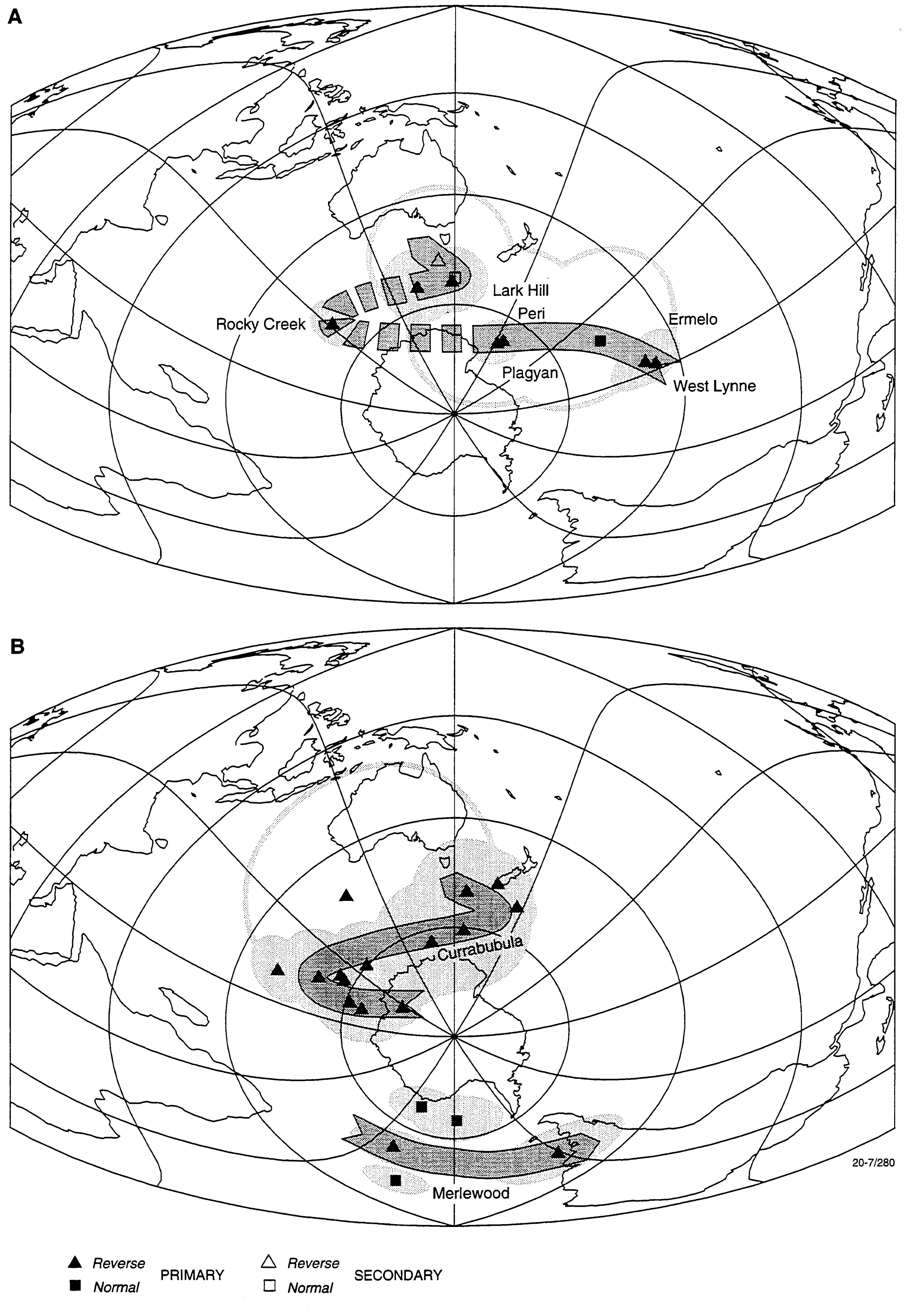
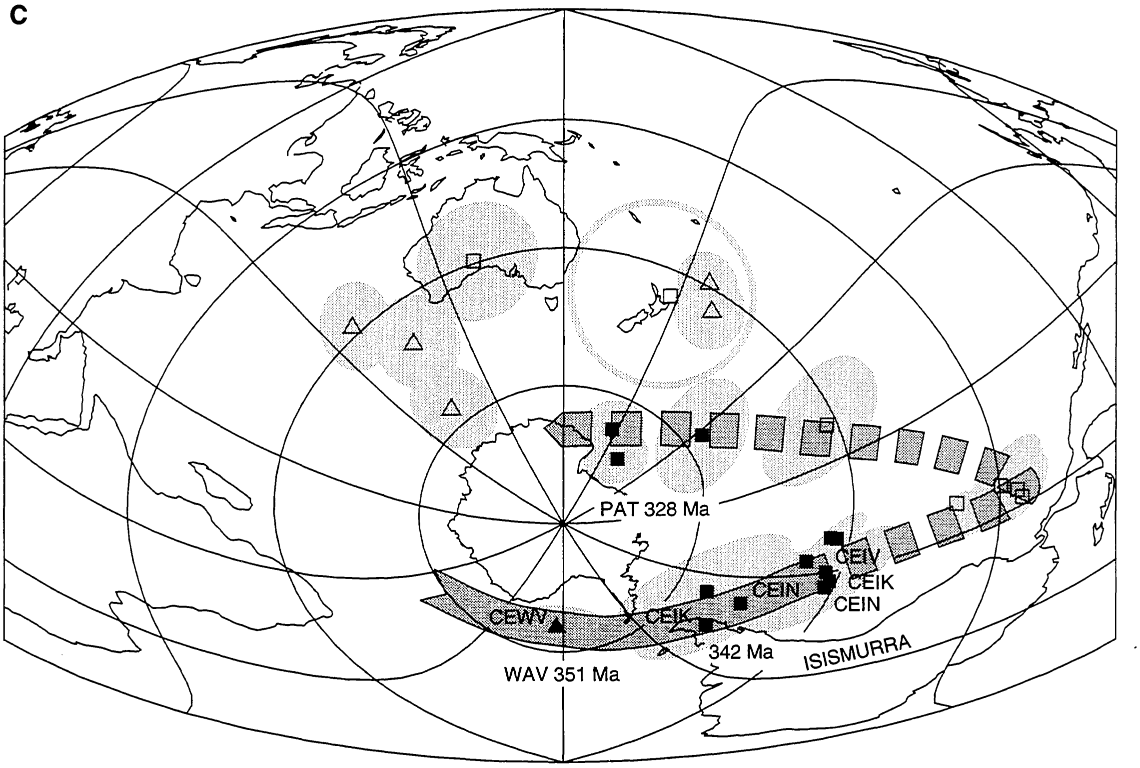
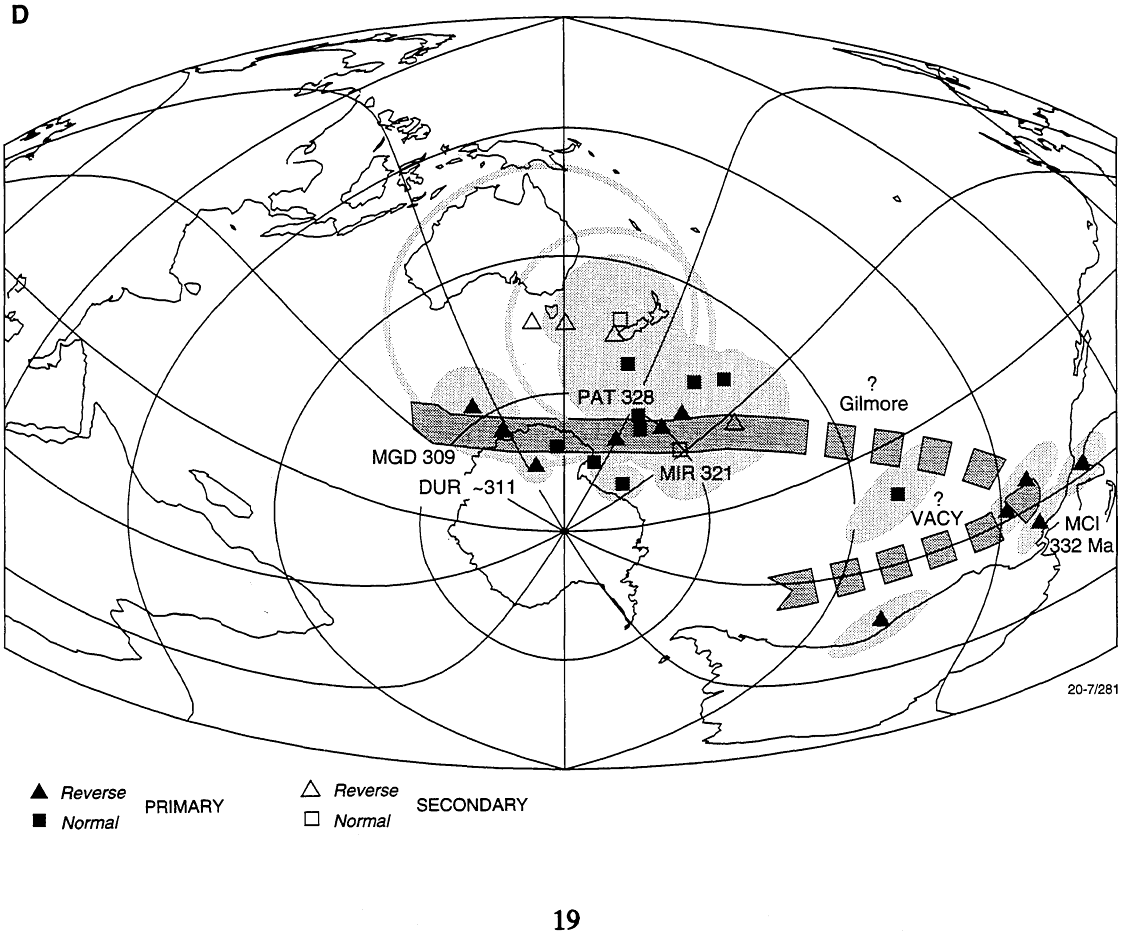


Figure 12 APWP trajectories based on pilot results (Klootwijk, 1996e, table 1.3) for [above] A: the Gravesend/Rocky Creek Syncline; B: Werrie Syncline; [opposite page] C: Rouchel block; D: Gresford block.

C


PAT 328 Ma
CEIV
CEIK
CEIN
CEWV
CEIK
CEIN
342 Ma
ISISMURRA
WAV 351 Ma

D


PAT 328
?
Gilmore
MGD 309
DUR ~311
MIR 321
?
VACY
MCI
332 Ma
20-7/281
Reverse
Normal
PRIMARY
Reverse
Normal
SECONDARY

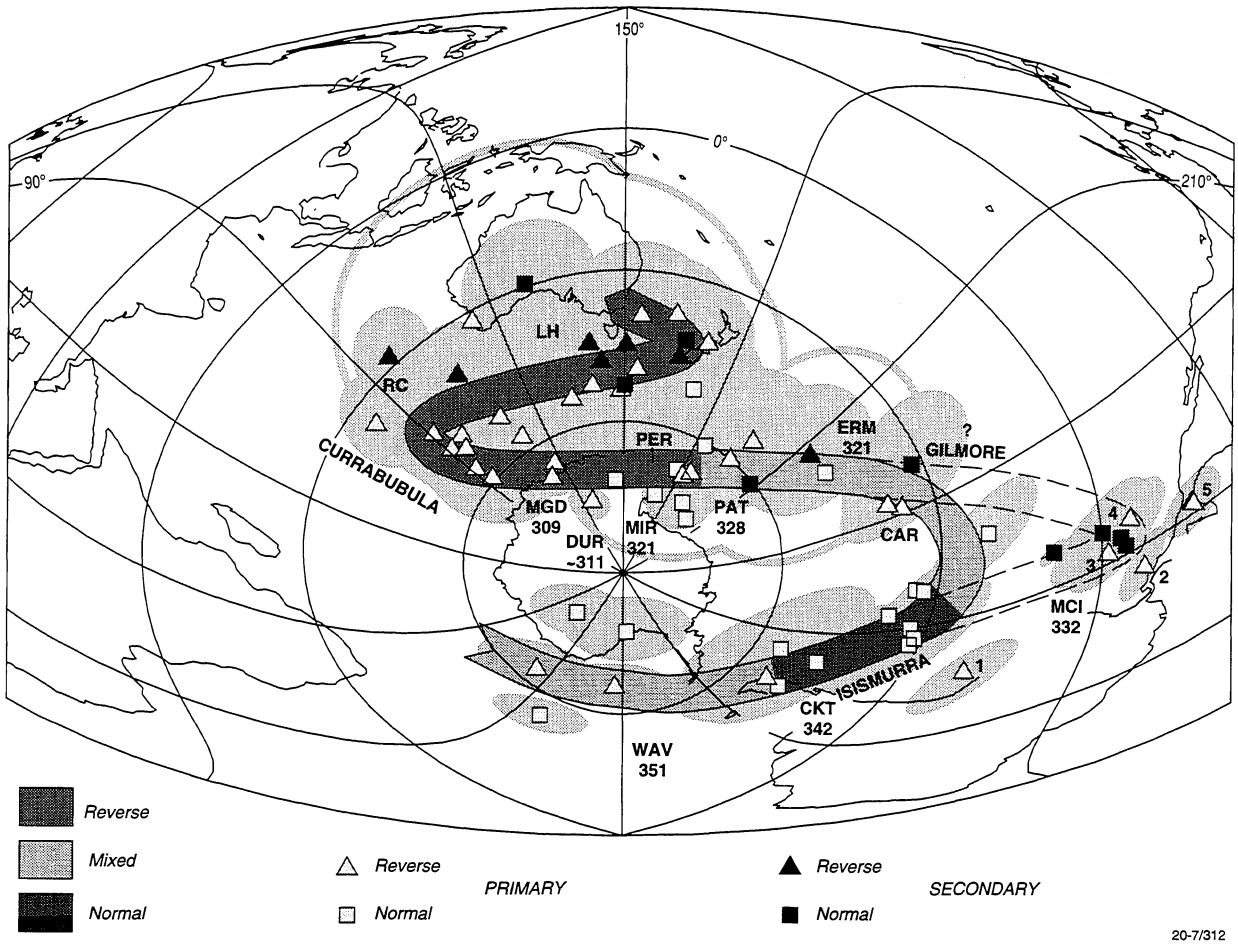


Figure 13 Carboniferous APWP for New England/Australia based on integration of APWP trajectories for the four studied tectonic blocks detailed in Figure 12A-D. Acronyms: WAV=Waverley Formation (Rouchel block); CKT=Curra Keith Tongue (Rouchel block); MCI=Martins Creek Ignimbrite Member (Gresford block); CAR=Caroda Formation (Gravesend/Rocky Creek Syncline); ERM=Ermelo Dacite Tuff (Gravesend/Rocky Creek Syncline); PER=Peri Rhyodacite, Clifden Formation (Gravesend/Rocky Creek Syncline); PAT=Paterson Volcanics (Gresford block); MIR= Mirannie Volcanic Member (Gresford block); DUR=Mount Durham Tuff Member (Gresford block); MGD=Matthews Gap Dacite Tuff Member (Pokolbin Hills: southward adjacent to the Gresford block but across the Hunter Thrust); RC=Rocky Creek Conglomerate (Gravesend/Rocky Creek Syncline); LH=Lark Hill Formation (Gravesend/Rocky Creek Syncline). See Figure 11A for Currabubula Formation and Figure 11B for Isismurra Formation and Gilmore Volcanic Group. The preferred polepath is drawn with exclusion of the reverse polarity MCI poles (1-5) and several closely comparable normal polarity overprint poles from the Isismurra Formation, for reasons discussed in Klootwijk (1996b).

It is not clear whether the cause of this problem has to be sought in the interpretation of the SHRIMP dates, or in the palaeomagnetic results (Klootwijk,1995,1996b). Clearly, the reality or otherwise of the mid-Carboniferous northward excursion can be established beyond doubt, through further palaeomagnetic definition of the initial part of the southward-moving palaeolatitude curve (Fig.14B).

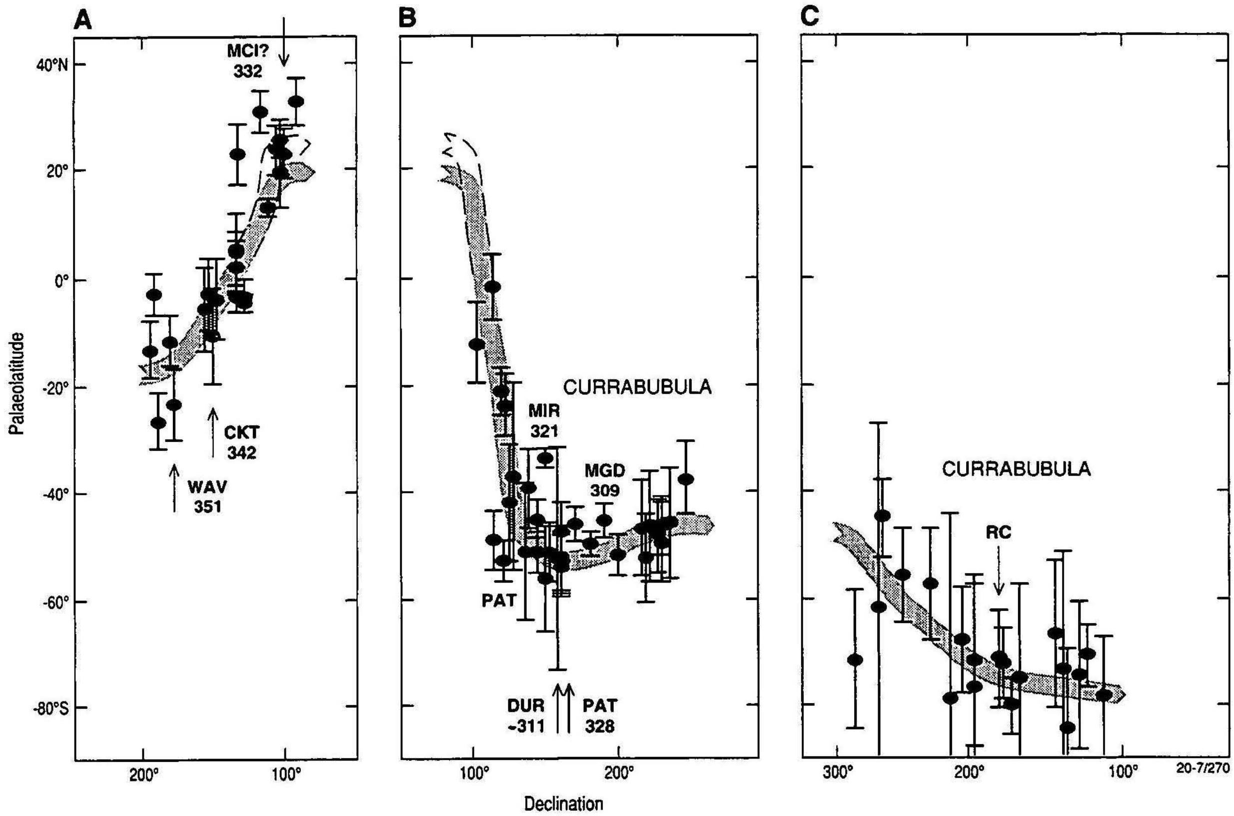


Figure 14 Palaeolatitudinal evolution of New England/Australia (Armidale: 151.7°E, 30.5°S, as the reference point) based on pole positions detailed in Figures 12 and 13. Palaeolatitudes are shown against declinations, used as a proxy for relative age control, for the three successive APWP swings, A: Early Carboniferous - Waverley Formation to Martins Creek Ignimbrite Member, "eastward" limb, B: middle–Late Carboniferous - Martins Creek Ignimbrite Member to Currabubula Formation," westward" limb, C: latest Carboniferous - Currabubula Formation to Lark Hill Formation, "eastward" limb. For acronyms see caption to Figure 13. The preferred palaeolatitude pattern in subfigures A and B is drawn with exclusion of the MCI results as discussed in Klootwijk (1996b).

The northward excursion may have significant implications for evolution of Gondwana-Laurasia interactions and in particular for tectonic evolution of Australia in relation to the Central Asian Fold Belt. This is best demonstrated in terms of Australia's overall Phanerozoic palaeolatitudinal movement pattern, based on a compilation of palaeolatitude data with reliable age control (Fig.15). The figure shows that Australia's Carboniferous northward excursion was followed by a Triassic-Jurassic northward excursion of smaller magnitude and finally by continuing northward movement after Cretaceous initiation of eastern Gondwana's fragmentation. The Indian palaeolatitude data, compiled from continental (Klootwijk,1984) and Ninetyeast Ridge data (Klootwijk et al.,1991,1992), show a comparable pattern, but suggest that the Triassic-Jurassic northward excursion was more extensive and started earlier, perhaps. The movement patterns for the two continents show that eastern Gondwana underwent northward excursions at times broadly coincident with the Variscan, Cimmerian and Alpine cycles of accretion of Gondwana fragments to southern Laurasia (Fig.16). This suggests that eastern Gondwana was involved as a carrier in the

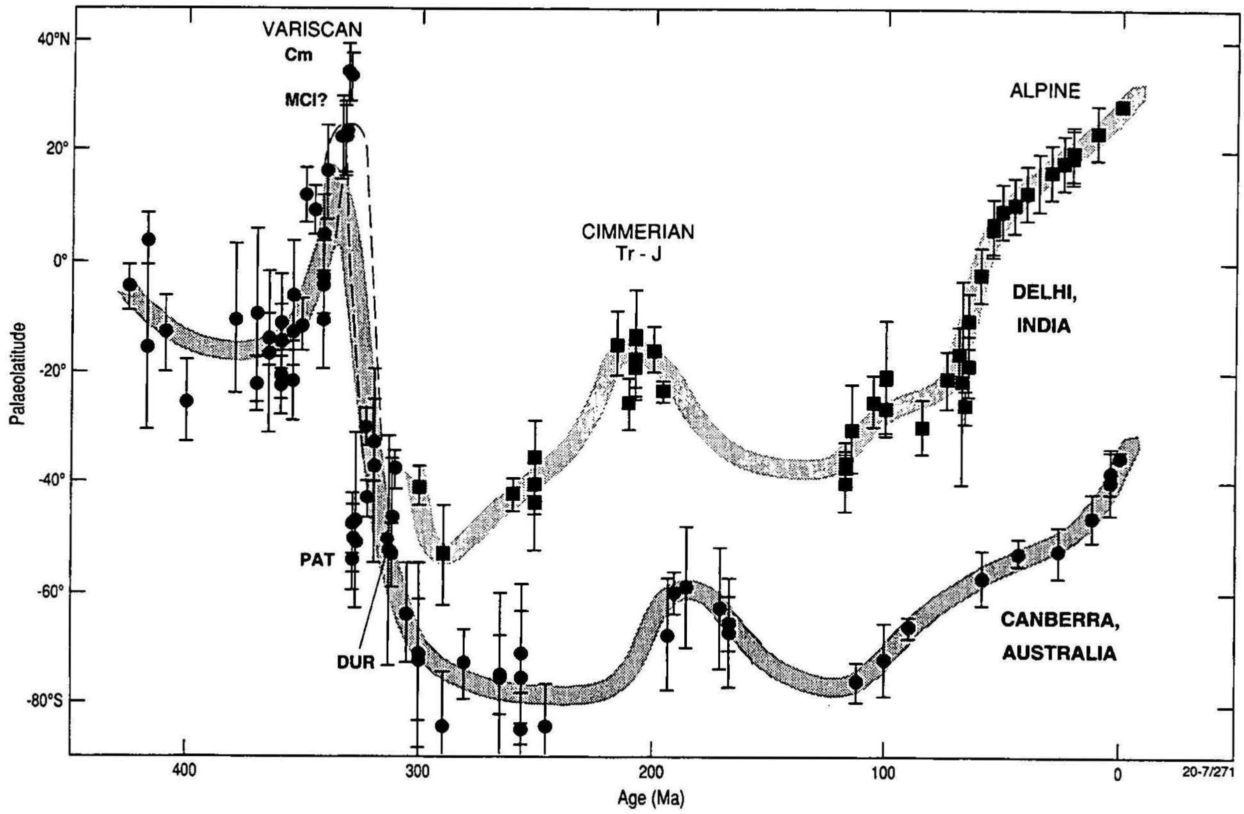


Figure 15 Comparison of Middle Palaeozoic to Recent palaeolatitudinal control for Australia (Canberra: 149.1°E, 35.3°S, used as the reference point) and Late Palaeozoic to Recent control for India (Delhi: 77.2°E, 28.7°N, reference). The preferred palaeolatitude pattern for Australia is drawn with exclusion of the MCI results as discussed in Klootwijk (1996b) and in the captions to Figures 13 and 14.

transport of these fragments, in contrast to prevailing geodynamic models which envisage rifting of continental slivers from a rather stationary Gondwana (e.g. Sengör,1984,1987; Scotese in Klein et al.,1994). The carrier concept for the movement of these fragments, or ribbon continents, situated on the northern rim of Gondwana, may provide a plausible transport mechanism and may explain how these fragments conserved their original palaeogeographic relationships throughout the fragmentation-Tethyan crossing-accretion process.

The carrier concept can be tested by comparing Australia's palaeolatitudinal pattern with that of Gondwana fragments accreted to southern Laurasia. The Tarim block is the obvious test case. There is well-established geological evidence for convergence of the Tarim block with the Central Asian Fold Belt by the middle Carboniferous, and the Tarim block has considerable palaeomagnetic control from American, Russian and Chinese studies. Despite this control, the Tarim data suffer from the polarity uncertainty that is common to Palaeozoic data of the Cathaysian continents. The southern hemisphere palaeolatitude option (Fig.17), generally adopted in Russian studies, shows an Early Carboniferous movement that is directly comparable in magnitude and timing with Australia's northward excursion. This similarity is interpreted as strong support of the carrier concept. This leads to the suggestion that

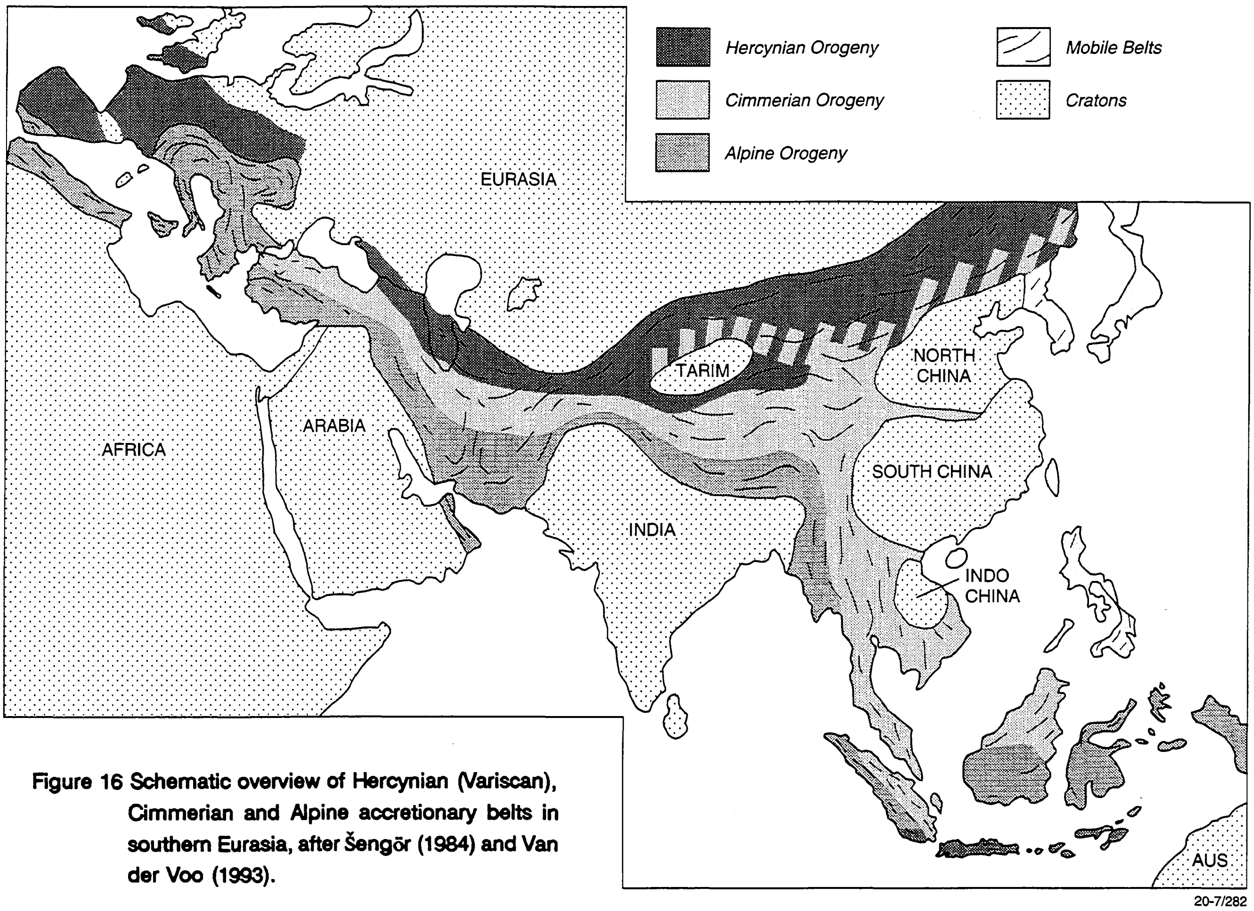


Figure 16 Schematic overview of Hercynian (Variscan), Cimmerian and Alpine accretionary belts in southern Eurasia, after Şengör (1984) and Van der Voo (1993).

Gondwana fragments of Variscan accretion origin, the Cathaysian continents, and probably also North Pacific terranes of "Pacifica" origin, were carried northward on eastern Gondwana's northern rim until middle Carboniferous contact with the Central Asian Fold Belt. Upon reversal of eastern Gondwana's movement from northward to southward, some Gondwana fragments such as the Tarim block remained incorporated in the Central Asian Fold Belt, whilst others such as the Cathaysian continents and Pacifica fragments separated at an early stage and remained parked at low latitude locations for the remainder of the Late Palaeozoic, allowing for some floral and faunal interaction between the Cathaysian continents and northern Gondwana. The passive-margin extension along eastern Gondwana's northern rim, that is to be expected as a consequence of the reversal to southward movement, may be reflected in the middle Carboniferous to Early Permian extensional regime along Australia's North West Shelf (AGSO North West Shelf Study Group,1994), in the Late Carboniferous to Permian climax in rifting of Indo-Pakistan's northwest margin (Pogue et al.,1992), the middle Carboniferous initiation of the Panjal Trap volcanism in the Kashmir Himalaya, and in the Late Carboniferous initiation of Gondwana basins in eastern India (Krishnan,1968).

Middle Carboniferous convergence of Greater Australia with the Central Asian Fold Belt may provide a provocative mechanism for the middle Carboniferous Kanimblan/Alice Springs Orogeny tectonism that is so visibly expressed in extensive kink-banding along the eastern seaboard of the TOS and crustal shortening across the Amadeus Transverse Zone (Powell,1984; Teyssier,1985; Dunlap et al.,1995a). This

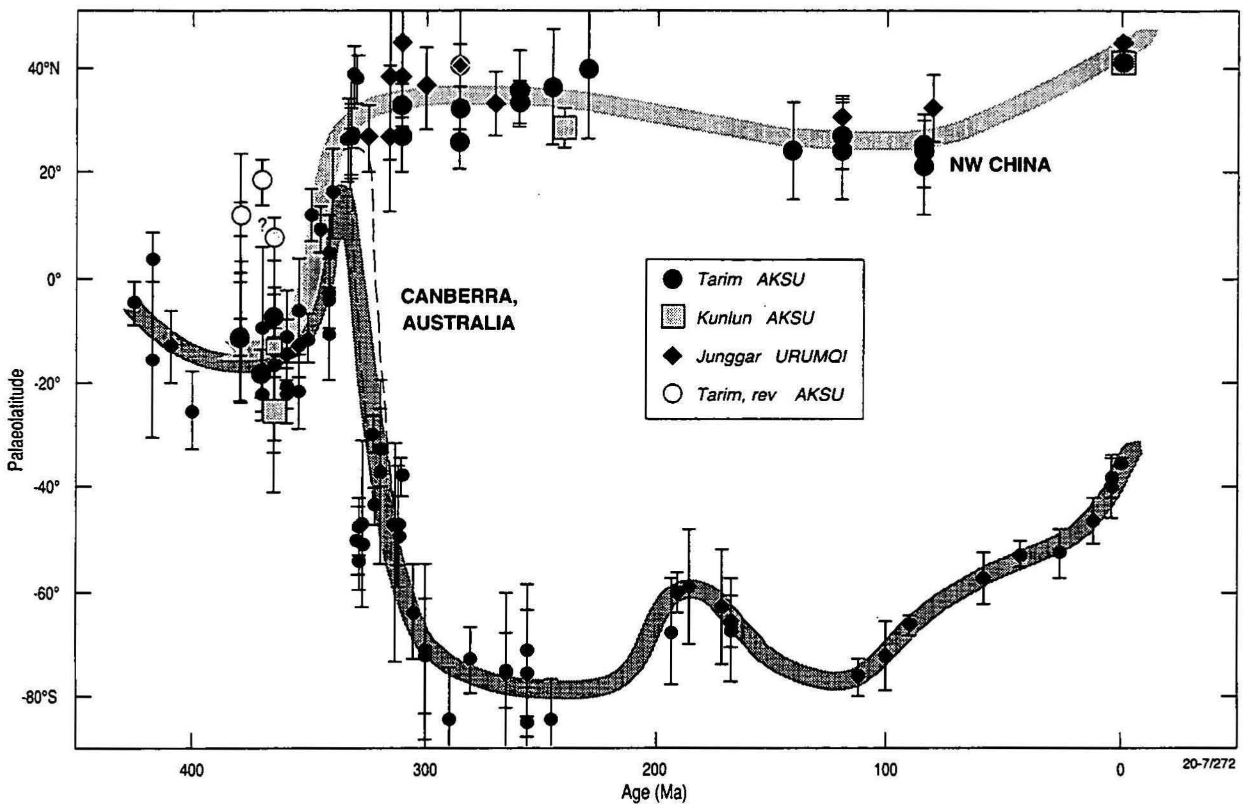


Figure 17 Comparison of Middle Palaeozoic to Recent palaeolatitudinal control for Australia (Canberra: 149.1°E, 35.3°S, reference) and the wider Tarim block including the Junggar Basin (Urumchi: 87.6°E, 43.8°N reference) and Kun Lun (Aksu: 80.3°E, 41.2°N, reference). See caption to Figure 15.

deformation has been attributed recently (Veevers et al.,1994a) to far-field stresses that originated from the well-established middle Carboniferous convergence of northwest Gondwana and southern Laurasia to form Pangea. This innovative and provocative hypothesis identifies Australia's middle Carboniferous tectonism as a Variscan deformation event, but does not explain how such far-field stresses could possibly be transmitted across the full extent of Gondwana without affecting intervening zones of weakness in Africa and India. The newly-documented evidence presented, indicating middle Carboniferous contact of eastern Gondwana with the Central Asian Fold Belt, now provides a more acceptable, closer origin for such far-field stresses: in both cases, Australia's middle Carboniferous deformation is identified as a Pangea-forming Variscan event.

Mesozoic and Cenozoic APWP

The Mesozoic APWP has received only minor attention over the past two decades and the polepath has advanced little in concept or detail beyond the path defined by Embleton (1981, fig.3). This polepath is basically a conceptual polepath, mainly based on a limited number of averaged poles. The path shows the general outline, ill-defined in shape and time, of a (Late Triassic/) Early Jurassic loop (apex ~185 Ma or earlier), followed by a Late Jurassic/Early Cretaceous loop (apex ~140 Ma) and finally a cusp

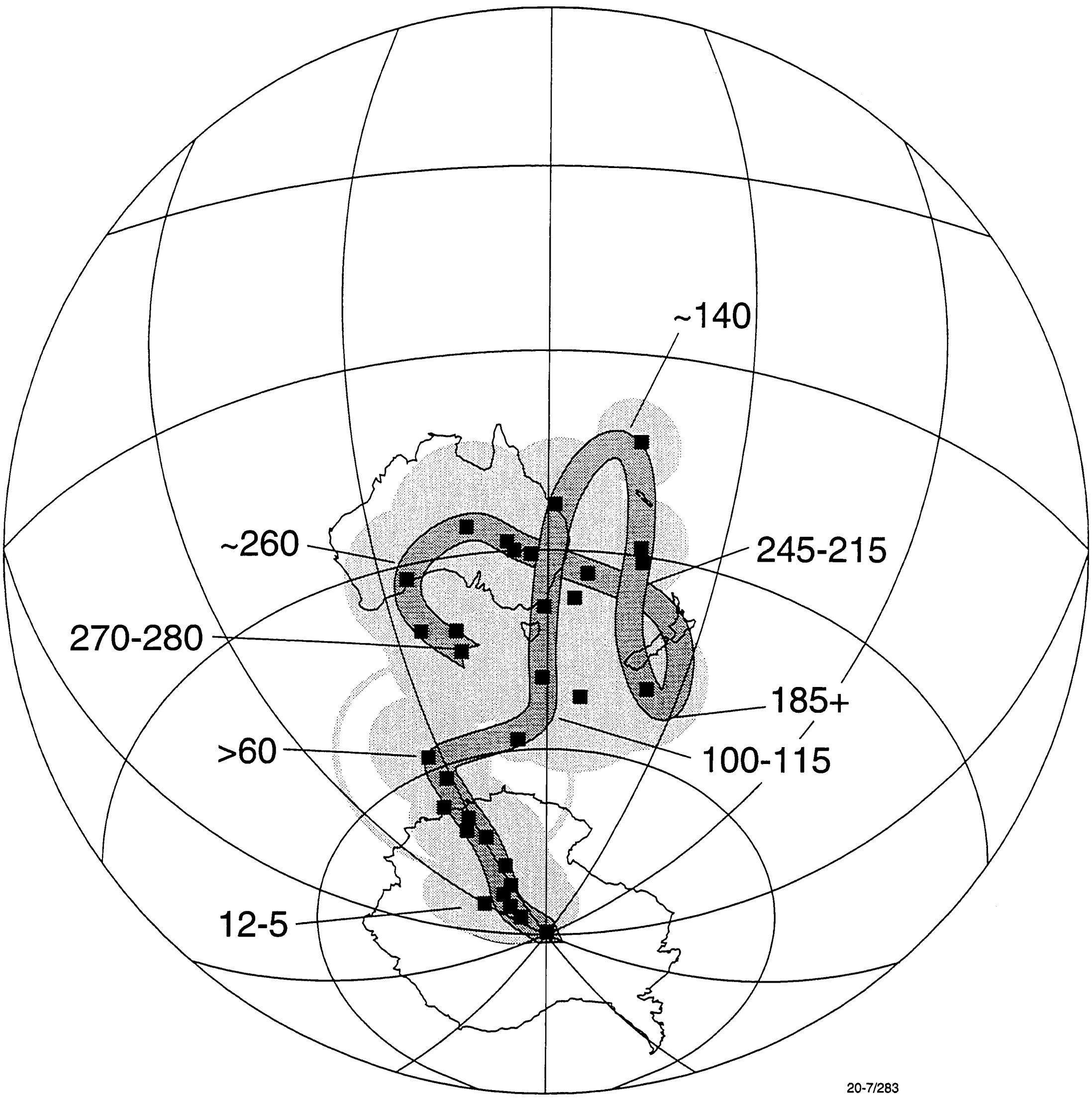


Figure 18 Australian Late Palaeozoic-Cenozoic APWP, compiled from data detailed in Klootwijk (1996e, tables 1.1 and 1.2) and for the latest Mesozoic and Cenozoic from Idnurm (1985) and Klootwijk et al. (1993). Approximate dates for the loops and cusps are listed in the text.

in the Early/Late Cretaceous (100-115 Ma). This path corresponds to southward movement of Australia during the Triassic, northward movement during the Jurassic, and again southward movement during the Early Cretaceous, followed by mainly counterclockwise rotational movement during the Late Cretaceous.

The latest Cretaceous and Cenozoic polepath is far better defined and is summarised in Idnurm (1985), with minor upgrades in Idnurm (1994). An alternative polepath based on a weighted least-squares fit procedure was proposed by Musgrave (1989) and rebuffed by Idnurm (1990) on procedural shortcomings. Idnurm's path (see Klootwijk,1996e, table 1.2) is followed here as the preferred option.

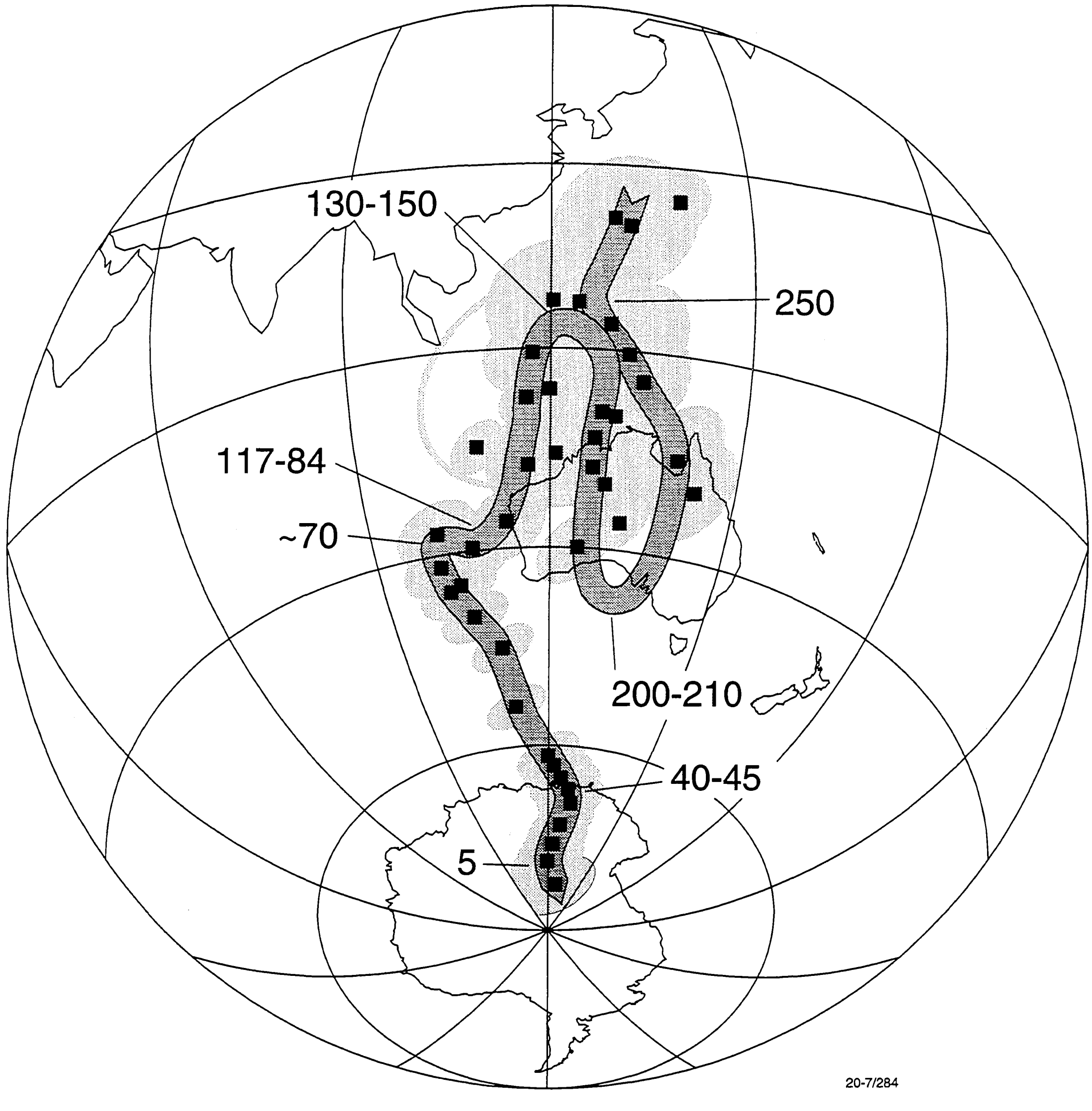


Figure 19 Indian Late Palaeozoic-Cenozoic APWP, compiled from data detailed in Klootwijk (1996e, tables 1.4 to 1.6). Approximate dates for the loops and cusps are listed in the text.

The only other advance worth mentioning is the recent recognition of a minor loop in the Late Permian polepath. This loop is based on preliminary and as yet unpublished results from the Gerringong Volcanics, Broughton Formation and Bong Bong Sill from the Illawarra Coast, and also from the Newcastle Coal Measures (Giddings et al.,1994; Théveniaut et al.,in press). These preliminary results have been obtained in search for the younger boundary of the PCRS. Known to postdate the Gerringong Volcanics, the younger boundary has now been shown to predate the Newcastle Coal Measures and also the Jerrys Plain Subgroup of the Wittingham Coal Measures of Kazanian to possibly Ufimian age. The loop is shown on the Late Palaeozoic APWP for the craton (Fig.5), on the Carboniferous APWP for New England (Fig.13), and also as a forerunner on the Mesozoic and Cenozoic APWP (Fig.18).

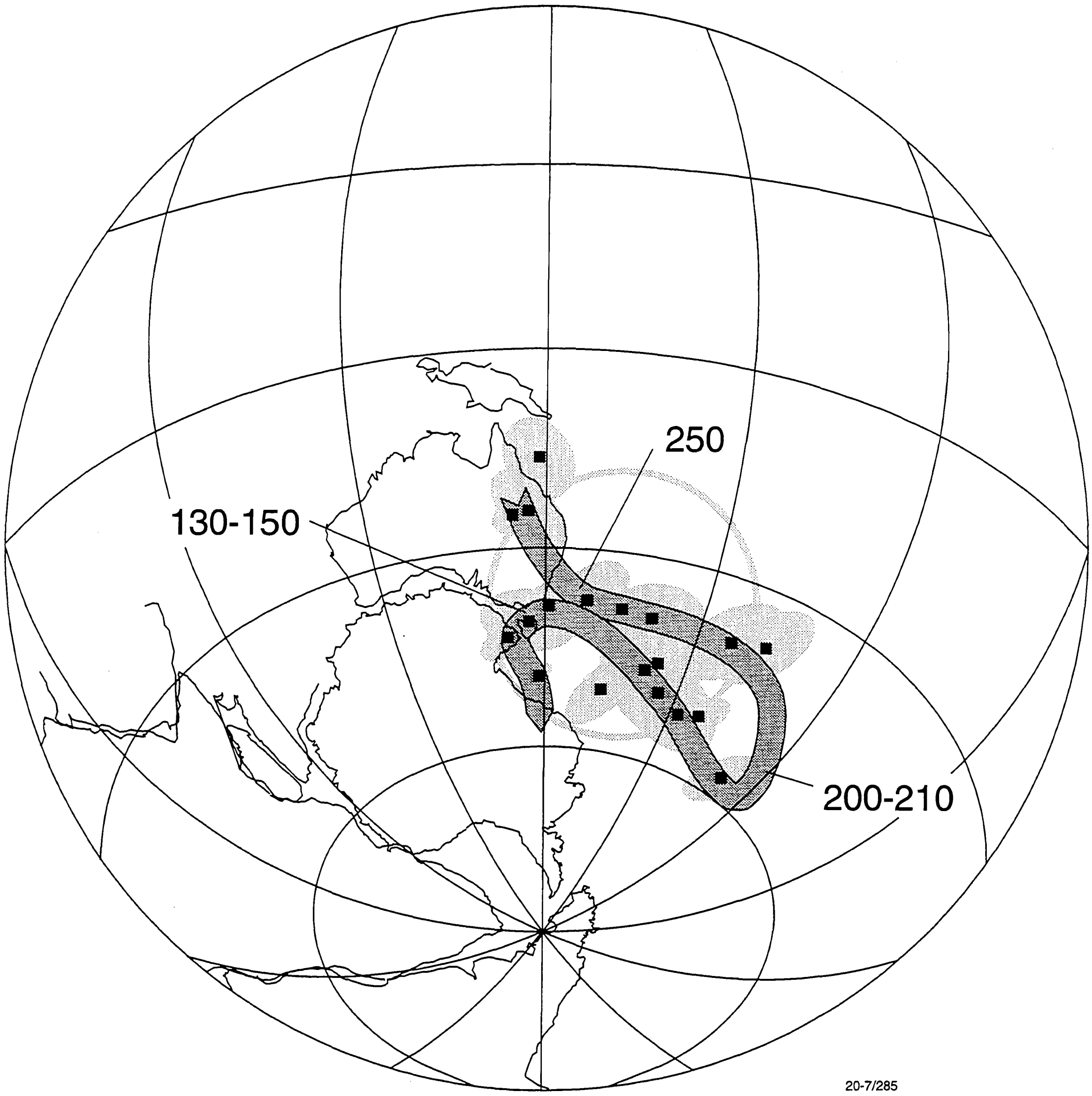


Figure 20 Indian latest Palaeozoic - Mesozoic APWP transferred to Australia. Gondwana reconstruction anchored to Australia in its present-day position

Indian APWP

The Palaeozoic part of the Indian APWP is poorly defined, but the Mesozoic and Cenozoic parts are well-established from studies on the Indian Gondwana sequence (Agarwal,1980; Klootwijk and Agarwal, unpublished) and Ninetyeast Ridge (Klootwijk et al.,1991,1992) respectively. The Early and Middle Cambrian results from India, corrected for local rotation of extrapeninsular fold belts, are in reasonable agreement within a Gondwana reconstruction with the equivalent part of the Australian APWP (compare Fig.2 with Fig.1). Other Palaeozoic data have been obtained either from the extrapeninsular fold belts, for which rotation corrections have not resulted in intelligible polepath results, or from basal Gondwana successions which may have been contaminated by overprinting related to the Deccan Trap volcanism.

Eastern Gondwana Phanerozoic polepaths

The Mesozoic part of the Indian APWP (Fig.19) shows various loops and cusps which are comparable, but not similar, to the Australia Mesozoic APWP. The path is characterised by an extensive Triassic-Jurassic loop with an apex around the Triassic/Jurassic time boundary, followed by a Jurassic/Early Cretaceous loop with an apex around the Jurassic/Cretaceous time boundary. This is followed by a cusp postdating the Rajmahal Traps result (117 Ma), a latest Cretaceous/earliest Tertiary cusp, and finally a slight inflection in the Eocene part of the path.

Loops and cusps on the Australian and the Indian APWPs

Transfer of the Indian Mesozoic APWP to Australia within a Gondwana reconstruction (Fig.20) shows general compatibility of the loop structures, but obvious mismatch in detail. The Indian Triassic-Jurassic loop is far more extensive than the Australian loop. It may well be that the apex of the loop is undefined by Australian data and that the Australian Early Jurassic results define a point on the return limb rather than the apex of the loop. The extent of the Indian loop, the implied northward movement of eastern Gondwana toward low to moderate southern latitudes, and the latest Triassic-earliest Jurassic date for its apex are in good agreement with the presence of Late Triassic reef structures on the North West Shelf (von Rad et al.,1992a; Gradstein,1992). The Indian Jurassic/Early Cretaceous loop, in contrast, is less extensive than the Australian loop and the Indian polepath may be the underdetermined path for this time interval.

The Australian and Indian Phanerozoic polepaths show good potential to relate loops and cusps in the paths to fundamental tectonic events that have affected eastern Gondwana and the Australian and Indian plates after fragmentation. However, the price to pay for virtual neglect of the Australian and Indian Mesozoic APWPs over the past fifteen years is our current inablity to date these loops and cusps with appreciable accuracy. There are good prospects to achieve greater accuracy, provided that a sustained effort is made to improve the Australian Mesozoic APWP. Australia's main source and reservoir rocks on the North West Shelf are Mesozoic in age. Interpretation of source rock and reservoir rock development may benefit greatly from proper knowledge of the geodynamic/tectonic implications of the Australian APWP. As such, further study of the Australian Mesozoic APWP should be considered a priority project. Currently available age constraints on loops and cusps on the Australian and Indian Phanerozoic APWPs are listed hereunder.

Australia ~age	India ~age	Loop/Cusp	Figure
CB/O		loop	2B
DI (Ce)		cusp	5
Ce-l, 330-335 Ma		loop	5, 13
Cl-Pe, ~300 Ma		loop	5,13
Pe-l, ~270-280 Ma		loop	5,13
~260 Ma		loop	18
~245-215 Ma	~250 Ma	cusp	18-20
~185+ Ma	210-200 Ma	loop	18-20

~140 Ma	130-150 Ma	loop	18-20
~100-115 Ma	<117-84> Ma	cusp	18,19
>60 Ma	**~70 Ma**	cusp	18,19
	~40-45 Ma	cusp	19
Tm-pl (3Ma < >12Ma)		cusp	18

PALAEOLATITUDE AND PALAEODECLINATION EVOLUTION

Palaeolatitude plots have been constructed for all continental blocks and terranes (see Klootwijk,1996e, tables 1-6) with additional construction of palaeodeclination plots for several selected fragments to emphasise rotational movement. For each continental block and terrane all individual directional results have been transferred to a central easily identifiable location, providing "normalised" palaeodeclinations and palaeoinclinations, and palaeolatitudes as derivatives thereof. Stratigraphic ages have been converted to absolute ages according to the AGSO Phanerozoic Timescale (Young and Laurie,1996). The palaeolatitude (declination) versus age plots also indicate the precision level of the palaeolatitude (declination), but do not show precision in age because stratigraphic ages and stratigraphic intervals have been represented only by representative absolute mean ages.

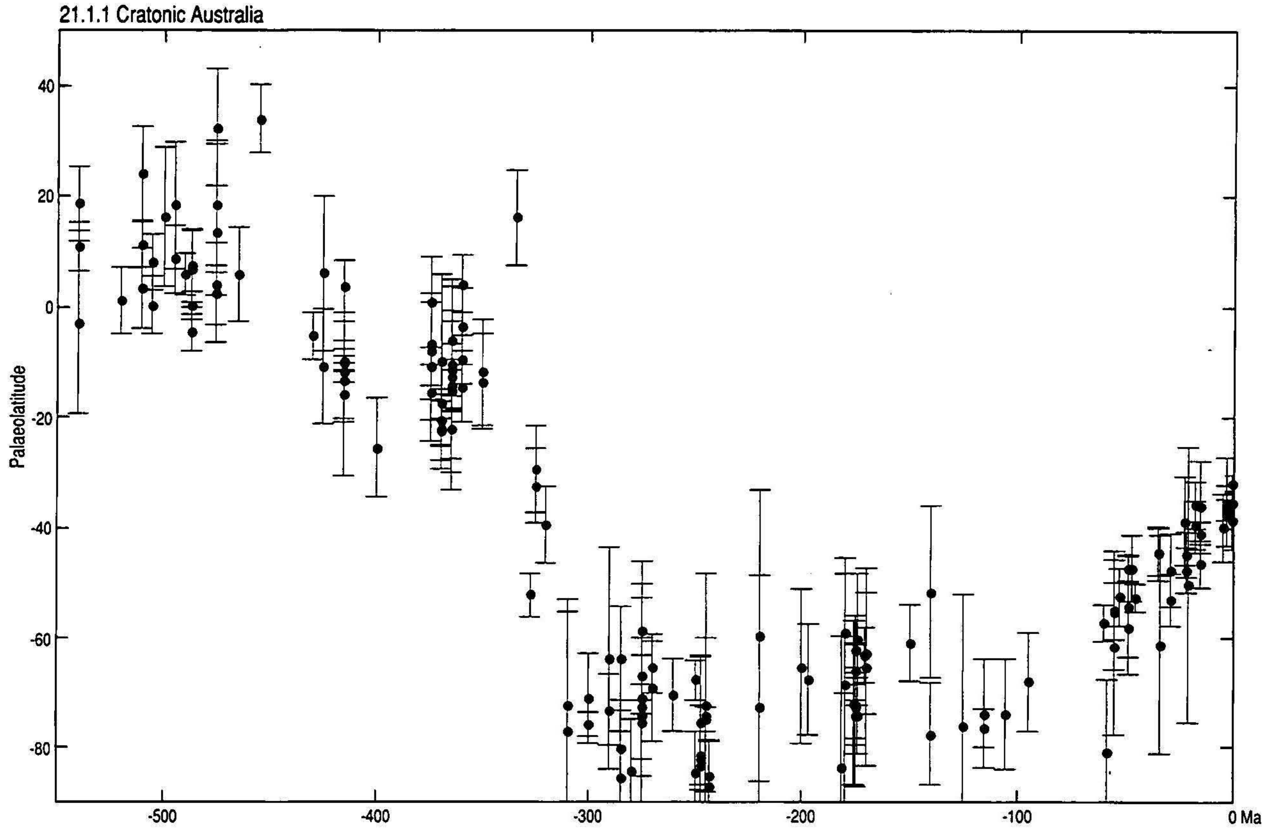
Palaeolatitude (declination) plots for all tectonic units (see Klootwijk,1996e, tables 1-6) are reproduced in Figure 21. For ease of reference, figure numbers correspond with numbers for the tables listed in Klootwijk (1996e). Features on several of the plots that are of obvious interest and relevance to Gondwana's fragmentation process are noted hereunder. Observations on general movement patterns and time constraints on fragmentations are discussed in the following chapter.

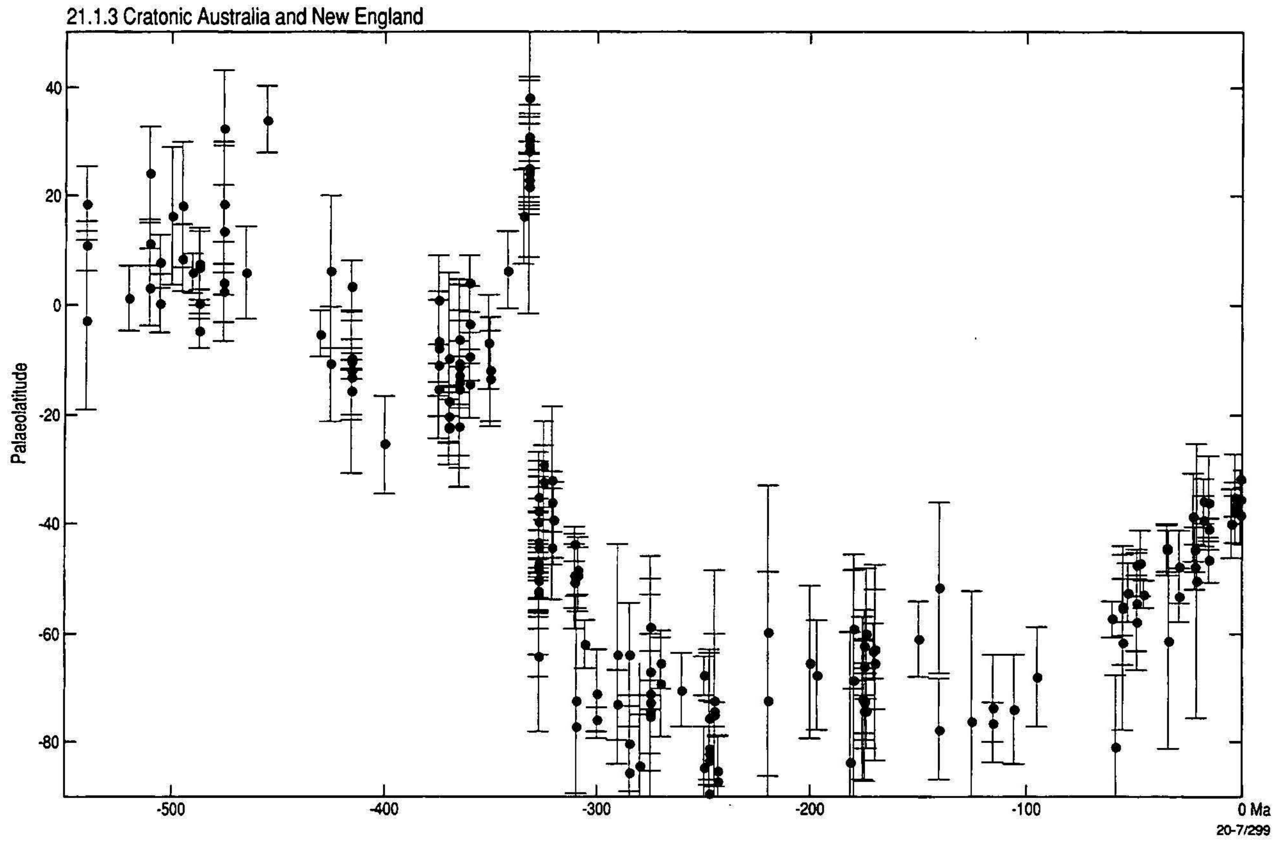
Australia

The main features of Australia's palaeolatitudinal evolution have been discussed earlier. Figure 21.1.1 shows Australia's movement according to cratonic data and Figure 21.1.3 according to combined cratonic and New England data. The figures indicate low northern latitudes (Canberra reference) during the Cambrian and Ordovician, followed by low southern latitudes during the Silurian and Devonian. The Early Carboniferous northward movement to moderate northern latitudes, indicated by the New England data (Fig.21.1.3), is supported by a northern latitude result from the Lachlan Fold Belt (Fig.21.1.1). The very fast southward movement toward southpolar latitudes during the Late Carboniferous may be followed by a minor northward excusion during the middle and Late Permian and a slightly more extensive northward excursion during the Late Triassic-Early Jurassic. Northward movement to present latitudes was proceeding during the earliest Tertiary, and may have started already in the Late Cretaceous.

Indian Subcontinent

The data from India, Pakistan and Nepal (Fig.21.1.6) indicate low southern latitudes for the Indian Subcontinent (Delhi reference) during the Early Palaeozoic and possibly also during the Middle Palaeozoic. Middle Palaeozoic data are not available. India was situated at moderate to high southern latitudes during the latest Carboniferous, may have undergone a minor northward excursion during the Permian and started on a substantial northward excursion during Early Triassic, reaching low southern


21.1.1 Cratonic Australia
Palaeolatitude
40
20
0
-20
-40
-60
-80
-500
-400
-300
-200
-100
0 Ma


21.1.3 Cratonic Australia and New England
Palaeolatitude
40
20
0
-20
-40
-60
-80
-500
-400
-300
-200
-100
0 Ma
20-7/299

21.1.6 India - Pakistan - Nepal

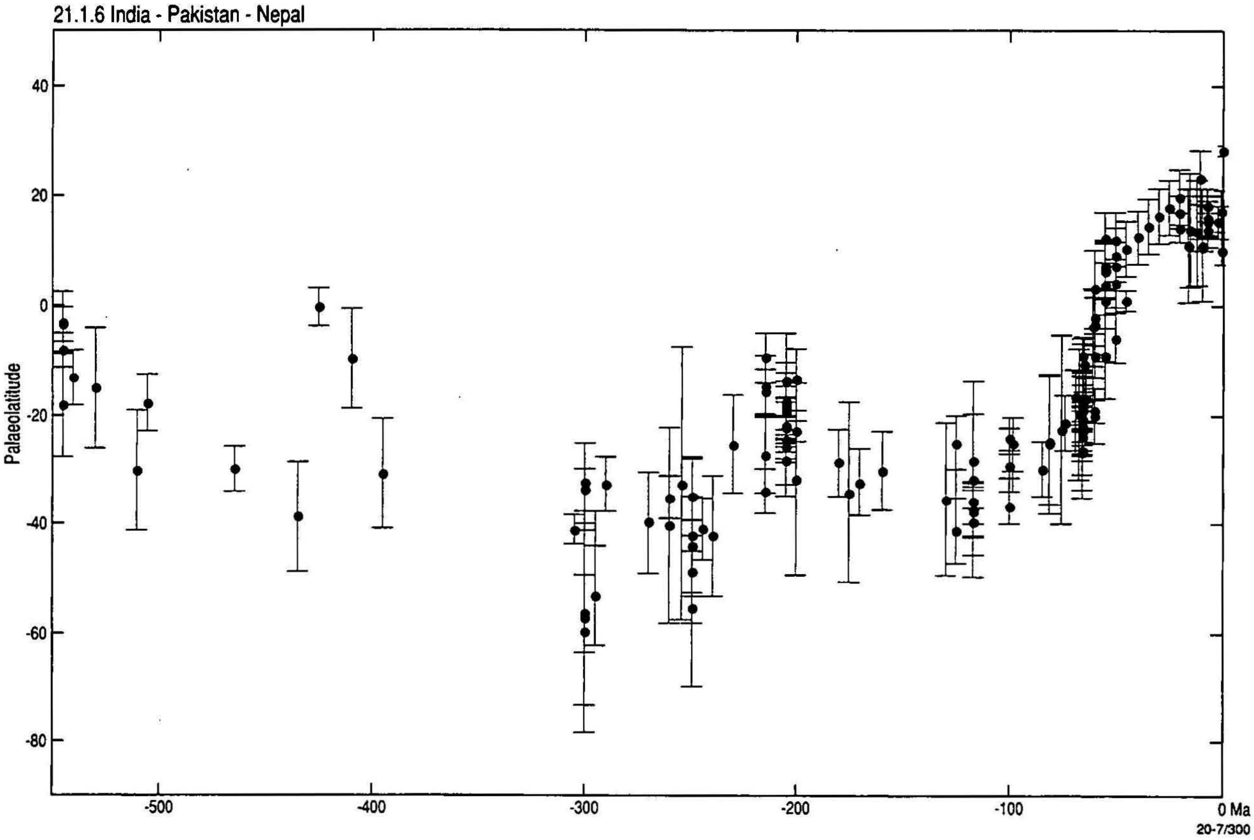


Figure 21 Phanerozoic palaeolatitudinal evolution for continental fragments and terranes according to the data listed in Klootwijk (1996e, tables 1-6). Palaeolatitude data for individual fragments and terranes have been presented for common sites as listed in Table 2. Several selected palaeodeclination plots are shown in order to complement palaeolatitude plots. Gondwana - [opposite page] 21.1.1: Australia (Canberra); 21.1.3: Australia-New England-Tamworth Belt (Armidale); [above] 21.1.6: India-Nepal-Pakistan - mean results (Delhi).

latitudes by the latest Triassic-earliest Jurassic before returning to moderate southern to tropical latitudes by the Middle Jurassic. Fast to very fast northward movement started in the Late Cretaceous.

Siberian Platform

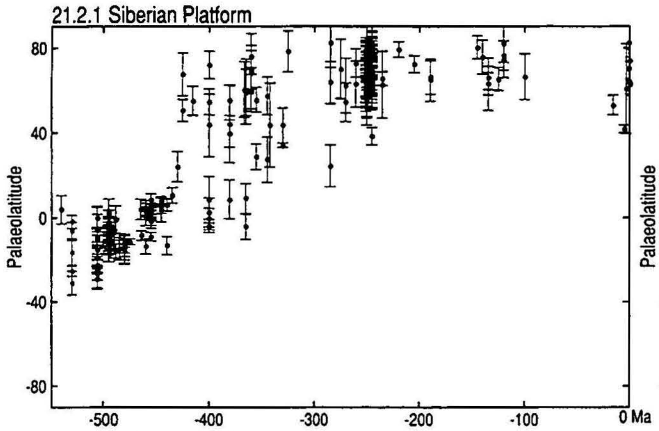
Individual data show a considerable spread in palaeolatitudes, particularly for the Middle to Late Palaeozoic (Fig.21.2.1). Compiled mean data according to Khramov and Rodionov (1980) and Khramov et al. (1981) show a gradual northward movement (Mirnyy reference) during the Palaeozoic, from low southern latitudes to northpolar latitudes (Fig.21.2.2A). It is important to realise that Siberia has undergone ~180 degrees of clockwise rotation from the Late Ordovician till Recent, and that present-day northern Siberia was south-facing during the Early Palaeozoic (Fig.21.2.2B).

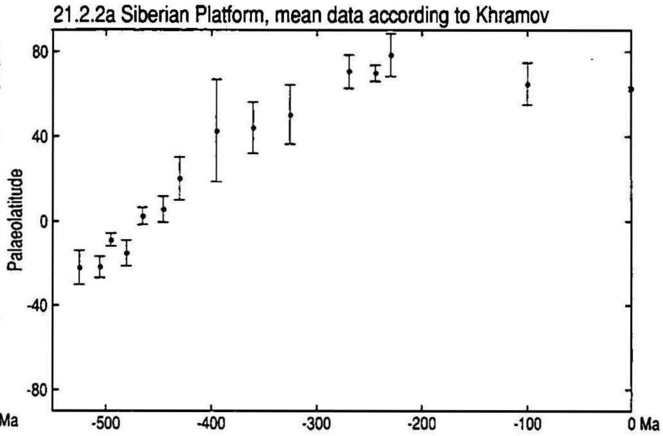
Cathaysian blocks

North China (Beijing reference) underwent a gradual northward movement during the Late Permian and Triassic from equatorial latitudes to moderate northern latitudes (Figs 21.3.1,21.3.2A), followed by a

Table 2: Common sites for palaeomagnetic data plotted in Figure 21 and listed in Klootwijk (1996e, tables 1-6)

1.1	Australia	CANBERRA	149.1E,35.3S
1.2	Australia - mean poles	CANBERRA	149.1E,35.3S
1.3	Australia/New England/Tamworth Belt	ARMIDALE	151.7E,30.5S
1.4	India/Nepal	DELHI	77.2E,28.7N
1.5	Pakistan	DELHI	77.2E,28.7N
1.6	India/Nepal/Pakistan - mean poles	DELHI	77.2E,28.7N
1.7	New Zealand	WELLINGTON	174.8E,41.3S
2.1	Siberian Platform	MIRNYY	114.0E,62.5N
2.2	Siberia - mean poles	MIRNYY	114.0E,62.5N
3.1	North China	BEIJING	116.5E,39.9N
3.2	North China mean poles (Zhao/Enkin)	BEIJING	116.5E,39.9N
3.3	Mongolia	ULAN BATOR	106.9E,47.9N
3.4	Korea	SEOUL	127.0E,37.5N
3.5	AlaShan/Hexi corridor mn poles (Zhao)	LAN-CHOU	103.8E,36.0N
3.6	South China	CANTON	113.3E,23.1N
3.7	South China mean poles (Zhao/Enkin)	CANTON	113.3E,23.1N
3.8	Indochina	PHNOM PENH	104.9E,11.6N
4.1	Altai-Sayan	NOVOKUZNETSK	87.2E,53.7N
4.2	Kazakhstan	ARAL'SK	61.7E,46.9N
4.3	Junggar	URUMCHI	87.6E,43.8N
4.4	Tarim	AKSU	80.3E,41.2N
4.5	Tarim/Junggar mean poles (Zhao-Enkin)	AKSU	80.3E,41.2N
4.6	Ferghana	FERGHANA	71.3E,40.4N
4.7	Shan-Thai-Malay	CHIANG MAI	99.0E,18.8N
4.8	Qiangtang	YAGMO	89.8E,32.8N
4.9	Lhasa	LHASA	91.2E,29.7N
4.10	Amur	KHABAROVSK	131.9E,43.1N
4.11	Turan	ASHKHABAD	58.4E,38.0N
4.12	Iran	YAZD	54.4E,31.9N
4.13	Afghanistan	KABUL	69.2E,34.5N
4.14	Kunlun	AKSU	80.3E,41.2N
4.15	Alay	GARM	70.4E,39.1N
5.1	Taimyr	KHATANGA	102.5E,72.0N
5.2	Kolyma	ZYRYANKA	150.8E,65.7N
5.3	Khatyrka/Maynitska	KHATYRKA	175.3E,62.1N
5.4	Barentz-Pechoria	PECHORA	57.3E,65.2N
5.5	Komandori	NIKOLSKAYA	166.1E,55.2N
6.1	Wrangell	McCARTHY	143.0W,61.4N
6.2	Stikine	HAZELTON	127.6W,55.3N
6.3	Alexander	PETERSBURG	133.0W,56.8N
6.4	Quesnell	KAMLOOP	120.4W,50.6N
6.5	Cache Creek	JAKES CORNER	134.0W,60.3n
6.6	Peninsula	ANCHORAGE	150.0W,61.2N
6.7	Porcupine	FORT YUKON	145.3W,66.6N
6.8	Eastern Klamath	KLAMATH FALLS	121.8W,42.2N
6.9	Chugagh-Prince William	CORDOVA	145.7W,60.5N
6.10	Crescent	VICTORIA	123.4W,48.4N
6.11	Decatur	SEATTLE	122.3W,47.6N
6.12	Guerrero	MANZANILLO	104.3W,19.0N
6.13	Maya	TONALA	93.7W,16.1N
6.14	Nicasio	SAN FRANCISCO	122.4W,37.8N
6.15	Salinia	SANTA CRUZ	122.1W,37.0N
6.16	San Nicolas	SANTA BARBARA	119.7W,34.4N
6.17	Santa Ana	SAN DIEGO	117.2W,32.8N
6.18	Slide Mountain	WATSON LAKE	128.8W,60.1N
6.19	Stanley Mountain	SANTA MARIA	120.4W,35.0N
6.20	Vizcaino	SAN DIEGO	117.2W,32.7N





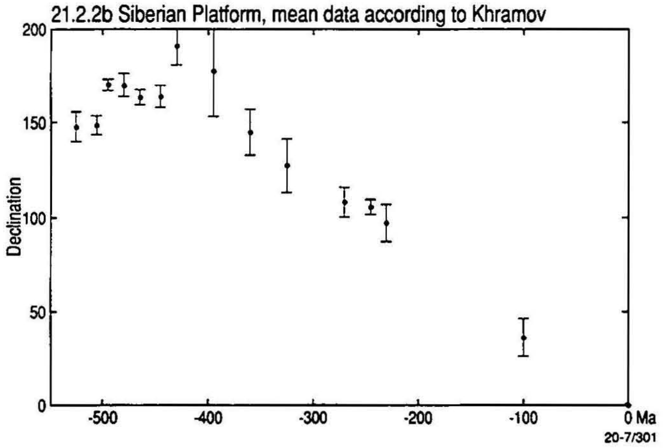
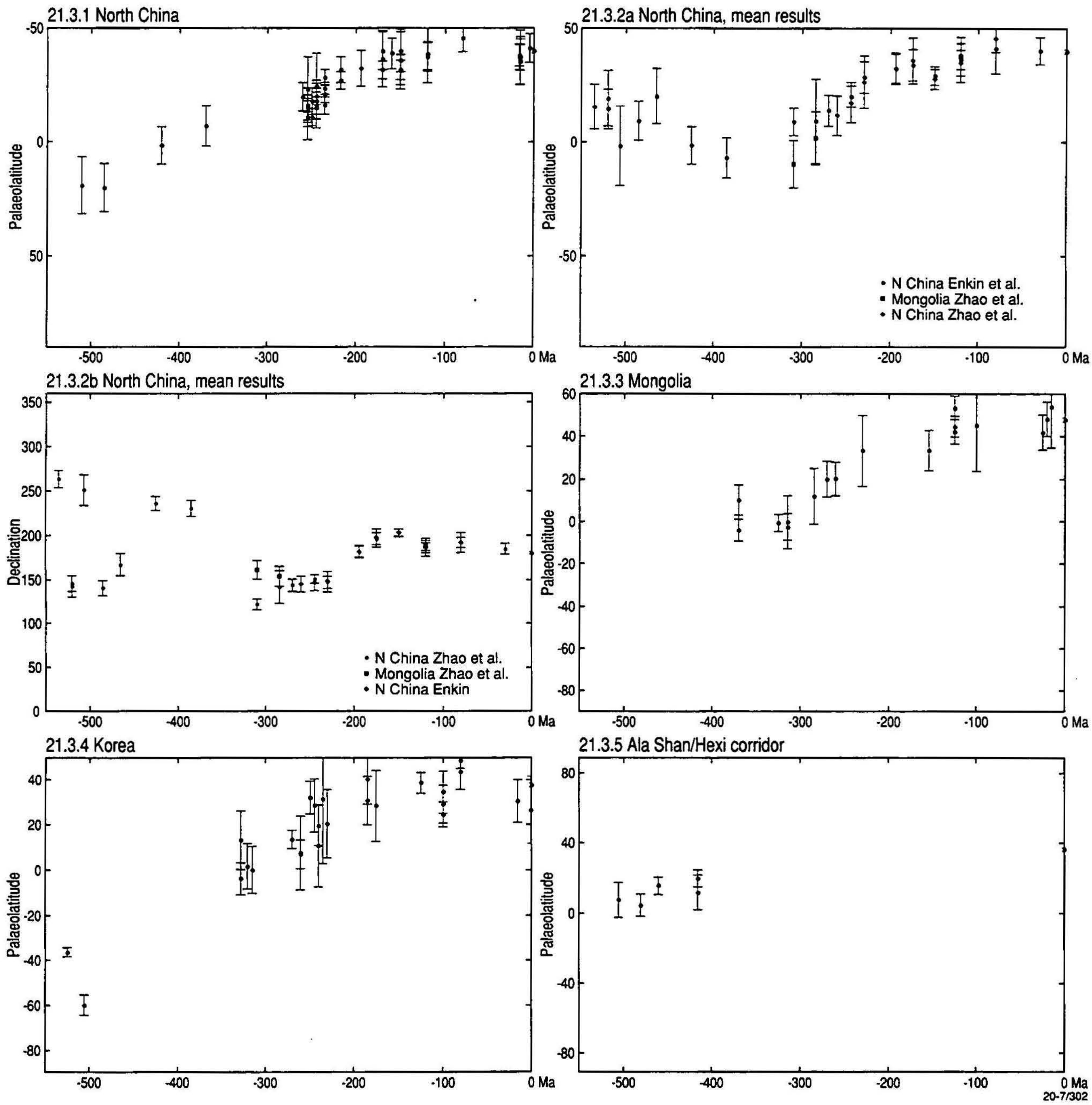


Figure 21 Continued. Laurasia - 21.2.1: Siberian Platform (Mirnyy); 21.2.2A: Siberia - mean palaeolatitude results (Mirnyy); 21.2.2B: Siberia - mean palaeodeclination results (Mirnyy);

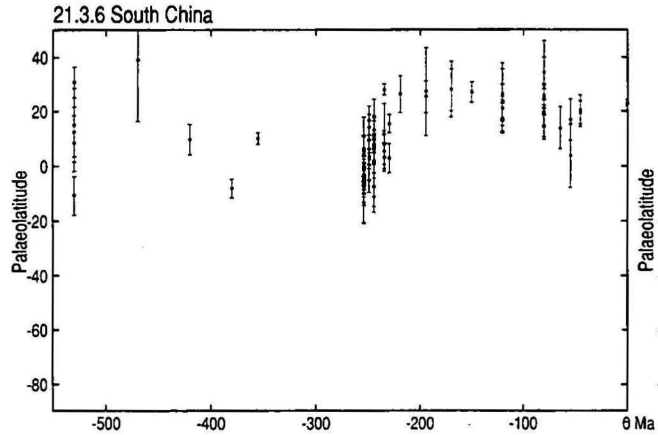
considerable counterclockwise rotation during the Late Triassic-Early Jurassic (Fig.21.3.2B). Early and Middle Palaeozoic data show low latitude positions, but the data suffer from the Palaeozoic polarity uncertainty common to all Cathaysian continents. Zhao et al.'s (1996; Fig.21.3.2A) interpretation of polarities notably differs from the interpretation for some results advocated here (Fig.21.3.1).

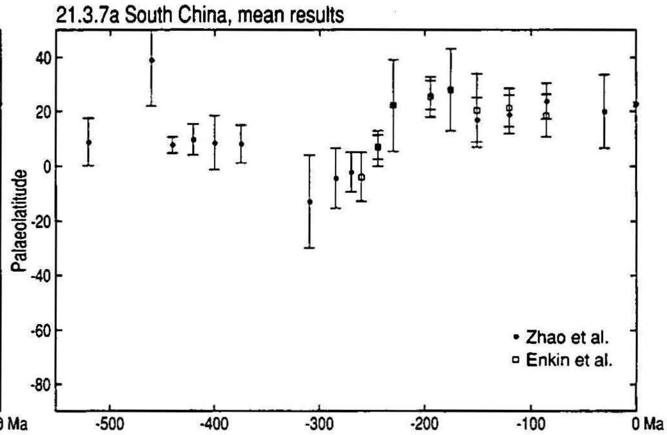
The *Mongolian* palaeolatitude pattern (Fig.21.3.3: Ulan Bator reference) and the *Korean* pattern (Fig.21.3.4: Seoul reference) show a Permian-Triassic northward movement similar to the North China block. The Early and Middle Palaeozoic results from the *Ala Shan-Hexi corridor* (Lan-Chou reference) indicate low (northern) palaeolatitudes that are in good agreement with North China (Fig.21.3.5).

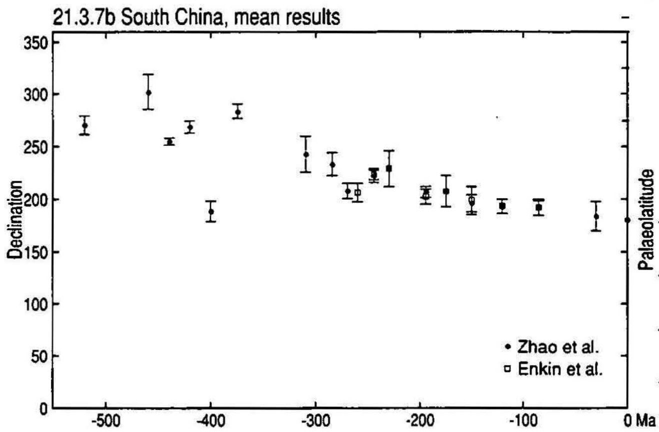
South China's palaeolatitudinal evolution (Fig.21.3.6, 21.3.7A: Canton reference) is comparable to North China. Both show low northern latitudes during the Early and Middle Palaeozoic, and ~40 degrees northward movement during the Permian and Triassic. The South China data suggest a limited southward movement during the Late Palaeozoic. This movement may have been associated with eastern Gondwana's southward movement, but has not been identified in the North China data. South

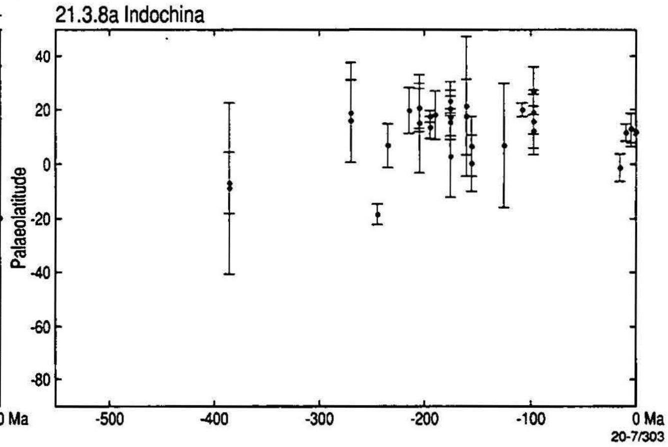


China's declination pattern (Fig.21.3.7.B) shows a gradual counterclockwise rotation during the Palaeozoic that has been observed also for the North China block. The subsequent Late Triassic-Early Jurassic minor clockwise rotation contrasts, however, with the slightly more extensive Late Triassic-Early Jurassic counterclockwise rotation of the North China block.









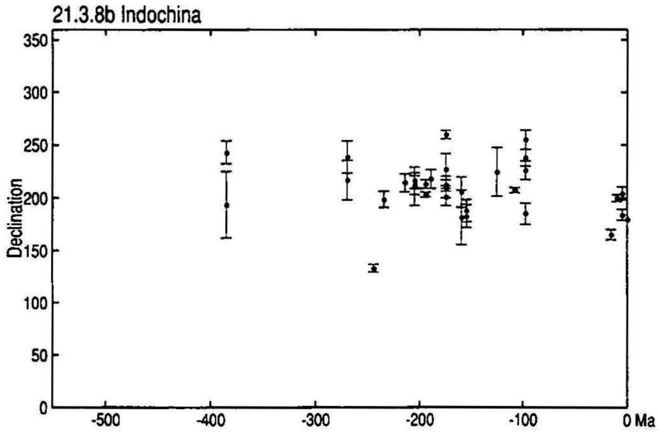
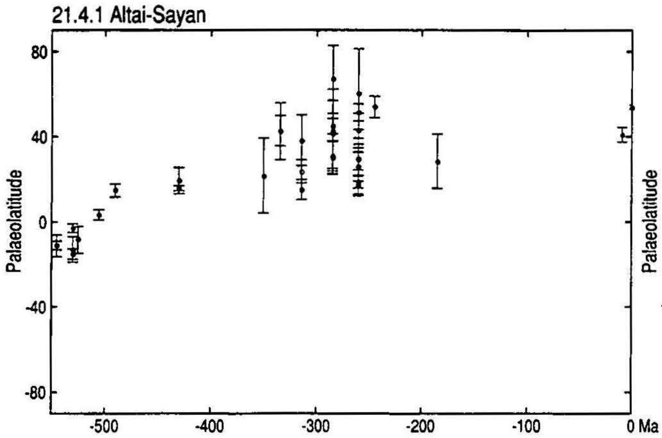


Figure 21 Continued. Cathaysia - [opposite page] 21.3.1: North China (Beijing); 21.3.2A North China - mean palaeolatitude results (Beijing); 21.3.2B North China - mean palaeodeclination results (Beijing); 21.3.3: Mongolia (Ulan Bator); 21.3.4: Korea (Seoul); 21.3.5: Ala Shan-Hexi corridor mean poles (Lan-Chou);[above] 21.3.6: South China (Canton); 21.3.7A: South China - mean palaeolatitude results (Canton); 21.3.7B: South China - mean palaeodeclination results (Canton); 21.3.8A: Indochina - palaeolatitude results (Phnom Penh); 21.3.8B: Indochina - palaeodeclination results (Phnom Penh).

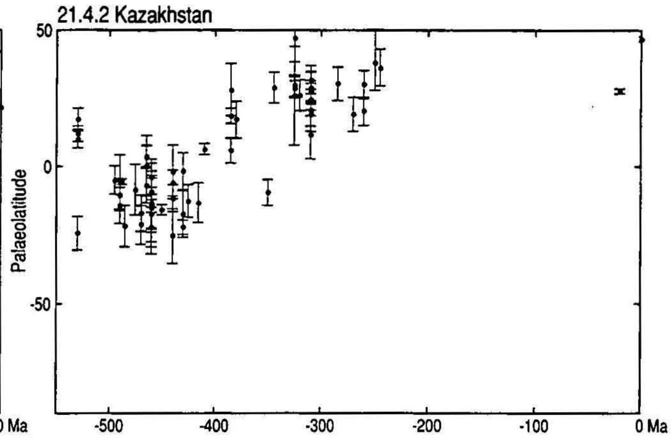
Figure 21 Continued, following two pages. South Asia - 21.4.1: [left page] Altai-Sayan (Novokuznetsk); 21.4.2: Kazakhstan (Aral'sk); 21.4.3: Junggar (Urumchi); 21.4.4: Tarim (Aksu); 21.4.5A Tarim-Junggar - mean palaeolatitude results (Aksu); 21.4.5B Tarim - mean palaeodeclination results, Late Palaeozoic clockwise rotation (Aksu); 21.4.5C Tarim - mean palaeodeclination results, Late Palaeozoic counterclockwise rotation (Aksu); 21.4.6: Ferghana (Ferghana); [right page] 21.4.7: Shan-Thai-Malay (Chiang Mai); 21.4.8: Qiangtang (Yagmo); 21.4.9: Lhasa (Lhasa); 21.4.10 Amur (Khabarovsk); 21.4.11: Turan (Ashkhabad); 21.4.12: Iran (Yazd); 21..4.13: Afghanistan (Kabul); 21.4.14: Kunlun (Aksu).

Palaeolatitude and palaeodeclination evolution

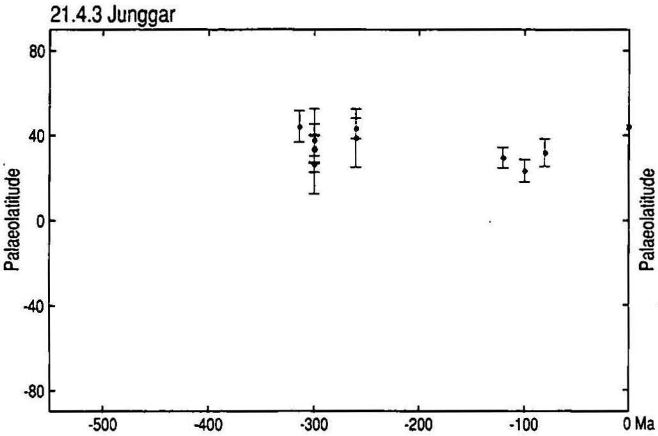
21.4.1 Altai-Sayan



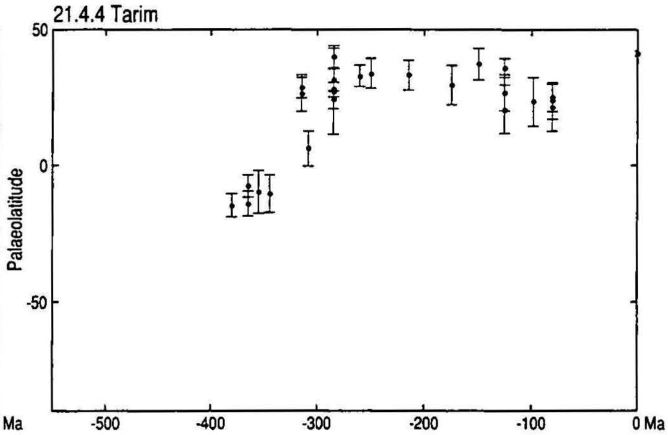
21.4.2 Kazakhstan



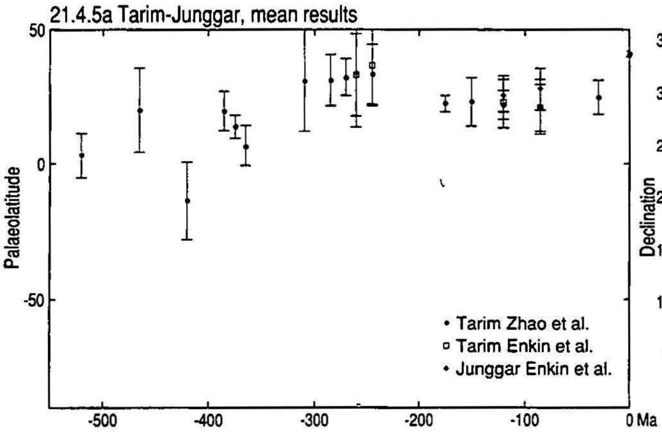
21.4.3 Junggar



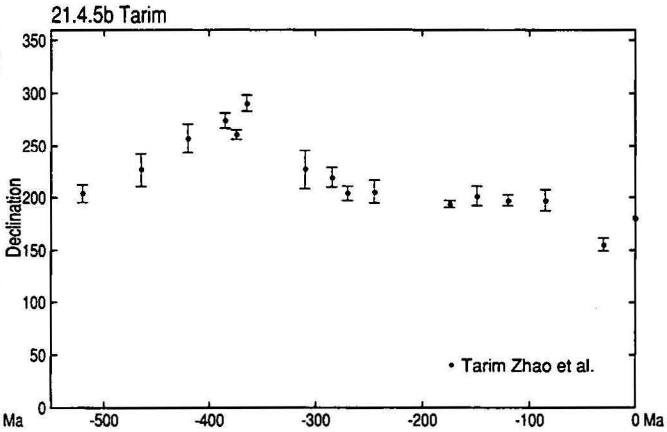
21.4.4 Tarim



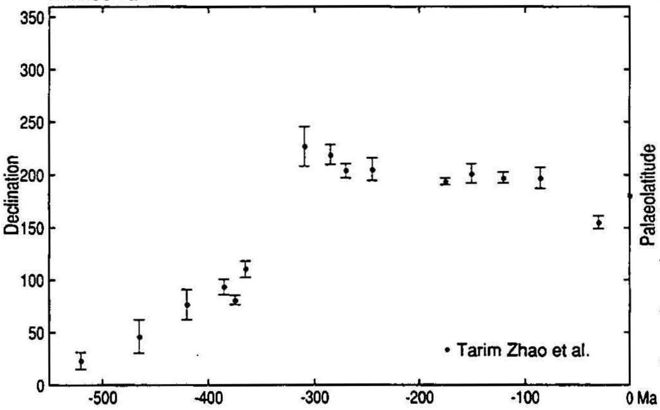
21.4.5a Tarim-Junggar, mean results



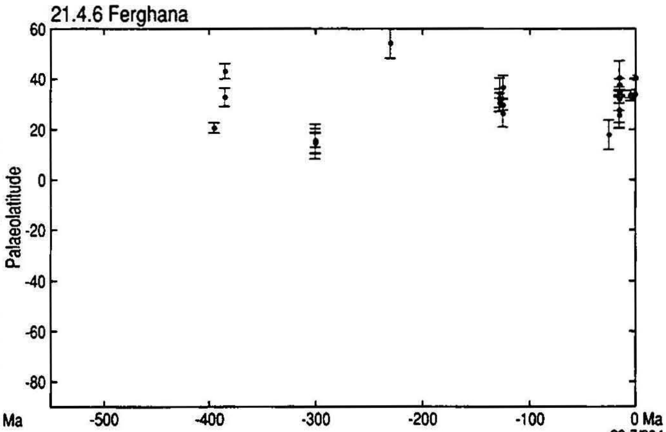
21.4.5b Tarim



21.4.5c Tarim



21.4.6 Ferghana



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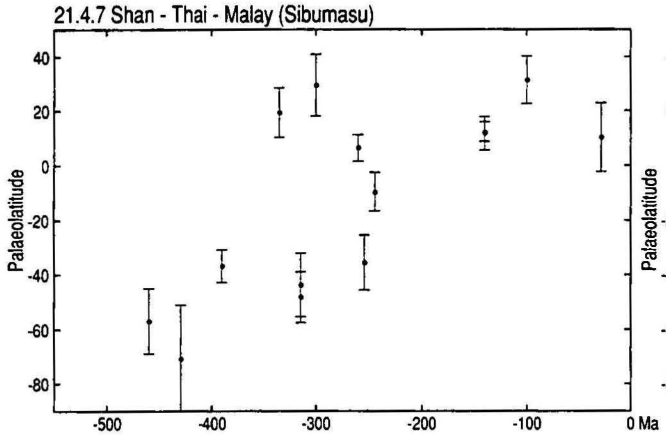
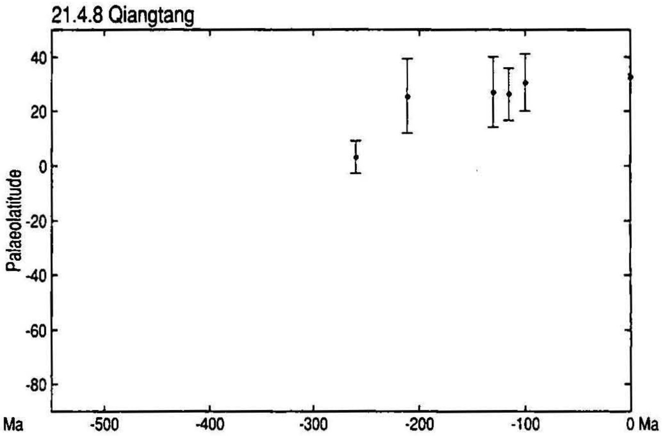
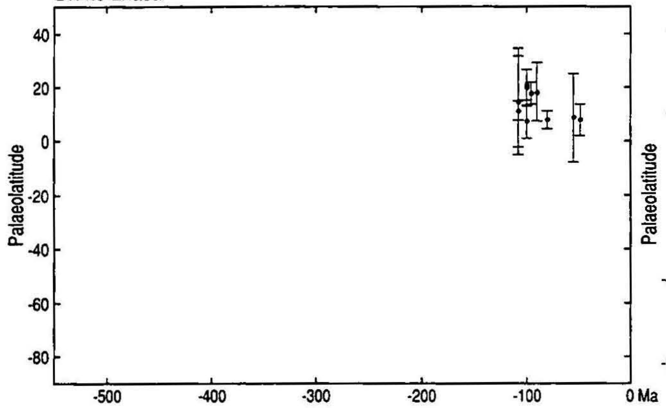
21.4.7 Shan - Thai - Malay (Sibumasu)



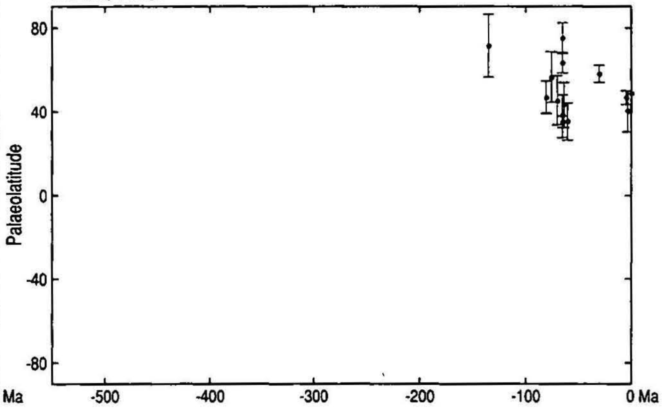
21.4.8 Qiangtang



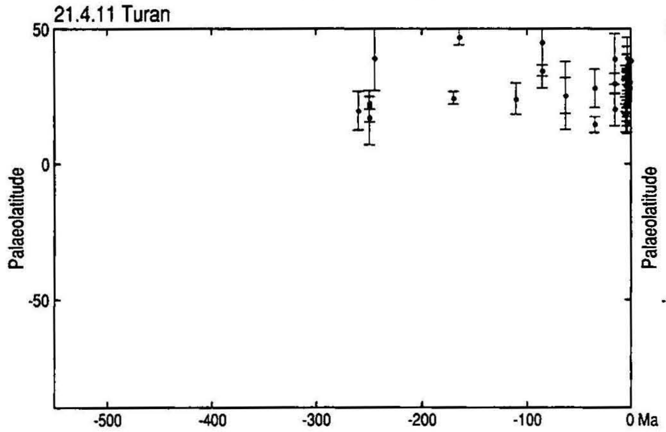
21.4.9 Lhasa



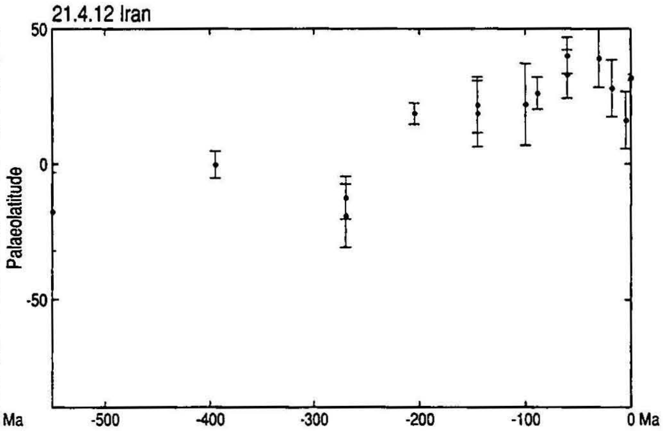
21.4.10 Amur



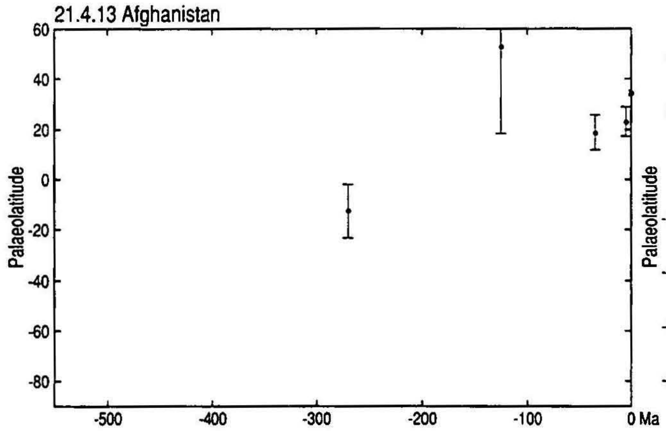
21.4.11 Turan



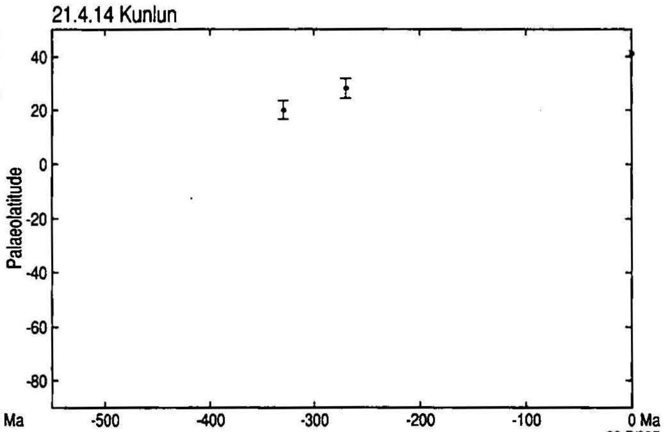
21.4.12 Iran



21.4.13 Afghanistan



21.4.14 Kunlun



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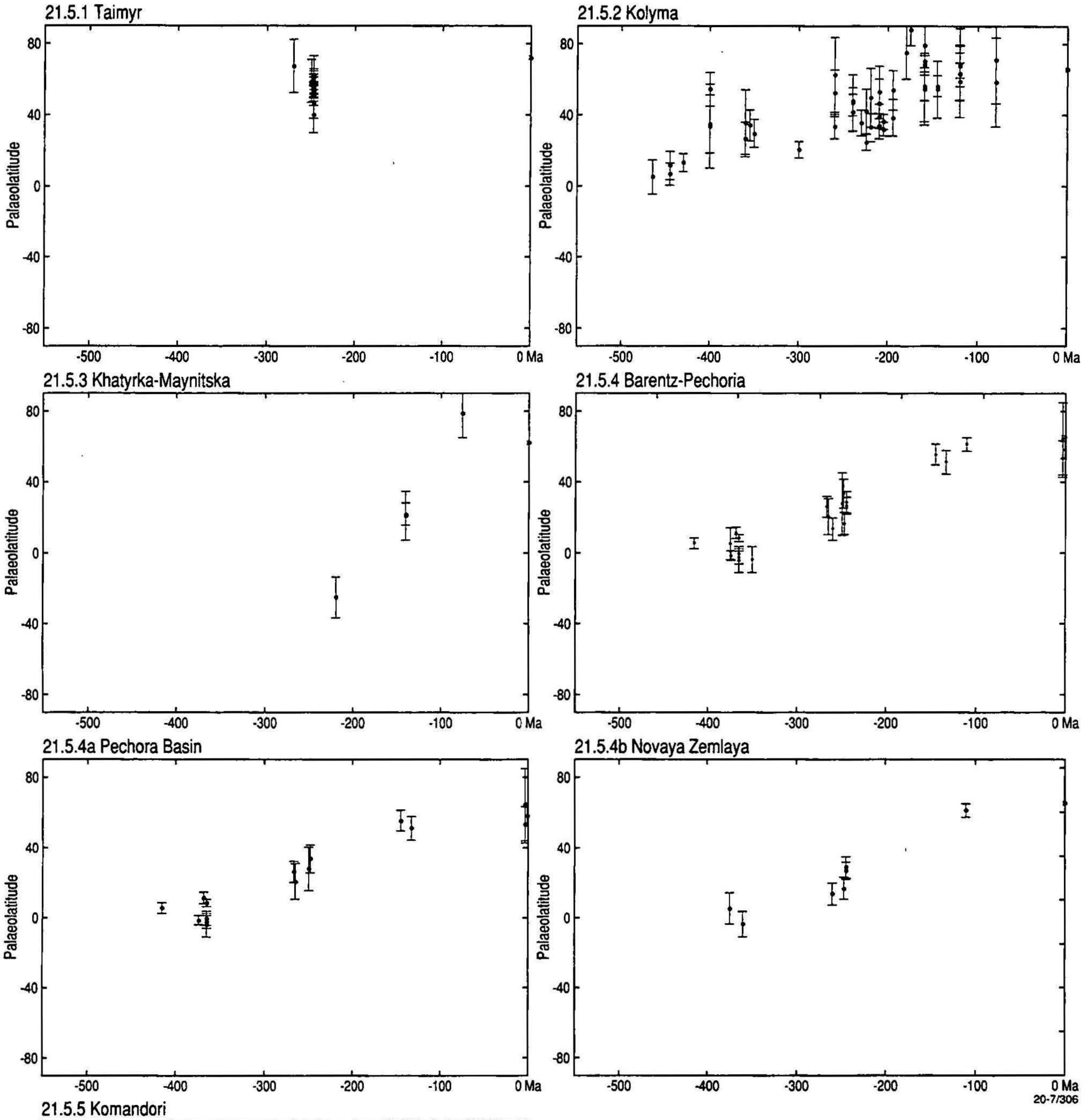


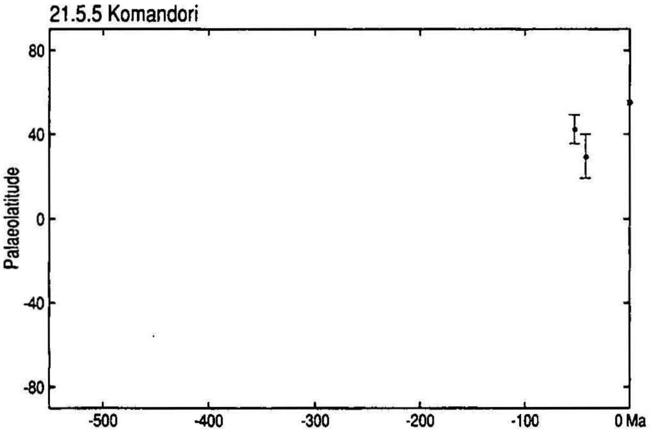


Figure 21 Continued. Northeastern and Northern Russia 21.5.1: Taimyr (Khatanga); 21.5.2: Kolyma (Zyryanka); 21.5.3: Khatyrka-Maynitska (Khatyrka); 21.5.4: Barentz-Pechoria (Pechora); 21.5.4A: Pechoria Basin (Pechora); 21.5.4B: Novaya-Zemlaya (Pechora); 21.5.5: Komandori (Nikolskaya).

Indochina's Palaeozoic data are limited to Early Devonian results and indicate a low southern latitude (Fig.21.3.8A: Phnom Penh reference). Triassic results indicate ~40 degrees northward movement, comparable to South China, but the general palaeolatitude pattern is somewhat distorted by several Permian results that are probably of overprint origin. Declination data show virtual absence of rotational movement (Fig.21.3.8B).

South Asian terranes

The *Altai-Sayan's* palaeolatitude pattern (Fig.21.4.1: Novokuznetsk reference) shows considerable northward movement during the Palaeozoic. Timing, magnitude and latitudes of the movement pattern are comparable to the pattern for the Siberian Platform (Fig.21.2.2A), indicating corresponding movements without obvious convergence.

The *Kazakhstan* pattern (Fig.21.4.2: Aral'sk reference) indicates fast northward movement over about 50 degrees of latitude during the Early Devonian, and virtually no further latitudinal movement thereafter.

The *Junggar* pattern (Fig.21.4.3: Urumchi reference) is limited to post-Variscan results. The pattern shows a rather constant latitude, but with a slight southward movement during the Late Mesozoic. Integration of the Junggar data with the Tarim data is shown in Figure 17.

The *Tarim* pattern (Fig.21.4.4: Aksu reference) is more eventful, although slightly complicated by the polarity uncertainty of pre-Variscan results that is common to all Cathaysian continents. The southern hemisphere interpretation (Fig.21.4.4), often followed in Russian studies (e.g. Biske et al.,1993; Biske,1995), implies about 40 to 50 degrees of northward movement and a substantial counterclockwise rotation of the Tarim block during the Visean (Fig.21.4.5C). The northern hemisphere option, often followed in Chinese studies (e.g., Zhao et al.,1996) indicates a northward movement of lesser magnitude and less well constrained in time (Fig.21.4.5A), with clockwise rotation (Fig.21.4.5B).

There is no obvious movement trend in the *Ferghana* pattern (Fig.21.4.6: Ferghana reference). Palaeozoic and Early Mesozoic data may have been affected by overprinting.

The *Shan-Thai-Malay (Sibumasu)* pattern (Fig.21.4.7: Chiang Mai reference) is complicated by obvious overprinting. The results yielding southern latitudes, intuitively-judged more reliable, indicate a considerable northward movement during the latest Permian-Early Triassic with further northward movement thereafter.

The *Qiangtang* pattern (Fig.21.4.8: Yagmo reference) suggests a latest Permian-Triassic northward movement, not unlike the movement pattern for the Shan-Thai-Malay block (Fig.21.4.7) which represents its eastern continuation.

The *Lhasa* pattern (Fig.21.4.9: Lhasa reference) is limited to Cretaceous results that show a low northern latitude.

The *Amur* pattern (Fig.21.4.10: Khabarovsk reference) is confined to Cretaceous and Tertiary results. Their latitudinal spread suggests reliability problems.

Palaeolatitude and palaeodeclination evolution

The *Turan* pattern (Fig.21.4.11: Ashkabad reference) is uneventful and indicates virtual absence of latitudinal movement from the Permian onward.

The few Early and Middle Palaeozoic results from *Iran* (Fig.21.4.12: Yazd reference) indicate equatorial to low palaeolatitudes comparable to other Gondwana fragments. The low southern latitude for the late Early Permian leaves open the possibility of a preceding Late Palaeozoic southward movement as part of Gondwana. The moderately northern latest Triassic position indicates an about 40 degrees northward movement in the intervening period, which may be indicative for Cimmerian dispersion.

The limited data for *Afghanistan* (Fig.21.4.13: Kabul reference) can be interpreted in further support for Cimmerian dispersion.

The *Kunlun* pattern (Fig.21.4.14) is limited and uneventful.

Northeast and North Russian terranes

The *Taimyr* results (Fig.21.5.1: Khatanga reference) are confined to the Late Permian and Early Triassic and are representative for the more southern part of the Taimyr region only. The results show little latitudinal movement with respect to their present position, in agreement with the palaeolatitude pattern for the Siberian Platform.

The *Kolyma (Omolon)* data (Fig.21.5.2: Zyryanka reference) indicate gradual northward movement from an equatorial Ordvocian position to Jurassic and subsequent positions at high northern latitudes.

The *Khatyrka-Maynitska* pattern (Fig.21.5.3: Khatyrka reference) shows a very extensive northward movement over about 100 degrees of latitude during the Jurassic and Cretaceous. The pattern is, however, based on few data only and needs further confirmation.

The *Barentz-Pechoria* pattern (Fig.21.5.4: Pechora reference) shows gradual northward movement from an equatorial Devonian position to a Cretaceous position at about 60 degrees North. The pattern shows similarities with the Siberian Platform pattern. Separate representation of data for the *Pechora Basin* proper (Fig.21.5.4A) and for the *Novaya Zemlaya* region of suspect exotic origin (Fig.21.5.4B) shows essentialy the same movement pattern.

The *Komandori* data (Fig.21.5.5: Nikolskaya reference) are confined to the Tertiary and are uneventful.

North American terranes

Data from the *Porcupine* terrane (Fig.21.6.1: Fort Yukon reference) are limited to Early to middle Tertiary overprints and indicate the absence of significant movements thereafter.

The *Wrangell* pattern (Fig.21.6.2: McCarthy reference) indicates a very extensive northward movement during a short period in the latest Triassic-earliest Jurassic. The terrane moved from an about 10 degrees South position during the Permian and Triassic, to an about 60-70 degrees North position, where it has remained from the Late Jurassic onwards.

Data from the *Peninsula* terrane (Fig.21.6.3: Anchorage reference) are limited to the latest Cretaceous and Cenozoic and indicate no significant movement.

Data for the Chugagh-Prince William terrane (Fig.21.6.4: Cordova reference) are limited to the Tertiary and show no evidence for latitudinal change.

Data from the *Cache Creek* terrane (Fig.21.6.5: Jakes Corner reference) are limited to Late Triassic to Middle Jurassic overprints, indicating a 30 degrees North position, with no further constraints on the timing of northward movement toward the terrane's present position at about 60 degrees North.

The palaeolattitude pattern for the *Slide Mountain* terrane (Fig.21.6.6: Watson Lake reference) indicates substantial northward movement from an equatorial latest Carboniferous position to about 50 degrees North in the Middle Jurassic and about 60 degrees North during the late Early Cretaceous.

The *Alexander* terrane (Fig.21.6.7: Petersburg reference) shows equatorial to low northern positions during the Middle and Late Palaeozoic with northward movement over about 40 degrees of latitude sometime during the Permian to Late Triassic.

The *Stikine* terrane (Fig.21.6.8: Hazelton reference) shows northward movement over about 30 degrees during the Jurassic and possibly the earliest Cretaceous.

The *Quesnell* terrane (Fig.21.6.9: Kamloop reference) suggests northward movement over about 30 degrees sometime during the Cretaceous or Tertiary.

Data for the *Crescent* terrane (Fig.21.6.10: Victoria reference) are limited to the Tertiary and show no evidence for latitudinal change.

The pattern for the *Decatur* terrane (Fig.21.6.11: Seattle reference) suggests about 60 degrees northward movement during the Early-to-Late Cretaceous, but the data are limited and need further confirmation.

The *Eastern Klamath* terrane (Fig.21.6.12: Klamath Falls reference) shows about 20 degrees northward movement during the Early Jurassic.

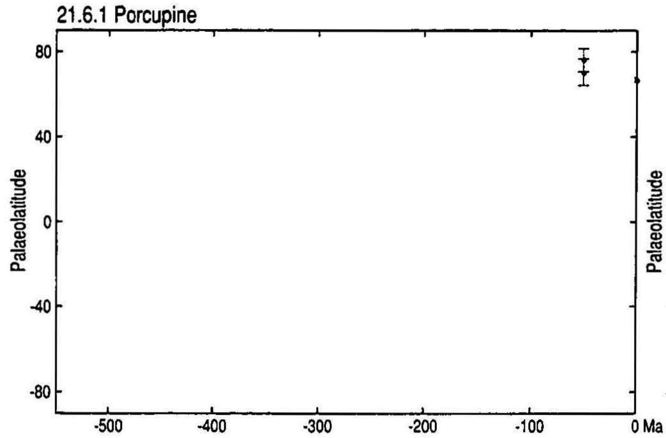
The palaeolatitude patterns for the *Nicasio* (Fig.21.6.13: San Francisco reference), *Salinia* (Fig.21.6.14: Santa Cruz reference) and *San Nicolas* (Fig.21.6.16: Santa Barbara reference) terranes indicate absence of latitudinal movement for the Cretaceous and Tertiary.

The *Stanley Mountain* terrane (Fig.21.6.15: Santa Maria reference) has undergone an about 50 degrees northward movement from the Late Jurassic onwards.

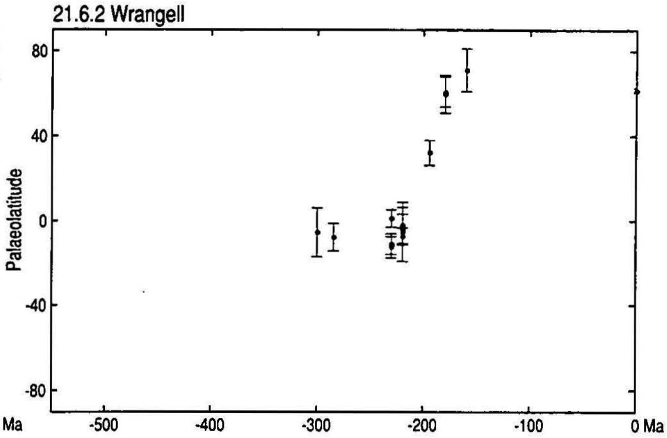
The pattern for the *Santa Ana* terrane (Fig.21.6.17: San Diego reference) indicates an about 30 degrees northward movement between the Middle Jurassic and late Early Cretaceous with constant latitude thereafter.

The palaeolatitude data for the *Vizcaino* terrane (Fig.21.6.18: San Diego reference) are restricted to the Late Cretaceous and show absence of latitudinal change thereafter.

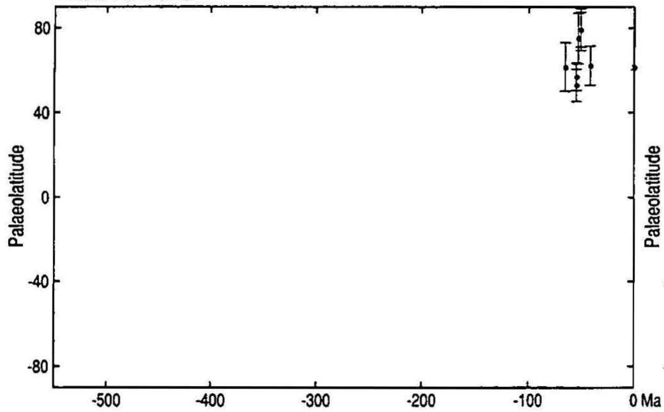
21.6.1 Porcupine



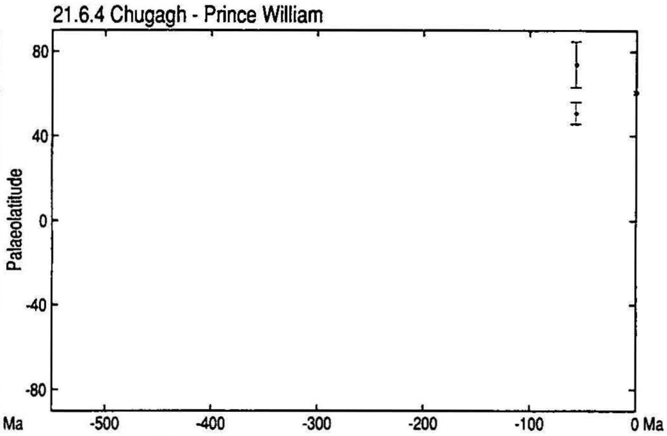
21.6.2 Wrangell



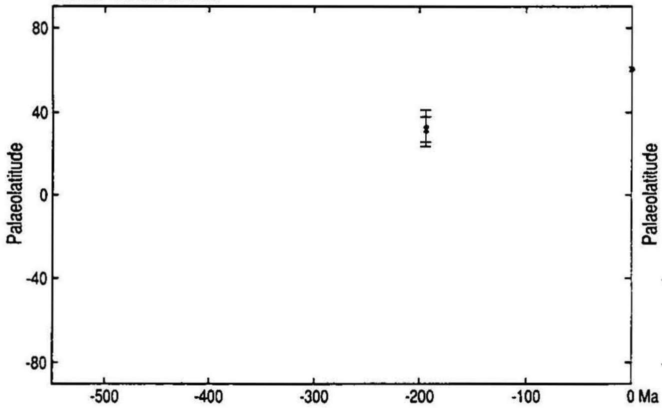
21.6.3 Peninsula



21.6.4 Chugagh - Prince William



21.6.5 Cache Creek



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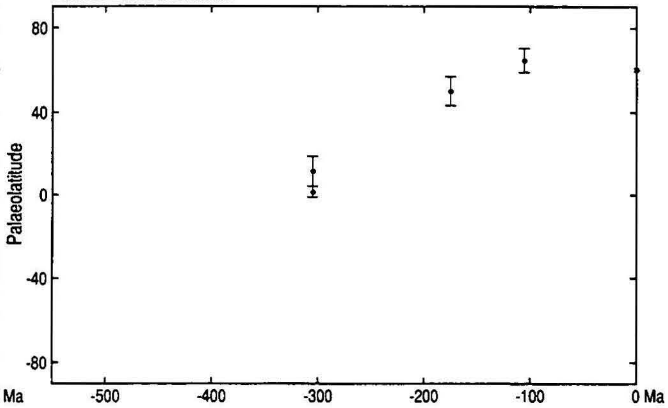
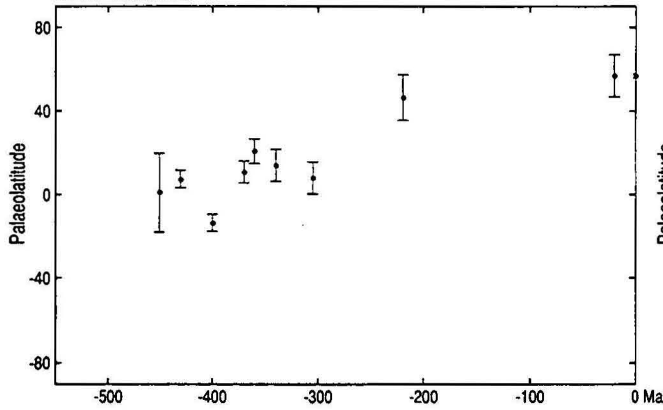


21.6.7 Alexander



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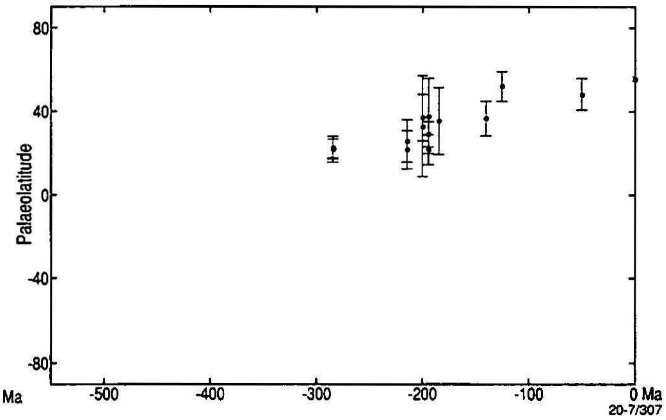

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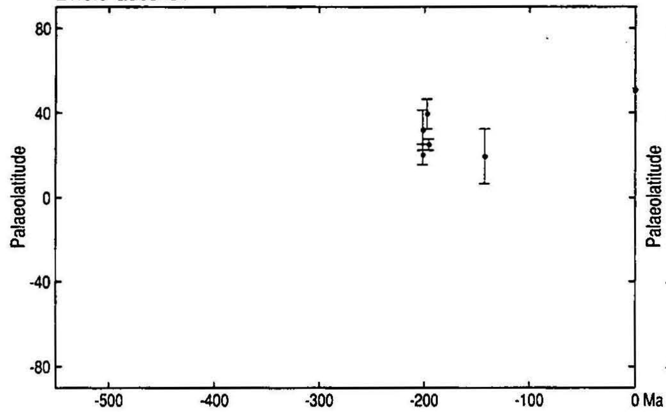
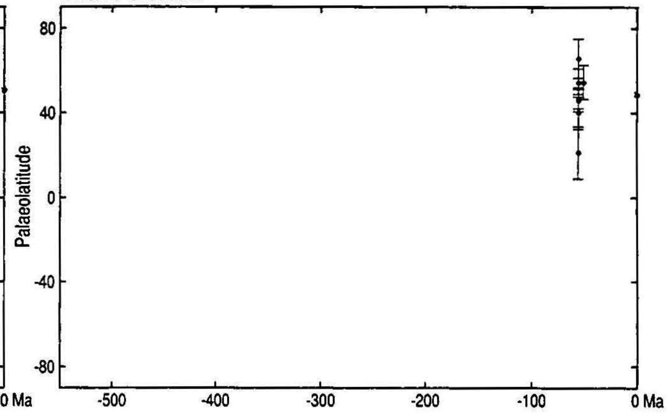
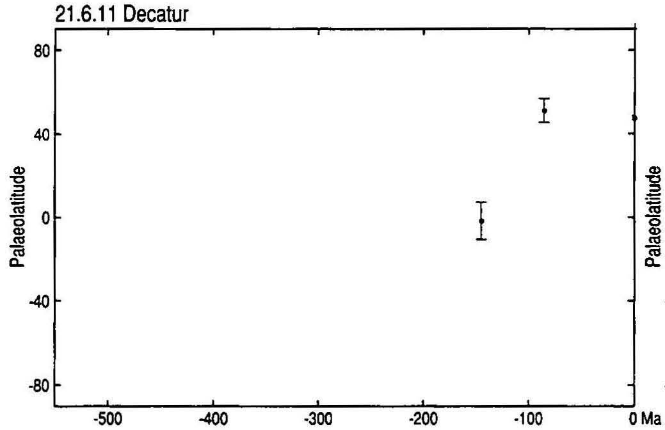
21.6.9 Quesnell



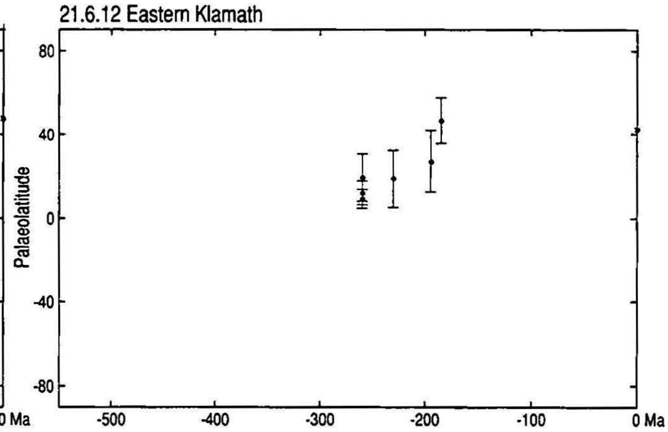
21.6.10 Crescent



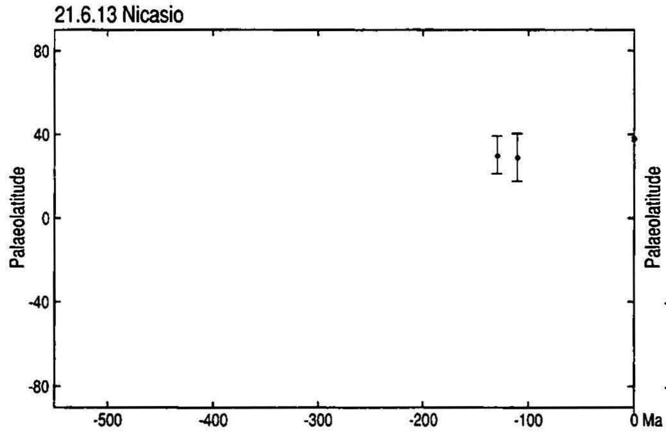
21.6.11 Decatur



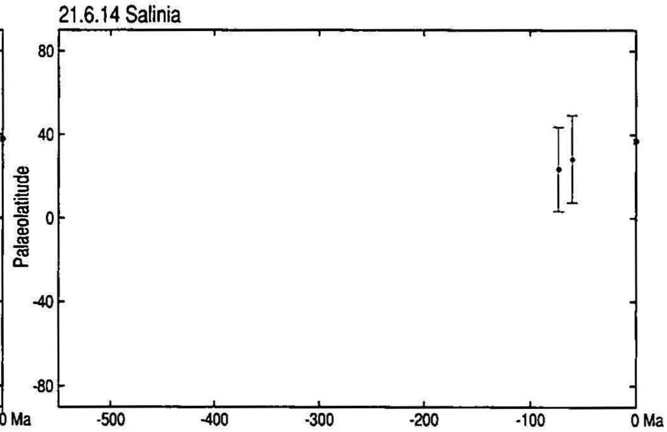
21.6.12 Eastern Klamath



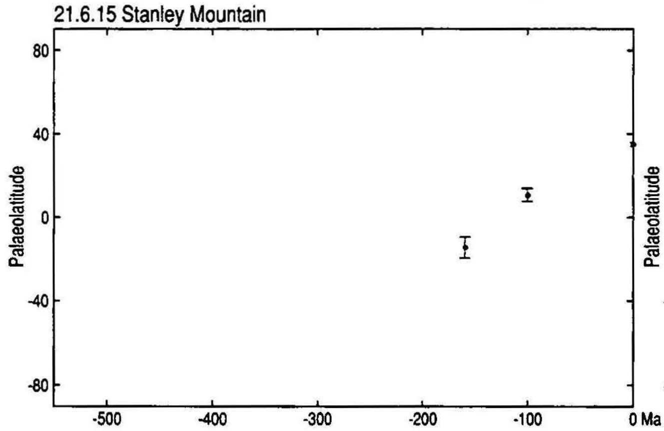
21.6.13 Nicasio



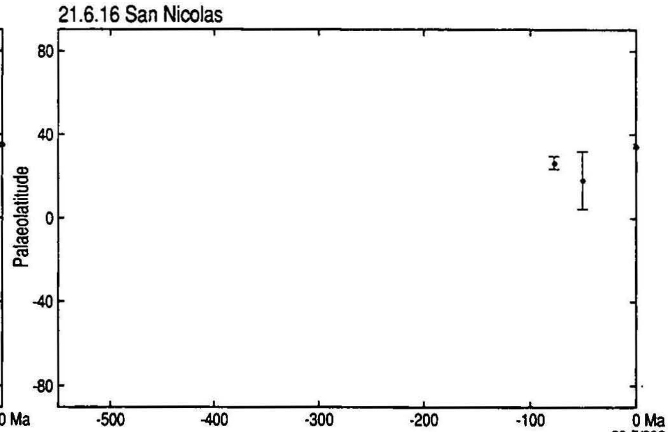
21.6.14 Salinia



21.6.15 Stanley Mountain



21.6.16 San Nicolas



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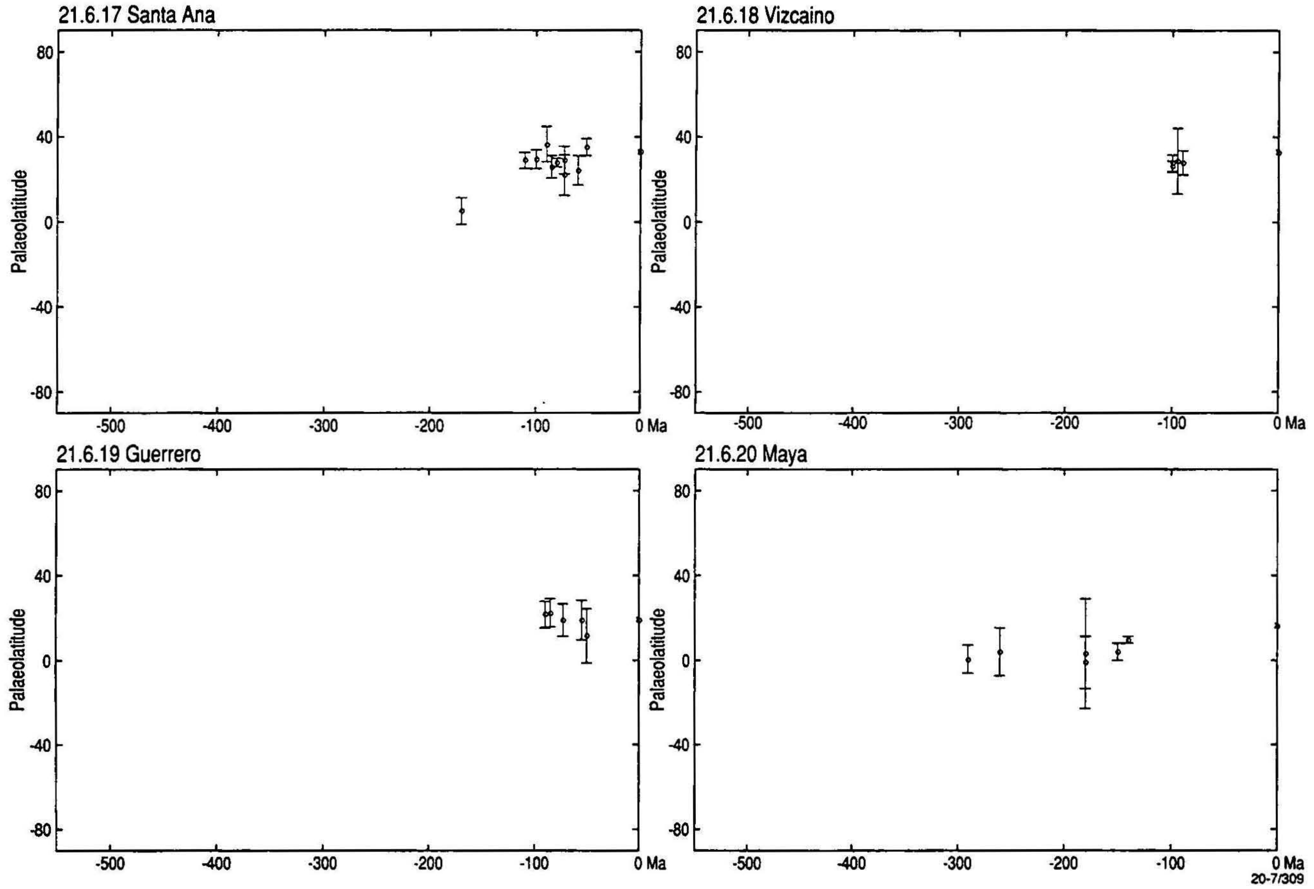


Figure 21 Continued. Previous two pages and above. North American Cordillera - [previous left page] 21.6.1: Porcupine (Fort Yukon); 21.6.2: Wrangell (McCarthy); 21.6.3: Peninsula (Anchorage); 21.6.4: Chugagh-Prince William (Cordova); 21.6.5: Cache Creek (Jakes Corner); 21.6.6: Slide Mountain (Watson Lake); 21.6.7: Alexander (Petersburg); 21.6.8: Stikine (Hazelton); [previous right page] 21.6.9: Quesnell (Kamloop); 21.6.10: Crescent (Victoria); 21.6.11: Decatur (Seattle); 21.6.12: Eastern Klamath (Klamath Falls); 21.6.13: Nicasio (San Francisco); 21.6.14: Salinia (Santa Cruz); 21.6.15: Stanley Mountain (Santa Maria); 21.6.16: San Nicolas (Santa Barbara); [above] 21.6.17: Santa Ana (San Diego); 21.6.18: Vizcaino (San Diego); 21.6.19: Guerrero (Manzanillo); 21.6.20: Maya (Tonala).

The *Guerrero* terrane (Fig.21.6.19: Manzanillo reference) shows absence of latitudinal movement during the latest Cretaceous and Cenozoic.

The pattern for the *Maya* terrane (Fig.21.6.20: Tonala reference) indicates continuous low northern latitudes from Permian to Recent.

PALAEOMAGNETIC CONSTRAINTS ON TIMINGS OF FRAGMENTATION

The dispersive motions of Greater Australia fragments that are now incorporated in southern and eastern Asia are likely to have been mainly of a latitudinal nature and obviously northward in direction. However, fragments that now form part of the North American Cordillera, and possibly also northeastern and northern Russia, may have initially dispersed eastward across Panthalassa (Palaeo-Pacific developed between eastern Australia and western North America during breakup of Rodinia), prior to large-scale northward movement along the Cordillera and possibly beyond along northern Siberia. Analysis of the palaeolatitudinal evolution of individual fragments based on the plots described in the preceding chapter (Fig.21) is, therefore, potentially very instructive in determining the timings of the start of northward motions. These timings may be interpreted as the times of fragmentation, in those cases where such movement is not also reflected in the latitudinal movements of Greater Australia. The Phanerozoic movement phases that have been identified for the various analysed continental blocks and terranes are described in order of ascending age.

Main palaeolatitude observations

- The *Siberian platform* (Fig.21.2.2) and the accretionary, mostly oceanic, terranes of the *Altai-Sayan* region (Fig.21.4.1) moved northward for the entire duration of the Palaeozoic.

- The *Kolyma (Omolon) block* (Fig.21.5.2) underwent gradual northward movement over about 60 degrees of latitude from at least the middle Ordovician till the Jurassic. The Middle Palaeozoic part of the movement pattern is not unlike that for Siberia. Zonenshain et al. (1990) describe a Late Devonian rifting phase, during which blocks now incorporated in the Kolyma structure separated from Siberia. They regard, however, a Palaeozoic Siberian origin for the Omolon block as unlikely and suggest an eastern Australian origin instead. Comparison of the Palaeozoic latitudinal movement patterns for the Omolon block and Australia (Figs 21.5.2 viz 21.1.3) is, however, equivocal.

- *Kazakhstan* (Fig.21.4.2) moved northward over ~50 degrees of latitude during the Early Devonian.

- Prior to its very fast Late Carboniferous movement to southpolar latitudes, *Australia* (Fig.21.1.3) moved northward over at least 40 degrees of latitude during the latest Devonian - middle Carboniferous (up to about the middle Visean ~340-330 Ma). The preferred polarity interpretation of the *Tarim block* data (Fig.21.4.4) indicates a contemporaneous northward movement of similar magnitude. The corresponding declination pattern of the Tarim block (Fig.21.4.5B,C) shows clockwise rotation during the Early and Middle Palaeozoic, in agreement with the clockwise rotation expected for Australia according to the KG-path (Fig.5). This supports the notion that the Tarim block was near to northeastern Gondwana during the Early and Middle Palaeozoic, although it may have become separated from northwestern Australia during the Early Cambrian as suggested by Li et al. (1994b,1996a,b) and Zhang et al. (1994).

- The few Pacifica fragments with Late Palaeozoic coverage *(Wrangell:Fig.21.6.2, Alexander: Fig.21.6.7, Stikine:Fig.21.6.8, Eastern Klamath:Fig.21.6.12, Maya:Fig.21.6.20, and possibly Slide Mountain:Fig.21.2.6)* show no latitudinal movement during the Carboniferous-Permian.

- The main Cathaysian continents *(North China:Fig.21.3.1, 21.3.2A, South China:Fig.21.3.6,21.3.7A and Indochina:Fig.21.3.8A)* have no or very limited palaeomagnetic coverage for the Late Palaeozoic, although limited data for *Mongolia (Fig.21.3.2)* and *Korea (Fig.21.3.4)* indicate virtual absence of northward movement during the Carboniferous and some limited northward movement during the Permian. The scanty palaeolatitude record of the Cathaysian continents markedly contrasts with the high resolution record for the Carboniferous of Australia. It needs to be further established whether absence of change in the palaeolatitude pattern for the Cathaysian continents reflects a low resolution problem or a separation from northeastern Gondwana prior to the Carboniferous.

- The *Australian* palaeolatitude pattern (Fig.21.1.3) suggests a minor northward excursion of eastern Gondwana during the middle to Late Permian, which could be related to initial disperison of Cimmerian continental blocks. This northward excursion is also apparent in the *Indian* palaeolatitude pattern (Fig.21.1.6), but is therein no better constrained than Permian.

- There is clear evidence from the *Australian* (Fig.21.1.3) and particularly the *Indian* (Fig.21.1.6) palaeolatitude patterns and APWPs (Figs 18,19,20) for a considerable northward excursion of eastern Gondwana during the Early Mesozoic, as discussed in the preceding section. Northward movement commenced in the Permo-Triassic, continued until the northeastern margin of Gondwana reached low southern latitudes by the latest Triassic-earliest Jurassic, with subsequent reversal to southward motion for the remainder of the Jurassic. Extensive northward movements during the (latest Permian and) Triassic are indicated also by the palaeolatitude patterns of the *Cathaysian continents (North China-Mongolia-Korea-Ala Shan/Hexi corridor:Fig.21.3.1, 21.3.2A, 21.3.3,21.3.4, South China:Fig.21.3.6, and Indochina:Fig.21.3.8A)*, culminating in accretion to southern Laurasia by the Late Triassic and subsequent consolidation of suture zones. Palaeolatitude patterns for *several Cimmerian continental fragments, i.e. Shan-Thai-Malay (Fig.21.4.7), Qiangtang (Fig.21.4.8) and possibly Iran (Fig.21.4.12)* also indicate a substantial northward movement during the latest Permian and Triassic. The preferred interpretation is that eastern Gondwana was in some way involved as a carrier of these original Gondwana fragments in transport across the Palaeotethys and possibly accretion to Laurasia.

- Terranes of a possible Pacifica origin, now incorporated in the North American Cordillera and northeastern and northern Russia, generally show northward movements of younger age. There are a few exceptions: (i) the *Alexander* terrane (Fig.21.6.7) underwent northward movement over about 40 degrees sometime during the Permian to Late Triassic; (ii) the *Wrangell* terrane (Fig.21.6.2) underwent a very extensive and very fast northward movement over about 80 degrees during the latest Triassic-earliest Jurassic; and (iii) the *Eastern Klamath* terrane (Fig.21.6.12) underwent about 20 degrees northward movement during the Early Jurassic. More characteristic for the terranes are substantial northward movements during Jurassic-Cretaceous *(Khatyrka-Maynitska:Fig.21.5.3, Stikine:Fig.21.6.8)*, Cretaceous *(Decatur: Fig.21.6.11)* and Cretaceous-Cenozoic *(Quesnell:Fig.21.6.9)*.

Main palaeolatitude observations versus reconstruction models

Many, if not all, of the reconstruction models discussed in the accompanying Record (Klootwijk,1996a) show signs of recycled palaeomagnetically-based models and interpretations. Considerable progress has been achieved over the past decade in improving palaeomagnetic data-acquisition and data-analysis techniques. It has now become increasingly clear that many of the older palaeomagnetic data are plagued by regional overprint effects. Consequently, many of the earlier palaeomagnetically-based geodynamic interpretations are now suspect, but often this may not have filtered through into reconstructions developed by workers outside palaeomagnetism. It is therefore instructive to compare the more relevant main observations from the primary palaeolatitude patterns here compiled with the main conclusions of the various reconstruction models.

- The northward movement pattern for the *Siberian Platform (Fig.21.2.1,21.2.2)* is in good agreement with the reconstructions of Zonenshain et al. (1990). This is not surprising, the patterns are essentially based on the same dataset (Khramov and Rodionov,1980; Khramov et al.,1981) as used in their reconstructions. The Palaeozoic northward movement of the *Altai-Sayan (Fig.21.4.1)* contrasts with mainstream Russian geodynamic interpretations (Zonenshain et al.,1990; Didenko et al.,1994; Mossakovsky et al.,1994) which argue for essentially meridionally aligned Palaeoasian and Palaeotethys Oceans and east-to-west rather than south-to-north transport of continental fragments and oceanic arcs. Šengör et al.'s (1993:fig.3,1994) evolutionary model for the Altaids, in contrast, incorporates such south-to-north transport.

- The gradual middle Ordovician to Jurassic northward movement of the *Kolyma (Omolon) block (Fig.21.5.2)* contrasts with Zonenshain et al.'s (1990, fig.122) interpretation of an extensive movement confined to the Jurassic.

- Early Devonian northward movement of *Kazakhstan (Fig.21.4.2)* is in good agreement with biostratigraphic observations, which suggest faunal interchange with north and central Australia up to at least the Middle Silurian (J. Shergold, pers. comm.,1996). Such timing of Kazakhstan's northward movement can be accomodated in Šengör et al.'s (1993, fig.3) reconstruction, but not so in Scotese and McKerrow's (1990) and Zonenshain et al.'s (1990) models which show movement of Kazakhstan together with Siberia from the Cambrian to the Early Carboniferous.

- *Australia's (eastern Gondwana)* latest Devonian-middle Carboniferous northward movement *(Fig.21.1.3)* is a new observation. Its provocative implications need further testing.

- The limited Late Palaeozoic data available for Cathaysian continents and Pacifica fragments do not show evidence for the latest Devonian-middle Carboniferous northward excursion concluded from the *Australian (Fig.21.1.3)* and *Tarim (Fig.21.4.4)* palaeolatitude patterns. This could be a resolution problem, although it may lend some support to reconstruction models purporting pre-Carboniferous separation of the Cathaysian continents, and perhaps Pacifica fragments, from eastern Gondwana (Gehrels and Saleeby,1987; Scotese and McKerrow,1990; Nie Shangyou et al.,1990; Nie Shangyou,1991).

- The minor middle to Late Permian northward movement of *Australia and India (Fig.21.1.3,21.1.6)* is a new palaeomagnetic observation. It is in line with geodynamic models for separation of (the) Cimmerian continent(al blocks) , e.g. Šengör (1984), Nie Shangyou et al. (1990), Nie Shangyou (1991), Metcalfe (1996).

- Triassic (and latest Permian) northward movement of the *Cathaysian continents (North China-Mongolia-Korea-AlaShan/Hexicorridor:Fig.21.3.1,21.3.2A,21.3.3,21.3.4;SouthChina:Fig.21.3.6;*

and Indochina:Fig.21.3.8A) and some of the *'Gondwana' fragments (i.e. Shan-Thai-Malay: Fig.21.4.7; Qiangtang:Fig.21.4.8 and possibly Iran:Fig.21.4.12)* is in agreement with mainstream models (e.g., Burrett,1974; Burrett et al.,1991; Šengör et al.,1988; Scotese and McKerrow,1990; Metcalfe,1996; Zonenshain et al.,1990; Hongzhen Wang and Xuangxue Mo,1996) indicating Late Triassic or younger suturing with southern Laurasia.

- The Permian to Late Triassic northward movement of the *Alexander terrane (Fig.21.6.7)* may support the Permian westward movement of some of the major terranes that are now part of the North American Cordillera *(Wrangellia, Stikinia and Eastern Klamath)* as suggested by Belasky and Runnegar (1993,1994). Evidence for Mesozoic and Cenozoic phases of northward movement seems quite compelling, although the interpretation of such data is still a matter of discussion amongst North American palaeomagnetists and regional geologists (e.g. Wynne et al.,1995,1996; Irving et al.,1995,1996; Monger and Price,1996).

PALAEOMAGNETIC CONSTRAINTS ON RECONSTRUCTIONS

It is a sobering observation that no more than a few percent of the ~2000 compiled results (Klootwijk,1996e, tables 1-6) proved useful to constrain the former configuration of northeastern Gondwana. Thorough, but by no means exhaustive, inspections of the data tables, analyses of polepaths, and trial-and-error reconstruction attempts, nevertheless showed good prospects for reconstruction of the Palaeozoic configuration of the Cathaysian continents (North China, South China, Indochina and Tarim) with respect to northeastern Gondwana. Prospects for reconstruction of Cimmerian continental fragments of surmised Australian origin i.e. the Shan-Thai-Malay and Qiangtang terranes, proved low and have not been pursued beyond the preliminary testing stage. Attempts to relocate the terranes of the North American Cordillera with respect to eastern Gondwana in a "Pacifica" configuration are frustated by the boudinaged nature of the terranes, necessitating individual pole positions rather than polepaths to be used, and by the general scarcity of Palaeozoic results, if not absence of a Palaeozoic basement altogether. Relocation attempts, therefore, have been restricted to the Alexander terrane, which has the better Palaeozoic palaeomagnetic coverage of the Cordilleran terranes.

North China - Australia

The Australian Early-to-Middle Palaeozoic polepath segment is better determined than that for North China. The Australian path is based on eight selected mean poles of Early Cambrian to Late Devonian age (Klootwijk,1996e, table 1.2) and represents the older extension of the alternative KG-path that has been discussed before (Fig.2). The shorter North China polepath trajectory is based on three mean poles of Late Ordovician to Middle-Late Devonian age (Fig.22A1), compiled by Zhao et al. (1996).The spline approximation procedure (Jupp and Kent,1987) of the GMAP for Windows program (Torsvik and Smethurst,1995) has been used to construct slightly smoothed polepaths with weighting according to α_{95} values for invidual results (e.g. Fig.22A2 for the North China block). The shape and location of these "splined" polepath segments are shown in Figure 22B1 for Australia (longer path) and for North China (shorter path), with both continents in their present position. For comparison with Gondwana polepaths (e.g., Schmidt et al.,1993,fig.1) the other Gondwana continents are also shown, reconstructed against Australia in its present position.

The North China "spline" has been fitted against the Australian "spline", aiming for a best fit in the better

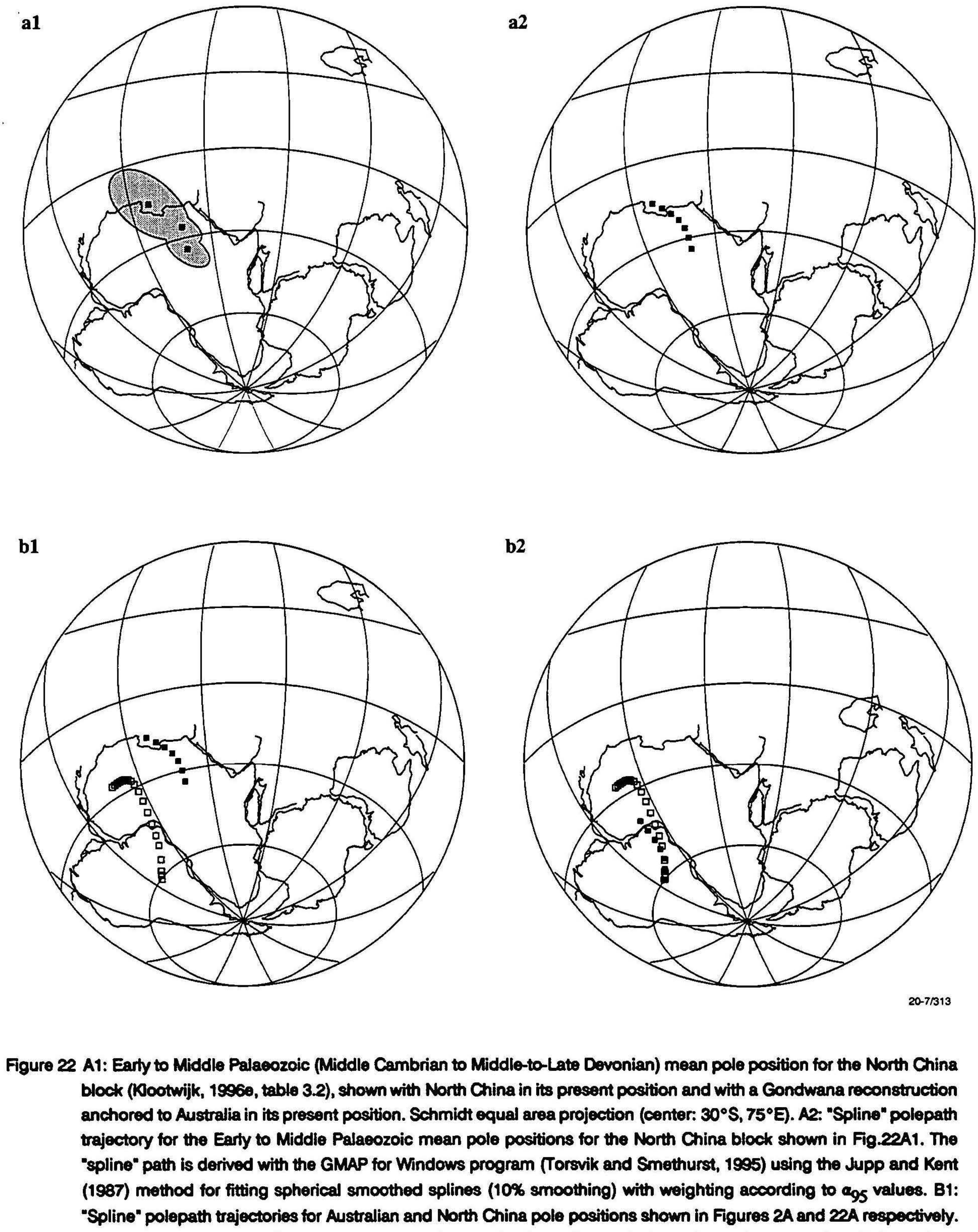
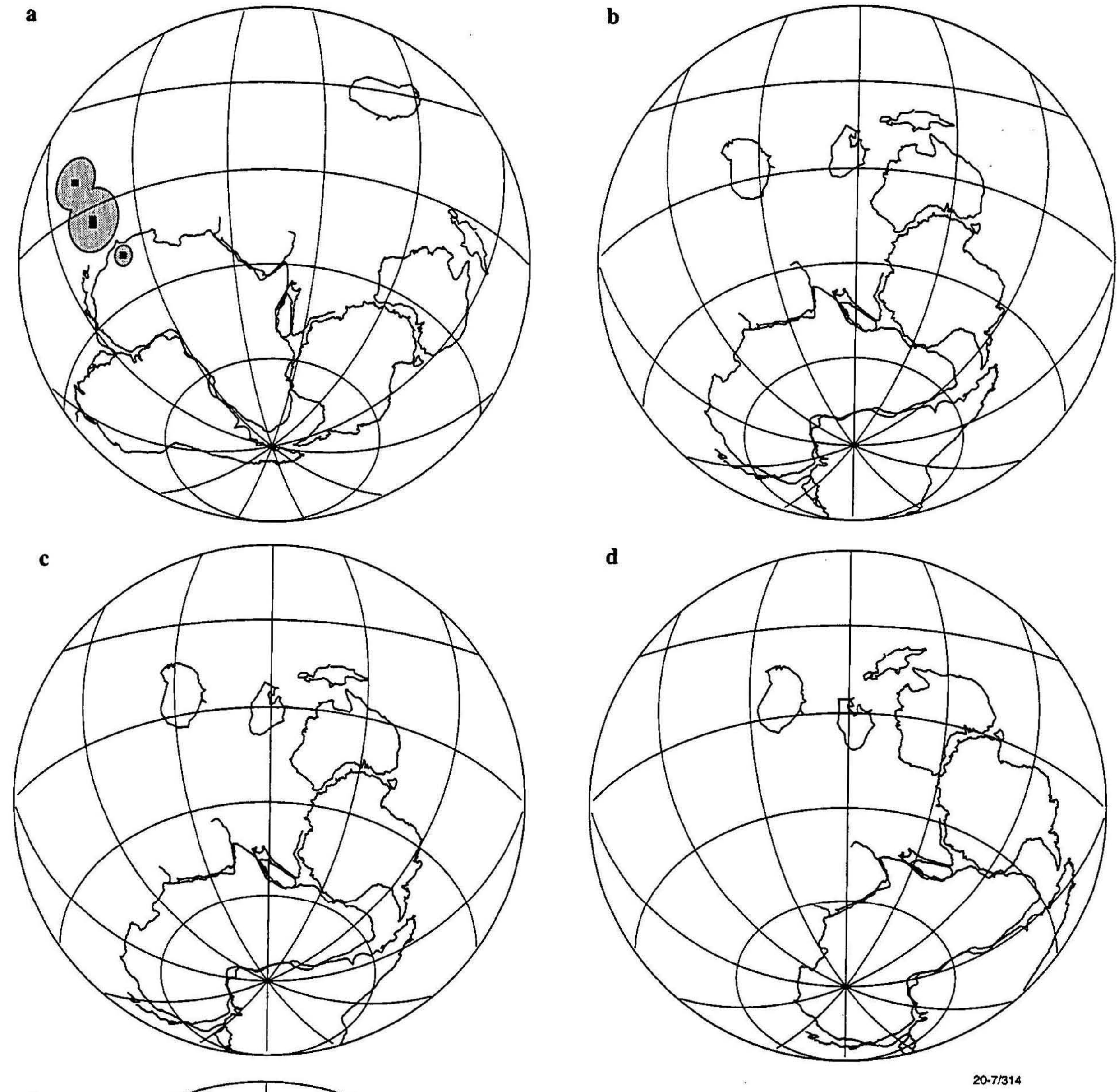


Figure 22 A1: Early to Middle Palaeozoic (Middle Cambrian to Middle-to-Late Devonian) mean pole position for the North China block (Klootwijk, 1996e, table 3.2), shown with North China in its present position and with a Gondwana reconstruction anchored to Australia in its present position. Schmidt equal area projection (center: 30°S, 75°E). A2: "Spline" polepath trajectory for the Early to Middle Palaeozoic mean pole positions for the North China block shown in Fig.22A1. The "spline" path is derived with the GMAP for Windows program (Torsvik and Smethurst, 1995) using the Jupp and Kent (1987) method for fitting spherical smoothed splines (10% smoothing) with weighting according to α_{95} values. B1: "Spline" polepath trajectories for Australian and North China pole positions shown in Figures 2A and 22A respectively. B2: Best fit of the North China "spline" polepath onto the Australian path through rotation around an Euler pole at 9.7°N, 180.3°E, +47.9°. Reconstruction of the North China block versus Australia through application of the same Euler rotation pole.



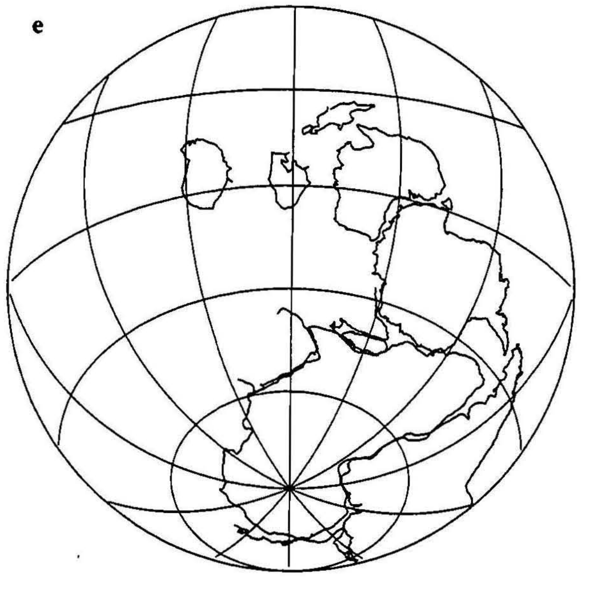


Figure 23 A: Early to Middle Palaeozoic (Cambrian - Middle Devonian) mean pole positions for the South China block (Klootwijk,1996e, table 3.7), shown with South China in its present position and with a Gondwana reconstruction anchored to Australia in its present position. Schmidt equal area projection (center: 30°S, 75°E). B: Reconstruction of the South China block versus the combined Gondwana - North China block (Fig.22.B2), achieved through relocation of the Middle Devonian pole for the South China block (Klootwijk,1996e, table 3.7) and the Middle Devonian pole for Australia (Klootwijk,1996e, table 1.2) onto the geographic South pole. Longitudinal position of the South China block versus the North China block is

arbitrarily adjusted. Composite Euler rotation poles for the South China block: 6.4°, 107.9°, 99.7°. Schmidt equal area projection (center: 30°S, 120°E). C: As above for a Silurian pole position for the South China block and a Late Silurian pole position for Australia. Composite Euler rotation pole for South China block: 8.1°, 112.2°, 86.2°. D: As above for a Late Ordovician pole position for the South China block and an Early Ordovician pole position for Australia. Composite Euler rotation pole for the South China block: 10.0°, 119.5°, 74.3°. E: As above for a Cambrian pole position for the South China block and a Middle Cambrian pole position for Australia. Composite Euler rotation pole for the South China block: 9.4°, 114.0°, 88.1°.

defined Siluro-Devonian parts of the spline segments, achieved through a trial-and-error process of combining Euler rotation poles. The procedure provided a finite Euler rotation pole (Lat 9.7°, Long 180.3°, angle 47.9° [- for clockwise]) for the fit of the two polepath segments shown in Figure 22B2. This same Euler pole has also been used to relocate the North China block against Australia (Fig.22B2). This procedure of fitting polepath segments, "splined" or otherwise, provides unique locking of the two continental positions with respect to each other, and as far as known has not been achieved before for the North China block. Other published reconstruction attempts have been based so far on fitting of individual pole positions. Such a procedure leaves the block's longitude undetermined and does nothing to smooth out age differences between the poles on the trajectories that are being compared, nor to overcome individual pole position inaccuracies.

The palaeomagnetic reconstruction of the North China block against Australia (Fig.8A) is in striking agreement with an independently derived reconstruction (Fig.8B) based on biostratigraphic and lithostratigraphic evidence from Gondwana and from Cathaysian and Cimmerian continental fragments (Metcalfe and Nicoll,1994). This provides strong geological support for the palaeomagnetic lock of North China against Australia. The reconstruction, if sustained, represents a crucial corner stone for further reconstruction of the many "Cathaysian", "Cimmerian" and various other fragments that dispersed more recently from northeastern Greater Australia, and possibly also for the "Pacifica" fragments that were formerly adjacent to eastern Australia. The limited, but not inconsiderate, space between the North China block and northwestern Australia seems adequate to relocate the Shan-Thai-Malay and Qiangtang blocks, the Western Victoria Land and Lhasa blocks, and possibly other fragments such as Timor and Sumba.

South China - Australia

South China Palaeozoic palaeomagnetic data are plagued by pervasive overprints. The four mean pole positions of Cambrian to Middle Devonian age (Klootwijk,1996e, table 3.7, Fig.23A) selected by Zhao et al. (1996) show an age trend that is opposite in direction to the age trend of the Australian path used to fit the North China block against NW Australia. The reason for this mismatch in age trends is not clear. It cannot be resolved by using an older extension of the SLP-path which is far too complex to be useful. Whatever the cause for this mismatch e.g. overprinting, pole position and age inaccuracies, tectonic rotations, etc..., reconstruction through locking of "splined" or original polepath segments is not an option. As the next best recourse, the position of the South China block versus the combined Australia-North China-Gondwana configuration has been tested through relocating about equivalent-age southpoles for the South China block and Australia. In this method the equivalent-age southpoles are made coincident with the geographic South pole and the continental blocks are rotated accordingly. This procedure, carried out for selected Middle Devonian (Fig.23B), Silurian (Fig.23C), Ordovician (Fig.23D) and Cambrian (Fig.23E) poles, leaves the relative longitudes of the reconstructed blocks undetermined. An arbitrary, but geologically acceptable, choice has been made to reconstruct the South China block

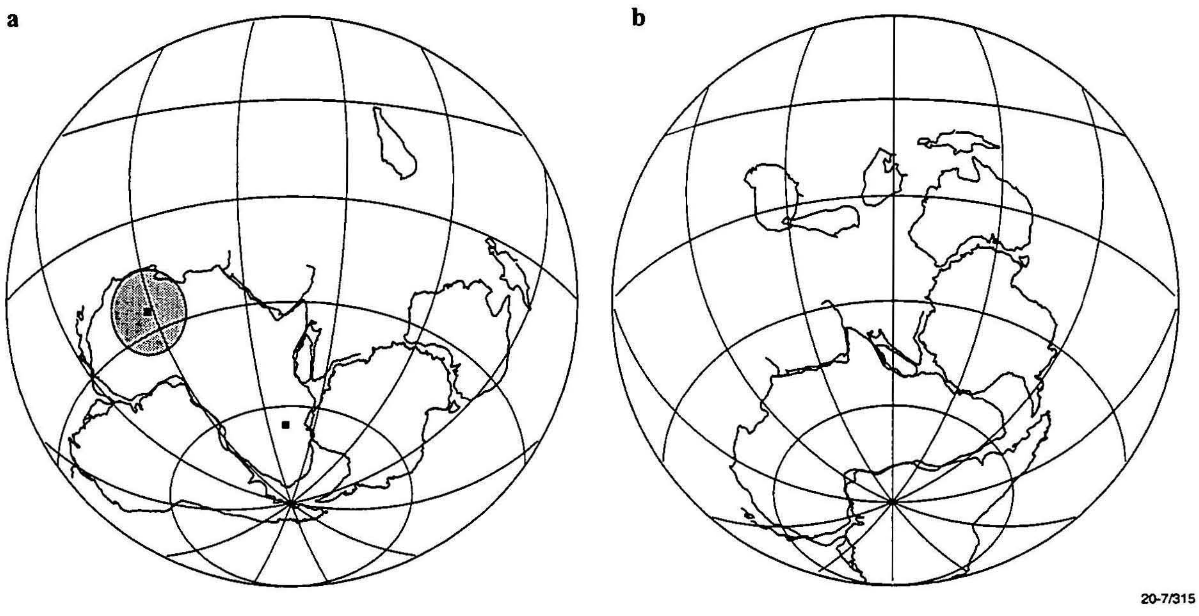


Figure 24 A: Devonian pole positions for the Indochina block (Klootwijk,1996e, table 3.8), shown with Indochina in its present position and with a Gondwana reconstruction anchored to Australia in its present position. Schmidt equal area projection (center: 30°S, 75°E). B: Reconstruction of the Indochina block versus the combined Gondwana - North China - South China block (Fig.23.B: Middle Devonian), achieved through relocation of the better defined one of two Devonian pole positions for the Indochina block (Klootwijk,1996e, table 3.8) and the Middle Devonian pole position for Australia (Klootwijk,1996e, table 1.2) toward the geographic South pole. Longitudinal position of the Indochina block versus the North China block is arbitrarily adjusted. Composite Euler rotation pole for the Indochina block: 3.9°, 120.7°, 65.7°.

closely to the west of the North China block. Comparison of the four individual Middle Devonian to Cambrian reconstructions shows a reasonable degree of stability in the relative positions of the South and North China blocks. The Middle Devonian reconstruction, which is based on the best defined and best matching ages, is arbitrarily taken as the preferred reconstruction.

Indochina - Australia

Pole positions for Indochina of pre-Late Palaeozoic age i.e. predating the younger estimates for the time of separation of Cathaysian continents from Gondwana, are confined to two Devonian poles with limited documentation only (Klootwijk,1996e, table 3.8, Fig.24A). Reconstruction according to the above described procedure and using the better defined of the two Devonian pole positions, locates the Indochina block close to, and to the south of, the North and South China blocks (Fig.24B), with the proviso that relative longitudinal positions are arbitrary.

Tarim - Australia

The pre-Late Palaeozoic mean pole positions for the Tarim block, compiled by Zhao et al. (1996; Klootwijk,1996e, table 4.5), are of uncertain polarity. The Middle Palaeozoic results (Fig.21.4.5B,C; Fig.25A) indicate a declination shift that is far larger than indicated by Middle Palaeozoic Australian data. Thus some rotation of the Tarim block separate from Gondwana may have occurred. This prevents

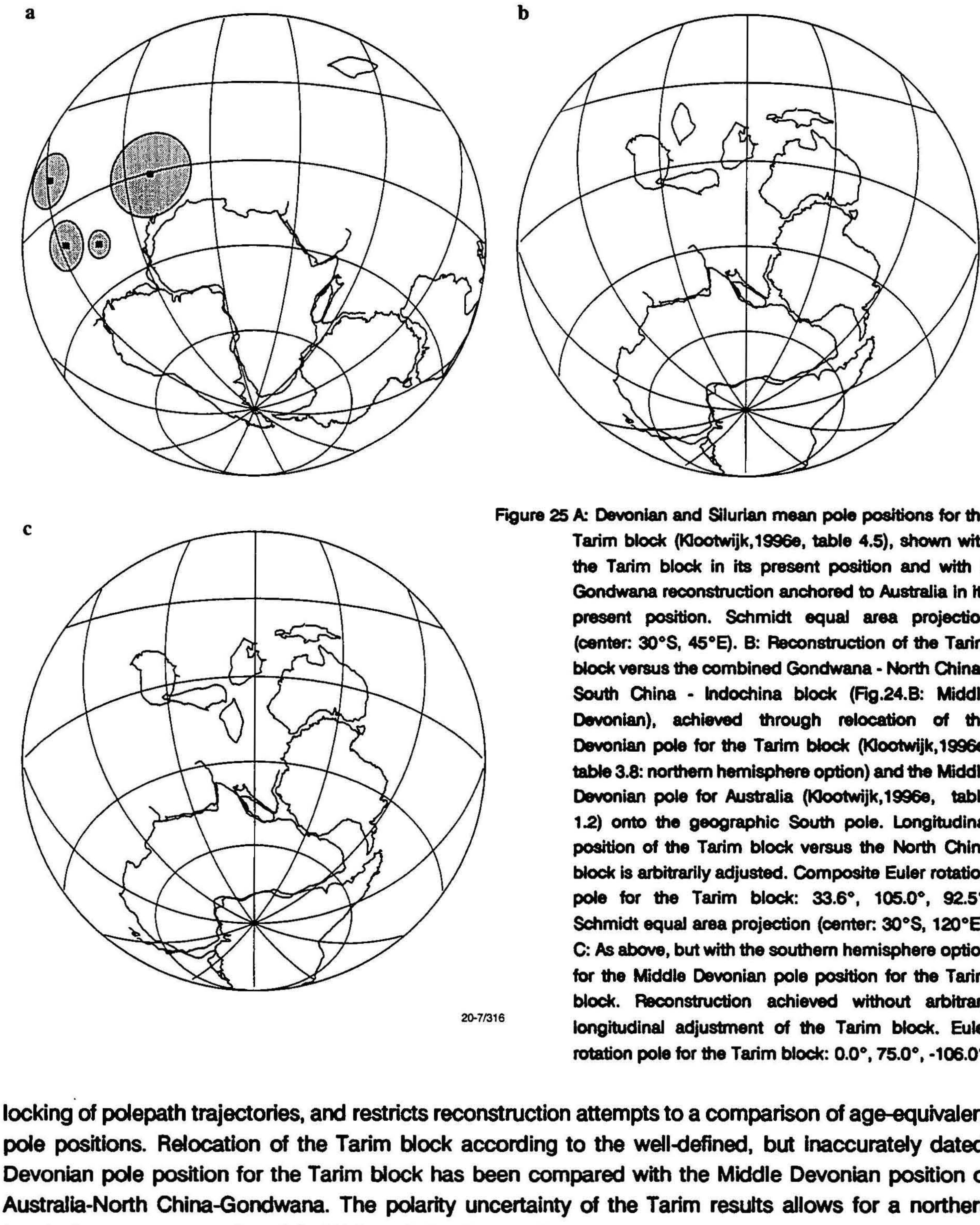


Figure 25 A: Devonian and Silurian mean pole positions for the Tarim block (Klootwijk,1996e, table 4.5), shown with the Tarim block in its present position and with a Gondwana reconstruction anchored to Australia in its present position. Schmidt equal area projection (center: 30°S, 45°E). B: Reconstruction of the Tarim block versus the combined Gondwana - North China - South China - Indochina block (Fig.24.B: Middle Devonian), achieved through relocation of the Devonian pole for the Tarim block (Klootwijk,1996e, table 3.8: northern hemisphere option) and the Middle Devonian pole for Australia (Klootwijk,1996e, table 1.2) onto the geographic South pole. Longitudinal position of the Tarim block versus the North China block is arbitrarily adjusted. Composite Euler rotation pole for the Tarim block: 33.6°, 105.0°, 92.5°. Schmidt equal area projection (center: 30°S, 120°E). C: As above, but with the southern hemisphere option for the Middle Devonian pole position for the Tarim block. Reconstruction achieved without arbitrary longitudinal adjustment of the Tarim block. Euler rotation pole for the Tarim block: 0.0°, 75.0°, -106.0°.

locking of polepath trajectories, and restricts reconstruction attempts to a comparison of age-equivalent pole positions. Relocation of the Tarim block according to the well-defined, but inaccurately dated, Devonian pole position for the Tarim block has been compared with the Middle Devonian position of Australia-North China-Gondwana. The polarity uncertainty of the Tarim results allows for a northern hemisphere reconstruction (Fig.25B) and also for an alternative southern hemisphere reconstruction, with the proviso of arbitrary longitudinal positions for both reconstructions. The northern hemisphere relocation positions the Tarim block outboard of the North and South China blocks and favours dispersion schemes that argue for an early separation, may be in association with Kazakhstan (e.g. Zonenshain et al.,1990). The southern hemisphere option (Fig.25C), in contrast, locates the Tarim

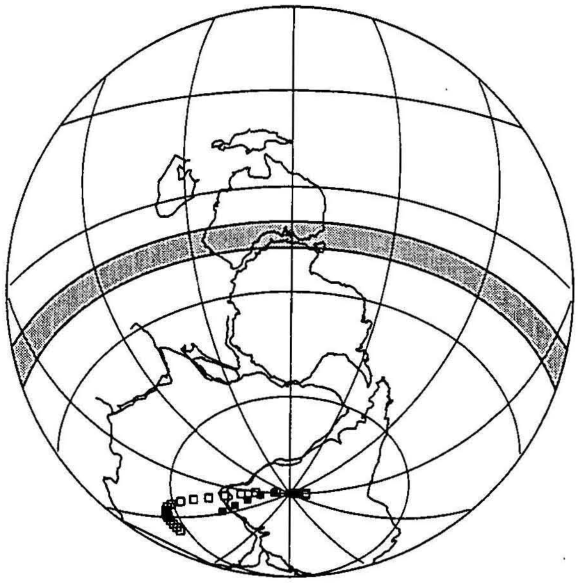


Figure 26 Relocation of the the combined Gondwana-North China block (Fig.22B) according to an Early Devonian (392.5 Ma) "splined" pole position for Australia (57.8°S, 12.6°E: Euler rotation pole: 0.0°, 102.6°, 32.2°). The shaded zone indicates the Early Devonian palaeolatitudinal position and associated accuracy error interval for the reference locality of the Alexander terrane (Table 2) according to the result of Bazard et al. (1995) for the Early Devonian Karheen Formation (Klootwijk,1996e, table 6.7). Schmidt equal area projection (center: 30°S, 150°E).

block inboard of the Cathaysian blocks and close to northwestern Australia. This favours reconstructions that argue for a close lithostratigraphic relationship of the Tarim block and the Kimberley region of northwestern Australia (Li et al.,1994b; Zhang et al.,1994) and also supports the argument presented earlier that latest Devonian-Early Carboniferous northward movement was jointly with Australia.

Alexander terrane - Australia

The Alexander terrane has a more extensive coverage of Palaeozoic results than any other terrane in the North American Cordillera. It is therefore taken as a palaeomagnetic test case for a former "Pacifica" - Australia relationship. Given the tectonised and boudinaged nature of the far-travelled Alexander terrane it is, in the absence of first-hand knowledge about tectonic relationships, highly imprudent to combine pole positions from different parts of the terrane. Comparison of polepaths is thus not a viable option, and the test case is confined to comparison of a well-defined Early Devonian pole position for the Alexander terrane (Bazard et al.,1995; Klootwijk,1996e, table 6.7) with the age-equivalent mean pole position for Australia (~392 Ma) obtained from the "splined" approximation of Australia's Early-to-Middle Palaeozoic results. Relocation of Gondwana and the previously-fitted North China block (Fig.8A,22B2) according to this Early Devonian "splined pole position" is shown in Figure 26, with the splined polepath relocated so that the Early Devonian south pole is coincident with geographic South pole. The Early Devonian palaeomagnetic result for the Alexander terrane defines the palaeolatitude of the sampled location at 13.5°S ± 4.1°. This palaeolatitude zone, as shown on Figure 26, corresponds with the Early Devonian palaeolatitude of the southern Lachlan Fold Belt, and is in good agreement with comparative lithostratigraphic arguments for a former relationship (Gehrels and Saleeby,1987).

GEOLOGIC CONSTRAINTS ON GREATER AUSTRALIA's FRAGMENTATION: TENTATIVE CORRELATIONS WITH PALAEOMAGNETIC CONSTRAINTS

An attempt is made to correlate significant geological events in the Phanerozoic evolution of the North West Shelf with loops and cusps on the Australian and Indian APWPs. Loops and cusps on the polepath are taken to reflect significant changes in plate tectonic reorganisation, and far-field stresses created upon such changes can be transmitted widely across lithospheric plates. Proper determination of the loops and cusps is a prerequisite not only for dating of the tectonic events, but importantly also for determination of the plate's movement pattern. For periods prior to the oldest preserved seafloor spreading episodes, Callovian-Oxfordian possibly Bathonian-Callovian, palaeomagnetic control is the only effective means to delineate movement patterns on plate and microplate scale and consequently to determine the orientation of the ensuing stress patterns.

The loops and cusps on the Australian and Indian APWPs have been described above and are detailed in Figures 2B,5,13,18-20. Geological detail is based mainly on subsurface information from the post-Early Carboniferous Westralian Basin (Northern Carnarvon Basin, onshore Canning Basin/Roebuck Basin, Browse Basin, Northern Bonaparte Basin) and on surface/subsurface information of the Palaeozoic and younger successions from the onshore continuations of these basins (Southern Carnarvon Basin, Canning Basin, Southern Bonaparte Basin). Considerable information is drawn also from the Amadeus and Ngalia Basins (Shaw et al.,1991a,b;1992b) mainly in relation to evolution of the Canning Basin, and also from the Tibetan Sedimentary Series of the Higher Himalayas of Nepal in the Thakkhola region (Gradstein and von Rad,1991; Gradstein et al.,1992; Kodama and Ogg,1992; Ogg et al.,1992; Ogg and von Rad,1994), representing the former on strike continuation of the Westralian Basin. Limited reference is made to evolution of the Tasman Fold Belt, and virtually no reference is made to the Perth Basin. Whilst the Perth Basin was included in the original definition of the Westralian Geosyncline (Teichert,1939,1951) and of the Westralian Basin (Yeates et al.,1987), inclusion with Australia's southern margin basins is nowadays preferred (Bradshaw et al.,1988; Cockbain,1989; Hocking et al.,1994; AGSO North West Shelf Study Group,1994; Etheridge and O'Brien,1994a,b).

The discussion does not address the Late Neoproterozoic-Early Cambrian Rodinia-to-Gondwana changeover. Such a fundamental change in plate configurations falls outside the scope of this Record. Furthermore, the changeover was completed prior to Early Ordovician initiation of the Canning Basin, the oldest onshore basin related to the Westralian Basin.

Correlations are addressed in chronological order beginning with the Cambro-Ordovician Delamarian Orogeny and following geologic or palaeomagnetic leads as convenient with the particular lead chosen not implying cause-or-effect. The discussion focuses in particular on the newly-proposed latest Devonian-mid Carboniferous northward excursion of eastern Gondwana and implications thereof for mid-Carboniferous dispersion of the Cathaysian continents, rather than on the widely-quoted Late Carboniferous-Early Permian dispersion of Sibumasu from a position outboard of Northwest Australia. The major impact of two subsequent fundamental changes in plate movements on the evolution of the North West Shelf will also be highlighted, i.e. eastern Gondwana's Late Triassic-Early Jurassic northward excursion and the Late Jurassic-Early Cretaceous, changeover from southward to northward movement.

Delamarian Orogeny

Cambro-Ordovician tectonism, corresponding in time with the Delamarian Orogeny, affected northwestern Australia i.e. the earliest Ordovician Sapphire Marsh Extensional Movement initiating the Canning Basin (Romine et al.,1994; Shaw et al.,1994), the Bloodwood Movement in the Ngalia Basin (Wells and Moss,1983; Young et al.,1995), shear zones in the King Leopold Orogen of the Kimberley block with K-Ar ages from muscovite at 510-500 Ma (Shaw et al.,1992a), and sag of the proto-Petrel Basin (Colwell and Kennard,1996). This Cambro-Ordovician tectonism and the Delamarian Orogeny may be reflected in the Cambro-Ordovician loop on the Australian polepath (Figs 2A,B).

Mid-Palaeozoic enigma: creeping rotation or major loop

The Middle Palaeozoic segment of the KG-path is characterised by an extensive and fairly smooth Ordovician to Early Carboniferous west-(over south)-to-east segment (Figs 3,5), without obvious loops and only a broadly developed Late Devonian (to possibly Early Carboniferous) cusp. This not particularly eventful segment is bound, however, by well-defined loops in the Cambro-Ordovician (Fig.2) and the mid-Carboniferous (Fig.13) that may be related to (i) the Delamarian Orogeny and the diastrophic phase of the Kanimblan/Alice Springs Orogeny respectively, and also to (ii) fundamental basin-forming stages of the North West Shelf with the Early Ordovician onset of deposition in the Canning Basin and the middle Carboniferous (Visean?) onset of the Westralian Basin (Yeates et al.,1987; Veevers,1988; Mory,1988; Mory and Beere,1988; Bradshaw et al.,1988,1994; AGSO North West Shelf Study Group,1994; Symonds et al.,1994; Etheridge and O'Brien,1994a,b; Shaw et al.,1994; Romine et al.,1995). It is somewhat surprising that the mainly Silurian Rodingan-Prices Creek Movement does not show up on the Middle Palaeozoic segment of the KG-path, which shows a smooth ongoing clockwise rotation whilst Australia remains in low southern to equatorial latitudes. The pole positions on this part of the path are, however, nearly exclusively based on results from the Tasman Fold Belt for which the possibility of Tabberaberan overprinting of the Middle Silurian to Middle Devonian segment has been suggested (Klootwijk et al.,1993; Klootwijk,1996b). In contrast, extension to older times of the SLP-path (Fig.4) as compiled in Klootwijk et al. (1993, fig.9A) and Klootwijk and Giddings (1993, fig.3C) would suggest, however, the presence of a Siluro-Devonian loop that could be related to the Rodingan-Prices Creek Movement.

Rodingan - Prices Creek Movement

The Rodingan Movement was defined in the Amadeus Basin as Late Ordovician to Middle Silurian (Wells et al.,1970; Shaw,1991; Oaks et al.,1991; Shaw et al.,1991a; Stewart et al.,1991; Romine et al.,1994). The Prices Creek Movement was defined in the Canning Basin as possibly starting in the Early-Middle Silurian with the main phase in the Early-to-Middle Devonian (Kennard et al.,1994; Romine et al.,1994; Shaw et al.,1994). It is thus difficult to separate the two phases and they may represent parts of the same tectonic cycle. The Rodingan-Prices Creek Movement was very important for trap formation, hydrocarbon maturation, and creation and modification of fluid movement pathways and mineral dissolution particularly in association with saline brines such as derived from the Late Ordovician Mallowa Salt in the Canning Basin (Romine et al.,1994) and from the Bitter Springs Formation in the Amadeus Basin (Oaks et al.,1991). The KG-path is poorly defined in the Middle Palaeozoic and shows no obvious feature that can be correlated with the extended Rodingan-Prices Creek Movement phase. This movement phase may be related, however, with dispersal of Kazakhstan from the outer margin of northeastern Gondwana. Kazakhstan's palaeolatitude pattern shows a large-scale northward movement over about 50 degrees of latitude during the Early Devonian (Fig.21.4.2), with biostratigraphic indications for continuing connection with north and central Australia up to at least the Middle Silurian (J. Shergold, pers. comm.,1996).

Pertnjara - Kerridy Movement phase and Pillara Extension

In the late Middle Devonian a new regime came into being that led during the Late Devonian and Early Carboniferous (Givetian-Frasnian to Visean) to a fundamental structural change affecting northwestern Australia with development of the North West Shelf Megashear (AGSO North West Shelf Study Group,1994) and ultimately to the mid-Carboniferous diastrophic phase of the Alice Springs Orogeny, discussed below separately. The tectonic responses to this new regime show remarkable regional differences with ongoing extension in the Palaeozoic onshore precursor basins of the Westralian Basin and ongoing compression in the intracratonic Amadeus and Ngalia Basins and also in the Wiso and Eastern Officer Basins. This led Braun et al. (1991) to postulate a major zone of decoupling between the two regions, the Lasseter Shear Zone, following earlier suggestions by Forman and Shaw (1973) for strike-slip movement between the Canning Basin and the Amadeus Basin. The speculative Lasseter Shear Zone (see also Walter and Gorter,1994; Nicoll,1995) and its better established outboard conjugate, the North West Shelf Megashear, are postulated as accomodation zones to northeast-directed extension, mostly in the upper crust, that led to formation of the Fitzroy Trough, the Petrel Sub-basin, the Southern Bonaparte Basin and the Browse basin (AGSO North West Shelf Study Group,1994). The extensional phase is particularly well-documented in the Fitzroy Trough of the Canning Basin (Bradshaw et al.,1988; Drummond et al.,1991; Shaw et al.,1994; Kennard et al.,1994 ; Southgate et al.,1994; Romine et al.,1995) where three movement phases are identified: i.e. the Gogo Movement (mid-Givetian to Frasnian), the Van Emmerick Extension (Late Frasnian) and the Red Bluffs Extension (Famennian to Tournaisian), and is also well-established in the Southern Carnarvon Basin (Baillie et al.,1994), the Northern Carnarvon Basin (Stagg and Colwell,1994), the offshore Canning Basin (Colwell and Stagg,1994), the Browse Basin (Symonds et al.,1994), the Southern Bonaparte Basin (Mory and Beere,1988), and in the Petrel Basin (Colwell and Kennard,1996: mainly subsidence phase B).

The contrasting intracratonic compression started with the Givetian-Frasnian Pertnjara Movement in the Amadeus Basin (Wells et al.,1970; Jones,1991; Stewart et al.,1991; Shaw,1991; Shaw et al.,1992b; Warris,1994) and with the contemporaneous Kerridy Movement in the Ngalia Basin (Wells and Moss,1983; Young et al.,1995). Compression essentially continued into the final diastrophic phase of the Alice Springs Orogeny, with some individual phases identified (Jones,1991; Walley et al.,1991) in the Middle Frasnian (Henbury Movement) and in the Late Frasnian-Early Famennian (Brewery Movement).

The onset of the Pertnjara-Kerridy-Pillara phase may be reflected in the Late Devonian (to possibly Early Carboniferous) cusp on the KG-path. This cusp is not very obvious on the (distorted) Aitoff projection plot (Fig.5), but the broad nature of its about 90 degrees change in direction is more impressive in global view. The Late Devonian-Early Carboniferous extensional (contractional) regime on the North West Shelf (intracratonic basins) can be related to the latest Devonian-Early Carboniferous northward movement of Greater Australia (Figs 14,15) that is based on the older limb of the Early-middle Carboniferous loop of the New England polepath (Fig.13).

Diastrophic Alice Springs Orogeny - Mount Eclipse Movement - Meda Movement

The final diastrophic phase of the Alice Springs Orogeny has been dated radiometrically at 340 to 320 Ma (Shaw,1991; Shaw et al.,1992b; Dunlap et al.,1991,1995a,b) and can be correlated with the final phase of the Mount Eclipse Movement (Visean) in the Ngalia Basin (Jones,1991; Shaw et al., 1992b,1994), the Meda Transpressional Movement in the Canning Basin (Shaw et al.,1992a), reactivation of mobile zones in the Halls Creek Province (Halls Creek Mobile Zone and Fitzmaurice Mobile Zone, Colwell and Kennard,1996), and the final kinkbanding phase (~330 Ma) of the Kanimblan Orogeny in the Tasman Fold Belt (Powell,1984; Powell et al.,1985; Goscombe et al.,1994). It represents the end of the Uluru stratotectonic Regime (Veevers,1984). This mid-Carboniferous continent-wide tectonic phase can be correlated with the apex of the Early-to-Late Carboniferous loop on the New England polepath (Fig.13), which has been interpreted (Klootwijk,1994,1995,1996b,c,d) as a short-lived contact between northeastern Gondwana and the Central Asian Fold Belt at moderate northern latitudes (Figs 15-17). This "Variscan" loop together with the preceding Delamarian loop (Fig.2A,B) delimit the extensive Middle Palaeozoic west-(over south)-to-east trajectory of the Australian polepath (Figs 2B,3,5,13), which indicates ongoing low southern to tropical latitudes for Australia and an ongoing clockwise rotation.

Westralian Basin formation - lower crustal extension

A major new phase of crustal extension in the North West Shelf region commenced in approximately the Visean (Namurian in the Petrel Basin, Colwell and Kennard,1996) and continued during the Late Carboniferous and Early Permian (Mory,1988; Mory and Beere,1988; Veevers 1988; Bradshaw et al.,1988; Cockbain,1989; Malcolm et al.,1991; Bradshaw et al.,1994; O'Brien,1993; Purcell and Purcell,1994; Hocking et al.,1994; AGSO North West Shelf Study Group,1994; Symonds et al.,1994; Colwell and Stagg,1994; Stagg and Colwell,1994; Romine et al.,1995; Miller and Smith,1996; Colwell and Kennard,1996), initiating the Westralian Basin (Yeates et al.,1987) and identified regionally in Australia as the changeover from the Uluru to the Innamincka stratotectonic Regime (Veevers,1984). The extension phase has affected all basins of the North West Shelf i.e. Northern Carnarvon, offshore Canning/Roebuck, Browse, Northern Bonaparte/Petrel (Colwell and Kennard, 1996: subsidence phases C?,D &E) and beyond, e.g. the Arafura Basin (Loosveld,1989, pers. comm. in Brakel and Totterdell,1990), through the mechanism of mainly lower crustal extension at such a scale (Etheridge and O'Brien,1994a,b) that crustal-throughgoing structures have developed which are fundamental to the current structural framework of the North West Shelf region. Extension was mainly in a NW-SE direction, although north-northwesterly to northerly extension is observed (Symonds et al.,1994), in obvious contrast to the NE-SW extension during the earlier Late Devonian-Early Carboniferous extensional phase. The older structural framework has been reworked, with Late Devonian-Early Carboniferous accomodation zones e.g. the North West Shelf Megashear, now spawning basin boundary faults, whereas relict basin boundary faults are reactivated as accomodation zones (Etheridge and O'Brien,1994a,b).

Middle to Late Carboniferous initiation of the Westralian Basin and associated thermal events, indicated by fission-track data, have led to a major phase of hydrocarbon maturation and migration (Etheridge and O'Brien,1994a,b; McCracken,1994; McConachie et al.,1996) and may also be related to mineralisation events on the Lennard Shelf. MVT-type mineralisations, such as the Cadjebut deposit, were deposited from overpressured hydrocarbon-rich saline brines during the middle Carboniferous prior to deposition of the Grant Group. This mineralisation was attributed to a global fall in sealevel (Eisenlohr et al.,1994), but is more likely related to the fundamental change in, and intensification of, the extensional tectonic regime, allowing circulation of warm saline brines as agens of dissolution, transport and deposition.

The mid-Carboniferous to Early Permian formation of the Westralian Basin is commonly associated with dispersion of the Sibumasu block (e.g. Veevers,1988; Purcell and Purcell,1994; AGSO North West Shelf Study Group,1994; Symonds et al.,1994) as part of the separation of Cimmerian continental fragments from the northeastern margin of Gondwana, even though the timing of this separation is well-constrained as Middle to Late Permian (Şengör,1984,1985,1987; Şengör et al.,1988). Newly-established evidence for a Devono-Carboniferous northern excursion of eastern Gondwana (Figs 14,15) makes it now far more likely that this extensional regime is associated with dispersion of the Cathaysian continents at tropical latitudes during an early stage of the very fast southward return movement of eastern Gondwana in the Late Carboniferous. The remarkable change in direction of the extensional regime, NE-SW to NW-SE, may be associated with the change in movement of eastern Gondwana as evidenced from polepath segments on the opposing limbs, "west-to-eastward" limb versus the "east-to-westward" limb, of the Carboniferous loop on the New England polepath (Fig.13).

~300 Ma Loop

This loop (Figs 5,13) may become better defined in time and space on the basis of forthcoming results for latest Carboniferous successions of the Tamworth Belt, i.e. the Currabubula Formation of the Werrie Syncline and the Rocky Creek Formation of the Gravesend/Rocky Creek Syncline. In its present definition this loop cannot be clearly correlated with individual tectonic events in northwestern Australia. Amongst the possibilities are: (i) the Drosera Erosional Event in the Canning Basin of late Westphalian to Stephanian age (Bradshaw et al.,1994; Shaw et al.,1994); (ii) the Point Moody Extensional Movement in the Canning Basin of Early Permian age (Kennard et al.,1994; Shaw et al.,1994); and (iii) the Waite Creek Movement of Sakmarian-Kungarian age in the Ngalia Basin and Arunta Block (Walley et al.,1991; Jones,1991). The loop may also be correlated with events in the Tasman Fold Belt, i.e. with (iv) the metamorphic event in the North D'Aguilar block of the northern New England Fold Belt around 305 Ma (Little et al.,1993a,b; Holcombe and Little,1994; R. Korsch, pers. comm.,1996), and (v) possibly the onset of oroclinal bending of the Texas - Coffs Harbour Megafold (Aubourg et al.,1994).

280-270 Ma Loop

This loop (Figs 5,13) also needs further definition in time and space, potentially achievable through follow-up work on the Featherbed Volcanics in northeastern Queensland (Klootwijk and Giddings,1993; Klootwijk et al.,1993). Currently available data indicate a minor northward excursion that can be dated for Australia as middle to Late Permian (Fig.21.1.3) and for India as no better than Permian (Fig.21.1.6). This loop and minor northward excursion can be related with separation of the Sibumasu (Shan-Thai-Malay)-Qiangtang blocks from northeastern Gondwana. This separation of Cimmerian continental fragments is generally dated as middle to Late Permian (Şengör,1984,1985,1987; Şengör et al.,1988; Metcalfe,1990; Audley-Charles,1991), although Metcalfe (1996) favours an Early-middle Permian separation. The loop also may be correlated with a major phase of extensional tectonics in the Tasman Fold Belt (e.g. Bowen Basin, Tamworth Belt), variously dated at 290-268 Ma (Veevers et al.,1993; Veevers et al.,1994b), beginning at ~285 Ma (Collins et al.,1993; Korsch and Totterdell,1996; R.Korsch, pers. comm.,1996) and main development ~275-270 Ma (Collins et al.,1993).

~260 Ma Loop

This loop (Fig.5,18) is a new observation from ongoing work on definition of the younger boundary of the Permo-Carboniferous Reversed Superchron in the Late Permian succession of the Illawarra region (Giddings et al.,1994). Its progression in time and space awaits further definition (e.g. Théveniaut et al.,in press). The loop may be related to Late Permian tectonism defined as Chinty Movement in the onshore Carnarvon Basin (Warris,1994) and generally dated as Kazanian-Tatarian (Bradshaw et al.,1994), or described as "Initial Compression" in the Petrel Basin (Colwell and Kennard,1996). In the Tasman Fold Belt of eastern Australia it may be related to the mid-Permian unconformity dated around 265 Ma

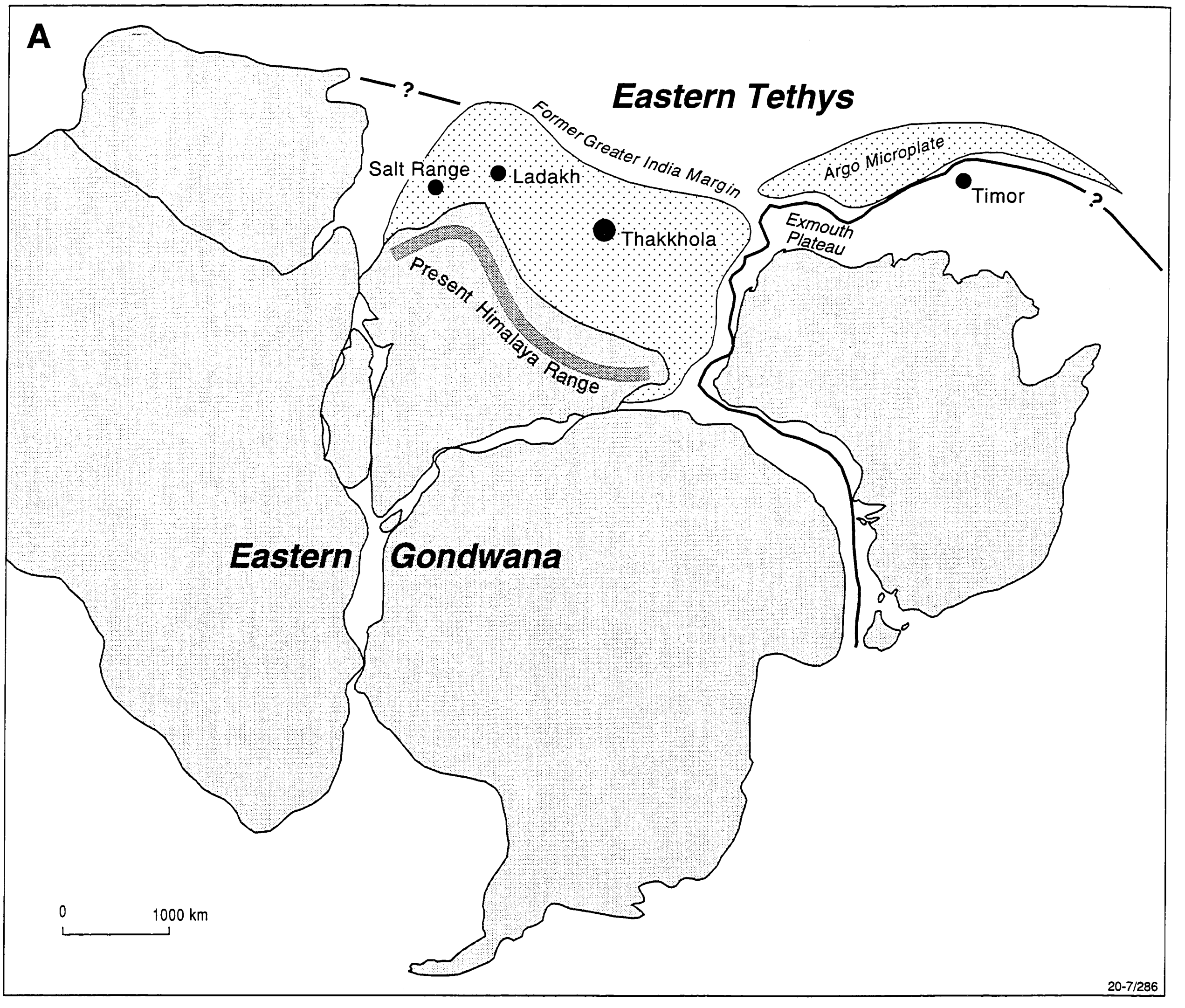


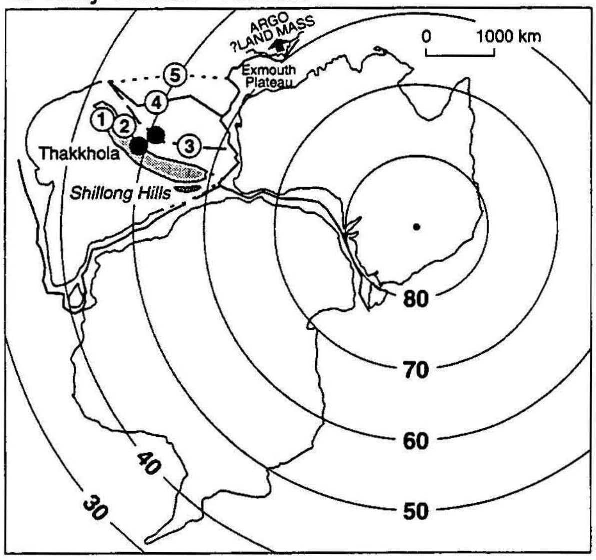
Figure 27 A: Permian-Triassic reconstruction of eastern Gondwana and Africa after Ogg and von Rad (1994, fig.1), showing the former juxtaposition of Greater India's northern margin, after Klootwijk et al. (1985,1991), and the Westralian Basin.

and a Late Permian contractional event (R. Korsch, pers. comm.,1996; Korsch and Totterdell,1996), to broad folding, uplift and erosion in the interval 268-258 Ma (Veevers et al.,1993,1994b), to the early contractional phase of the Hunter-Bowen Orogeny in the Bowen Basin starting at about 270 Ma (Stephens et al.,1996), or to the Fourth Tectonic Cycle (265-255 Ma) of Collins et al. (1993) taken as part of the Hunter-Bowen Orogeny.

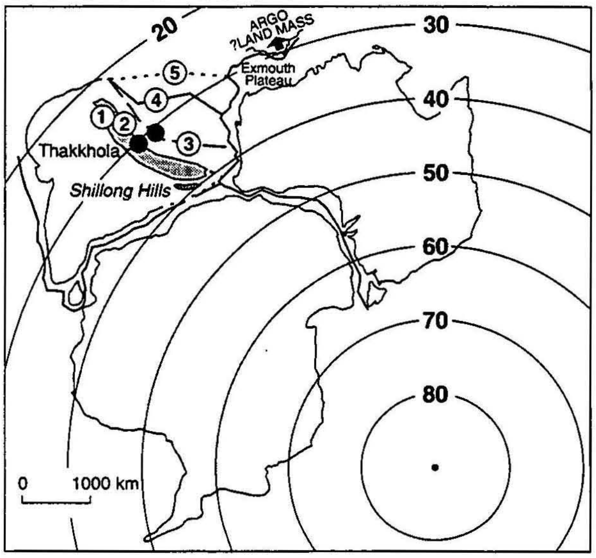
~250 Ma Cusp

This cusp is only poorly resolved on the Australian polepath (Fig.18; Giddings et al.,1994,fig.37) and the Indian polepath (Figs 19,20) and probably represents the least expressive and least defined palaeomagnetic feature discussed here. Given its poor age control it may relate to the latest Permian

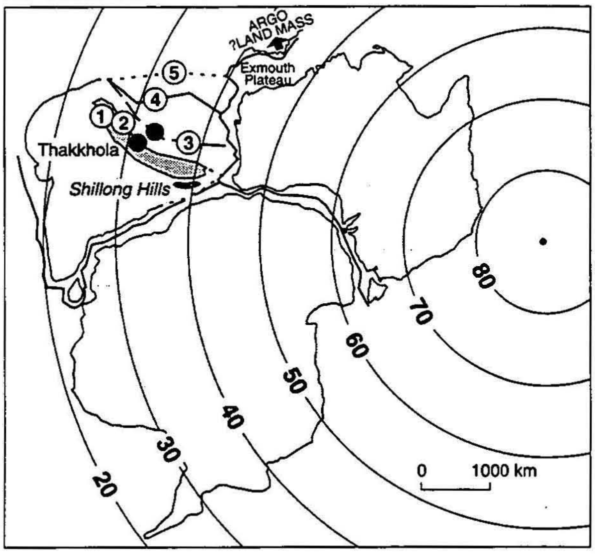
B. Early Triassic - Anisian



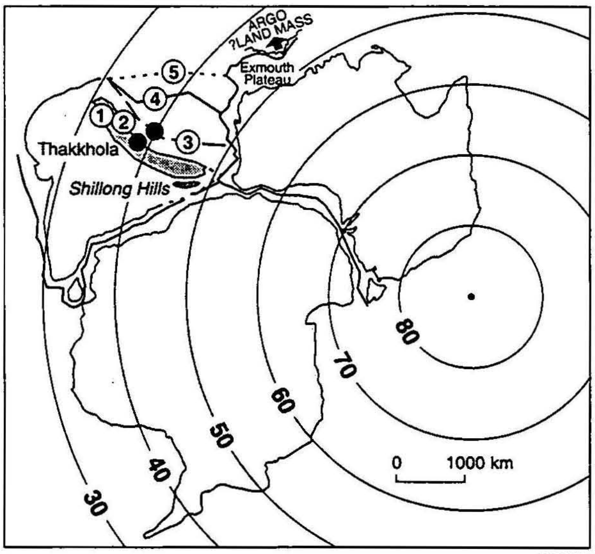
C. Sinemurian - Bathonian



D. Oxfordian - Tithonian



E. Earliest Berriasian



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F. Berriasian - Early Valanginian

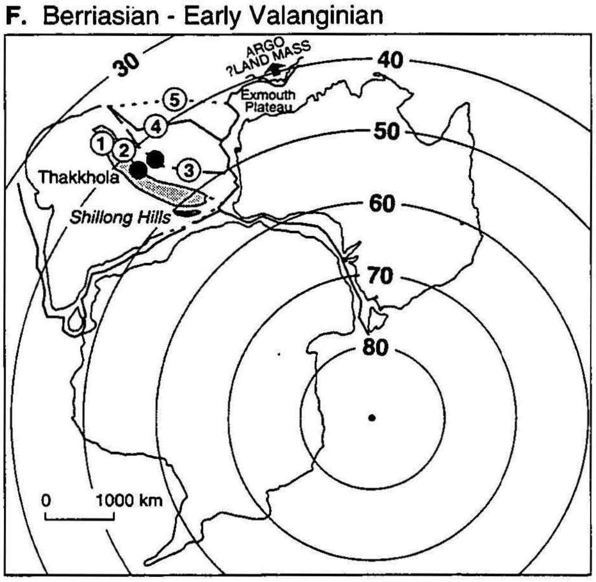

Figure 27B-F: Reconstructions of east Gondwana in B: Early Triassic (Anisian); C: Early-Middle Jurassic (Sinemurian-Bathonian); D: Late Jurassic (Oxfordian-Tithonian); E: earliest Cretaceous (earliest Berriasian); F: Early Cretaceous (Berriasian-early Valanginian) after Gradstein et al. (1992, figs 38a-e). 1 = Main Boundary Fault; 2 = Indus-Tsangpo Suture (ITS); 3 = minimum northward extent of India after unwinding the doubled crust south of the ITS; 4 = Kun Lun-southern Tsaidam mountain front; 5 = postulated northern edge of Greater India. The present-day position of the Thakkhola region, and its proposed palaeoposition are indicated as black circles. Lambert equal area projection.

Legrange extension of the Canning Basin (Kennard et al.,1994), or to the Late Permian-Early Triassic Bedout Movement, widely observed throughout the Westralian Basin (Cockbain,1989; AGSO North West Shelf Study Group,1994; Colwell and Stagg,1994; Hocking et al.,1994; Kennard et al.,1994; Symonds et al.,1994; Romine et al.,1995) and onshore in the Canning Basin (Shaw et al.,1994). In eastern Australia this cusp may be related to a general erosional phase around 255 Ma (Veevers et al.,1993,1994b; R. Korsch, pers. comm.,1996).

Fitzroy Movement

The Fitzroy Movement embraces an extensive mid-Triassic to Early Jurassic phase, characterised by Late Triassic-earliest Jurassic transpressional movements with local observations of mid-Carnian rifting, followed by a rifting period which became major during the Hettangian-Sinemurian-Pliensbachian. The transpressional movement phase is fundamental for the hydrocarbon potential of the North West Shelf, with major formation of reservoir and structural traps (Veevers,1988; AGSO North West Shelf Group,1994) and source generation, possibly enhanced by increased heating during the Early Jurassic (Arne et al.,1989).

Evolution of the Fitzroy Movement is well-known from extensive hydrocarbon exploration in the Westralian Basin, from ODP-drilling on the Exmouth Plateau and Argo Basin, and also from results of the Lost Ocean Expeditions (e.g. Gradstein et al.,1992) in the Tibetan Sedimentary Series of Nepal (Thakkhola), which represents the western pre-breakup equivalent of the Westralian Basin succession.

Some extension occurred across Pangea during the Ladinian-Carnian (Veevers,1989; Veevers et al.,1994b: 230 Ma). This rifting phase is observed in the Himalayan continuation of the Westralian Basin i.e. mid-Carnian rifting in the Thakkhola region of Nepal (Ogg and von Rad,1994) and may also have led to mid-Carnian block faulting on Australia's northwest margin (von Rad et al.,1992a,b; Ogg and von Rad,1994). Compressional tectonics dominated, however, throughout Australia, with the onset of the compressive Fitzroy Movement in northwest Australia, with the paroxysmal phase of the Hunter-Bowen Orogeny in the New England region at about 230 Ma (Fergusson and Leitch,1993; Veevers et al.,1993,1994b; Korsch and Totterdell,1996; Stephens et al.,1996; R. Korsch, pers. comm.,1996), and possibly with docking of the Gympie terrane with the New England Orogen during Anisian-Ladinian (Harrington and Korsch,1985). Late Triassic-earliest Jurassic ongoing transpressional movement is evidenced widely across the various basins of the Westralian Superbasin (AGSO North West Shelf Study Group,1994; Colwell and Stagg,1994; Etheridge and O'Brien,1994a,b; Southgate et al.,1994; Symonds et al.,1994; Colwell and Kennard,1996 [Deposition of syn-tectonic Malita Supersequence in the Petrel Basin during Basin Subsidence Phase G]) and the onshore Canning Basin (Jackson et al.,1992; Shaw et al.,1994), and can be correlated also with a prominent latest Triassic-Early Jurassic metamorphic phase on the eastern margin of Greater Australia that is evident from Rb-Sr measurements on the Torlesse terrane from the North and South Island of New Zealand (Adams,1996). Subsequent onset of rifting in the Hettangian-Sinemurian-Pliensbachian is a Tethyan-wide event, occurring more or less simultaneously in both the eastern Tethyan region of New Guinea (Pigram and Panggabean,1984; Struckmeyeret al.,1993) and in the western Tethyan region with destruction of the Western Mediterranean Triassic carbonate platform (Bernouilli and Lemoine,1980; Lemoine,1983,1984; Lemoine et al.,1886; Froitzheim and Manatschal,1996), in an obviously global event also evidenced in the subsequent opening of the North Atlantic (Veevers,1989).

The Fitzroy Movement phase can be readily correlated with a northward excursion of eastern Gondwana, whose general presence is well-established from the Australian and Indian polepaths (Figs 15,18-20) and palaeolatitude plots (Figs 21.1.3,21.1.6), but which unfortunately do not as yet carry sufficient detail to define the extent and evolution through time of this northward excursion. A parallel may be drawn with the preceding Devono-Carboniferous major northward excursion of eastern Gondwana and the postulated dispersion of the Cathaysian continents during the early stage of the middle-to-Late Carboniferous return movement, which may possibly be equated with the well-established dispersion during the late Middle Jurassic of a fragment, as yet unidentified (Argoland), from a position outboard of northwestern Australia and northern Greater India.

The Late Triassic-Early Jurassic northward excursion of eastern Gondwana can perhaps best be illustrated by the palaeomagnetic results from the Thakkhola region (Klootwijk and Bingham,1980), augmented with a compilation of Mesozoic palaeomagnetic data for Australia (Embleton,1984) and results from ODP Leg 123 (Ogg and von Rad,1994), very instructively represented in a Gondwana context in reports of the Lost Ocean Expeditions (Gradstein and von Rad,1991 [figures 38a-e]; Ogg et al.,1992; Gradstein et al.,1992; Ogg and von Rad,1994) and reproduced in Figures 27A-F. The figures clearly demonstrate eastern Gondwana's more than 30 degrees of northward movement during the Late Triassic, with northwestern India reaching tropical latitudes and Australia's North West Shelf reaching about 30 degrees South. Such palaeomagnetic reconstructions are supported by observations of Late Triassic red beds in the Vulcan graben (Woods,1994) and in the Petrel Basin (Colwell and Kennard,1996: Malita Supersequence) and Rhaetian reefs in ODP Site 764 on the Exmouth Plateau. (Gradstein and von Rad,1991; Gradstein,1992; von Rad et al.,1992a; Exon and von Rad,1994; Ogg and von Rad,1994).

Eastern Gondwana's Triassic-Jurassic northward excursion is also notable on the European and North American polepaths, albeit as excursions of lesser magnitude. Whether this polepath feature possibly reflects a global lithospheric movement has to be further established. Notably the Cathaysian continents, North and South China and Indochina (Figs 21.3.1,21.3.6,21.3.8A) and possibly Sibumasu (Fig.21.4.7), Qiangtang (Fig.21.4.8) and Iran (Fig.21.4.12), show a large-scale Triassic northward movement which can be broadly dated for at least the Cathaysian continents and Sibumasu as Early to Middle Triassic in age. This northward movement ultimately led to Triassic-Jurassic suturing with southern Laurasia. The Australian and Indian Early Mesozoic polepaths are unfortunately too poorly defined to establish a direct relationship, if any, between eastern Gondwana's northward movement and this Indosinian accretionary tectonic phase.

~140 Ma Loop

During the Jurassic eastern Gondwana returned toward higher southern latitudes. The Australian and Indian polepaths (Figs 18-20) are no more than broadly determined for the Jurassic and do not provide much detail for this southward movement (Fig.15). The various palaeopositions of Gondwana after Gradstein et al. (1992; Figures 27B-F) are, however, very instructive in detailing stages in the Triassic northward movement, the Jurassic southward return movement and the Cretaceous renewed northward movement. Despite the current absence of palaeomagnetic detail on evolution of this southward return movement, geological evidence from the North West Shelf indicates two fragmentation events during this movement phase, i.e. in the Callovian-Oxfordian and in the Valanginian. The earlier Callovian-Oxfordian drifting event ends the rifting process that commenced during the Hettanginian-Sinemurian-Pliensbachian and is clearly related to formation of the Argo abyssal basin, whose evolution is well dated from the M-sequence of marine magnetic anomalies (M26) and K-Ar dating of oceanic crust (Exon and von Rad,1994: 155 Ma). The Argoland fragment that broke away at this time (Veevers,1988; Veevers et al.,1991; Veevers and Li,1991) has not been positively identified for lack of primary palaeomagnetic results, but is probably represented by Western Victoria Land (off the North West Shelf) and the Lhasa block (off northern Greater India). Effects of this fragmentation are evident in all basins of the Westralian Superbasin (Bentley,1988; Cockbain,1989; Malcolm et al.,1991; Barber,1994; AGSO North West Shelf Study Group,1994; Baillie et al.,1994; Blevin et al.,1994; Colwell and Stagg,1994; Exon and Colwell,1994; Ramsay and Exon,1994; Shaw et al.,1994; Symonds et al.,1994; Romine et al.,1995; Miller and Smith,1996; Whittam et al.,1996; Colwell and Kennard,1996 [initial part of Subsidence Phase I in Petrel Basin]) as extensional features (Etheridge and O'Brien,1994a,b), a major unconformity (Exon and von Rad,1994), and salt dome activity (McCracken,1994; Woods,1994). Its effects are also well established in the Thakkhola region of Nepal as a ferruginous oölite horizon and by a Callovian-Oxfordian hiatus (Gradstein and von Rad,1991; Gradstein et al.,1992; Exon and von Rad,1994). This "oölite ferrugineuse" is widely observed throughout the Tibetan Sedimentary Series of the Higher Himalaya and elsewhere in southern Tibet and on the Indian subcontinent (e.g. Cutch, northern Pakistan).

The Callovian-Oxfordian extensional phase (North-to-Northwest — South-to-Southeast extension: Etheridge and O'Brien,1994a,b) is followed by a latest Jurassic-earliest Cretaceous (Tithonian-Berriasian) compression phase of similar direction that was crucial to formation of hydrocarbon traps (Etheridge and O'Brien,1994a,b). This compressional phase on the North West Shelf may be part of a wider phenomenon also expressed in a latest Jurassic-Early Cretaceous metamorphic event in the Torlesse terrane of the North and South Island of New Zealand (Adams,1966), and with a contrasting extensional regime along the southern Australian margin (Symonds et al.,1996), which all can be correlated in time with the apex of the Late Jurassic-Early Cretaceous loop. This compressional interlude in turn is followed by a second major extensional phase (Northwest-Southeast extension: Etheridge and O'Brien,1994a,b) during the (Berriasian-) Valanginian that led to separation of Greater India from Australia and formation of the Gascoyne Basin, the Cuvier Basin and ultimately the Perth Basin (Veevers,1988; Veevers et al.,1991; Veevers and Li,1991), with effects widespread throughout the Westralian Basin (Mory,1988; Malcolm et al.,1991; Barber,1994; Baillie et al.,1994; Exon and Colwell,1994; Exon and von Rad,1994; Ramsay and Exon,1994; Symonds et al.,1994; Miller and Smith,1996; Whittam et al.,1996; Colwell and Kennard,1996 [part of Subsidence Phase I]), and also in the Thakkhola region with influx of volcanoclastic material that may be related to breakup (Gradstein and von Rad,1991; Gradstein et al.,1992).

100-115 Ma Cusp

The general outline of a broad cusp is apparent from the Australian and Indian polepaths (Figs 18,19), but there is little constraint on its timing other than that the cusp predates the Late Cretaceous thermal event, or alternatively an uplift and erosion episode, along the eastern seaboard of Australia prior to initiation of rifting of the Tasman Sea at about 90-95 Ma (e.g. Klootwijk,1985; Moore et al.,1986; Kohn and Gleadow,1994; O'Sullivan et al.,1995,1996; Lackie and Schmidt,1996) and that the cusp postdates the extrusion of the Indian Rajmahal Traps (117 Ma). It is most likely that the cusp is related to the profound directional change in plate motions upon separation of Greater India from Australia and Antarctica (Powell et al.,1988, Veevers et al.,1991; Veevers and Li,1991; Baillie et al.,1994), to the first signs of extension in the Tasman Sea region (Veevers et al.,1991; Symonds et al.,1996), and to the start of separation of Australia from Antarctica (Veevers,1990; Veevers et al.,1991) at 96 Ma. The change may be expressed in the Cenomanian unconformity in the Canning Basin and the Browse Basin (AGSO North West Shelf Study Group,1994), the Cenomanian faulting phase in the Northern Carnarvon Basin (Romine et al.1995), uplift and reactivation in the Browse basin (Symonds et al.1994), salt dissolution and hydrocarbon movement in the Canning Basin (McCracken,1994), and the change from the Innamincka to the Poteroo stratotectonic Regime (Veevers,1984). If the cusp is older, it is possibly reflected in a change in sedimentation rate in the Surat Basin, in particular around 112 Ma (Korsch and Totterdell,1996; R. Korsch, pers. comm.,1996), or possibly to the middle to late Albian (105±5 Ma) change from a convergent margin to an extensional tectonic regime in the New Zealand margin of eastern Gondwana representing onset of rifting associated with seafloor spreading of the Tasman Sea (Laird,1996; Symonds et al.,1996).

~70 Ma Cusp

This cusp is pronounced on both the Indian and Australian polepaths (Figs 18,19). It most likely reflects a plate reorganisation upon initial contact of Greater India and southern Asia during the latest Maastrichtian (70-65 Ma: Klootwijk et al.,1991,1992), and possibly also northward propagation of seafloor spreading through the northern Tasman Basin into the Capricorn Basin at 69 Ma and Coral Sea at 63 Ma (Symonds et al.,1996). The change may be reflected in the TE erosional event in the Petrel Basin (Colwell and Kennard,1996).

40-45 Ma Cusp

This cusp is identifiable on the Indian polepath (Fig.19: Klootwijk et al.,1985, fig.5A; Klootwijk et al.,1991, fig.60), but is not clearly visible on the Australian path (Fig.18). It may be related to a global change in plate movements around 43 Ma (Fein and Jurdy,1986; Rangin et al.,1990), most visibly expressed in the sharp bends in the Pacific island chains (e.g. Hawaiian chain) reflecting a change in Pacific plate motion form northward to northwestward.

Oligocene? Movement

Mid-Tertiary tectonic reactivation affected the North West Shelf, e.g. uplift, transpression and change of tectonic style in the Browse Basin (Symonds et al.,1994); transpressional movement and fault reactivation in the offshore Canning/Roebuck Basin (Lipski,1994); and reactivation, structuring and uplift due to east-west compressional to transpressional activity on he North West Shelf (Etheridge and O'Brien,1994a,b). This reactivation phase is poorly dated as Oligocene or Oligocene-Early Miocene. This somewhat diffuse tectonic phase may be related to far-field effects of accretionary tectonics in New Guinea, i.e. accretion of the South Sepik Composite (Salumei) terrane in latest Eocene or Early Oligocene (Pigram and Davies,1987; Davies,1990; Klootwijk et al., in prep.) and/or accretion of the Bewani-Torricelli Arc complex in the Early-Middle Miocene (Pigram and Davies,1987; Davies,1990; Struckmeyer et al.,1993; Klootwijk et al.,in prep.). This movement phase is not really evident on the Australian polepath, although a weak eastward mid-Tertiary deflection (Fig.18) can be interpreted.

Mio-Pliocene Cusp

This cusp is well-expressed on the Australian polepath (Fig.18) as a western excursion, which is based in part on overprint poles and is therefore no better constrained in time than between 3 and 12 Ma. This cusp can be related to the Mio-Pliocene tectonic reactivation phase that is very evident across the North West Shelf (Parry and Smith,1988; Bradshaw et al.,1988; Cockbain,1989; Etheridge and O'Brien,1994a,b; Symonds et al.,1994; Romine et al.,1995). Many of the existing traps that were formed mainly during the

Jurassic rifting phases (Woods,1992), became reactivated during this phase and significant hydrocarbon migration occurred, probably driven by hot saline brines from Palaeozoic evaporitic sequences (O'Brien and Woods,1995; O'Brien et al.,1996). This late stage fluid flow is evident in fission track and fluid inclusion data (Lisk and Eadington,1994) and has led in the Vulcan Sub-basin to Late Miocene-early Pliocene cementation of the Grebe Sandstone and regionally to the formation of Hydrocarbon-Related Diagenetic Zones or HRDZ's (O'Brien and Woods,1995). This significant tectonic reactivation and migration phase can be related to contact between the Australian continental margin and southeastern Asia in the Timor region of the Banda Arc (Snyder et al.,1996). Initial contact is variously dated at between about 8 and 2.4 Ma (Richardson and Blundell,1996) or between 10 and 3-4 Ma (Hall,1996).

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REFERENCES

Adams, C.J., 1996. A Queensland provenance for New Zealand Permo-Triassic Torlesse metagreywacke terranes: A review of the age and isotopic evidence. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43: 1-6.

Agarwal, V.K., 1980. A palaeomagnetic study of Upper Palaeozoic to Lower Mesozoic sediments of the Gondwana System from coalfields of the Koel-Damodar Valley and the Son Valley, N.E. India. Unpublished M.Sc. Thesis, ANU, pp162.

Arne, D.C., Green, P.F., Duddy, I.R., Gleadow, A.J.W., Lambert, I.B. and Lovering, J.F., 1989. Regional thermal history of the Lennard Shelf, Canning Basin, from apatite fission track analysis: Implications for the formation of Pb-Zn ore deposits. Australian Journal of Earth Sciences, 36: 495-513.

Aubourg, C., Klootwijk, C.T. and Korsch, R.J., 1994. Magnetic fabric and palaeomagnetic studies in the Texas and Coffs Harbour blocks, New England Orogen. AGSO Record 1994/58, pp87.

Audley-Charles, M.G., 1991. Tectonics of the New Guinea area. Annual Reviews of Earth and Planetary Sciences, 19: 17-41.

AGSO North West Shelf Study Group, 1994. Deep reflections on the North West Shelf: Changing perceptions of basin formation. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 63-76.

Bachtadse, V. and Briden, J.C., 1991. Palaeomagnetism of Devonian ring complexes from the Bayuda Desert, Sudan - New constraints on the apparent polar wander path for Gondwana. Geophysical Journal International, 104: 635-646.

Baillie, P.W., Powell, C.McA., Li, Z.X. and Ryall, A.M., 1994. Tectonic framework of Western Australia's Neoproterozoic to Recent sedimentary basins. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 45-62.

Barber, P., 1994. Sequence stratigraphy and petroleum potential of Upper Jurassic-Lower Cretaceous depositional systems in the Dampier Sub-basin, North West Shelf, Australia. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 525-542.

Bazard, D.R., Butler, R.F., Gehrels, G. and Soja, C.M., 1995. Early Devonian paleomagnetic data from the Lower Devonian Karheen Formation suggest Laurentia-Baltica connection for the Alexander terrane. Geology, 23: 707-710.

Belasky, P. and Runnegar, B., 1993. Biogeographic constraints for tectonic reconstructions of the Pacific region. Geology, 21: 979-982.

Belasky, P. and Runnegar, B., 1994. Permian longitudes of Wrangellia, Stikinia and Eastern Klamath terranes based on coral biogeography. Geology, 22: 1095-1098.

Bentley, J., 1988. The Candace Terrace - A geological perspective. In: Purcell, P.G and R.R., (Eds), The North West Shelf, Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988: 157-171.

Bernouilli, D. and Lemoine, M., 1980. Birth and early evolution of the Tethys: the overall situation. In: Aubouin, J., Debelmas, J. and Latreille, M., (Eds), Géologie des Chaînes Alpines issues de la Téthys. Mémoires du B.R.G.M.,115: 168-179.

Biske, Y.S., Komissarova, R.A. and Talashmanov, Y.A., 1993. On Paleozoic horizontal movements on the northern margin of the Tarimskiy continent from paleomagnetic data. Vestn. SPbU, 7: 71-77.

Biske, Y.S., 1995. Late Paleozoic collision of the Tarimskiy and Kirghiz-Kazakh paleocontinents. Geotectonics, 29: 26-34.

Blevin, J.E., Stephenson, A.E. and West, B.G., 1994. Mesozoic structural development of the Beagle Sub-basin - Implications for the petroleum potential of the Northern Carnarvon Basin. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 479-496.

Bradshaw, M.T., Yeates, A.N., Beynon, R.M., Brakel, A.T., Langford, R.P., Totterdell, J.M. and Yeung, M., 1988. Palaeogeographic evolution of the North West Shelf region. In: Purcell, P.G and R.R., (Eds), The North West Shelf, Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988: 29-54.

Bradshaw, M.T., Bradshaw, J., Murray, A.P., Needham, D.J., Spencer, L., Summons, R.E., Wilmot, J. and Winn, S., 1994. Petroleum systems in West Australian basins. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 93-118.

Brakel, A.T. and Totterdell, J.M., 1990. The Permian palaeogeography of Australia. BMR Record, 1990/60, pp126.

Braun, J., McQueen, H. and Etheridge, M., 1991. A fresh look at the Late Palaeozoic tectonic history of Western-central Australia. Exploration Geophysics, 22: 49-54.

Burrett, C.F., 1974. Plate tectonics and the fusion of Asia. Earth and Planetary Science Letters. 21: 181-189.

Burrett, C., Duhig, N., Berry, R. and Varne, R., 1991. Asian and south-western Pacific continental terranes derived from Gondwana, and their biogeographic significance. In: Ladiges, P.Y., Humphries, C.J. and Martinelli, L.W., (Eds), Austral Biogeography. Australian Systematic Botany, 4: 13-24.

Cambridge, Paleomap Services, 1992. ATLAS Version 3.2. A mapping and global reconstruction system for the personal computer.

Chen, Z., Li, Z.X., Powell, C.McA. and Balme, B.E., 1993. Palaeomagnetism of the Brewer Conglomerate in central Australia, and fast movement of Gondwanaland during the Late Devonian. Geophysical Journal International, 115: 564-574.

Chen, Z., Li, Z.X., Powell, C.McA. and Balme, B.E., 1994. An Early Carboniferous paleomagnetic pole for Gondwanaland: New results from the Mount Eclipse Sandstone in the Ngalia Basin, central Australia. Journal of Geophysical Research, 99: 2909-2924.

Chen, Z., Li, Z.X. and Powell, C.McA., 1995. Paleomagnetism of the Upper Devonian reef complexes, Canning Basin, Western Australia. Tectonics, 14: 154-167.

Clark, D.A., 1996. New Permian, Devonian and Silurian poles from the Charters Towers Province - Implications for the Palaeozoic APWP of Gondwana. EOS Transactions American Geophysical Union, 77: W19.

Claoué-Long, J.C., Compston, W., Roberts, J. and Fanning, C.M., 1995. Two Carboniferous ages: A comparison of SHRIMP zircon dating with conventional zircon ages and $^{40}AR/^{39}Ar$ analysis. In: Geochronology,Time Scales and Global Stratigraphic Correlation, SEPM Special Publication, 54: 3-21.

Cockbain, A.E., 1989. The North West Shelf. The PESA Journal, 17:529-545.

Collins, W.J., Offler, R., Farrel, T.R. and Landenberger, B., 1993. A revised Late Palaeozoic-Early Mesozoic tectonic history for the southern New England Fold Belt. In: Flood, P.G and Aitchinson, J.C., (Eds), New England Orogen, Eastern Australia, University of New England: 69-84.

Colwell, J.B. and Stagg, H.M.J., 1994. Structure of the offshore Canning Basin: First impressions from a regional deep-seismic data set. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 757-768.

Colwell, J.B. and Kennard, J.M. (Compilers), 1996. AGSO Petrel Sub-basin Study 1995-1996, Summary Report. AGSO Record 1996/40, pp122.

Davies, H.L., 1990. Structure and evolution of the Border region of New Guinea. In: Carman, G.J and Carman, Z. (Eds), Petroleum Exploration in Papua New Guinea: Proceedings of the First PNG Petroleum Convention, PNG Chamber of Mines and Petroleum: 245-269.

Didenko, A.N., Mossakovskii, A.A., Pecherskii, D.N., Ruzhentsev, S.V., Samygin, S.G. and Kheraskova, T.N., 1994. Geodynamics of the Central-Asian Paleozoic Ocean. In: Dobretsov, N.L., Coleman, R.G. and Berzin, N.A. (Eds), Geodynamic Evolution of the Paleoasian Ocean. Russian Geology and Geophysics, 35: 48-61.

Drummond, B.J., Sexton, M.J., Barton, T.J. and Shaw, R.D., 1991. The nature of faulting along the margins of the Fitzroy Trough, Canning Basin, and implications for the tectonic development of the trough. Exploration Geophysics, 22: 111-116.

Dunlap, W.J., Teyssier, C., McDougall, I. and Baldwin, S., 1991. Ages of deformation from $^{40}Ar/^{39}Ar$ dating of white micas. Geology, 19: 1213-1216.

Dunlap, W.J., Teyssier, C., Hirth, J.G. and McDougall, I., 1995a. Thermal, mechanical and kinematic evolution of a ductile duplex: Ruby Gap Duplex, Central Australia. Geological Society of Australia Abstracts, 40: 39-40.

Dunlap, W.J., Teyssier, C., McDougall, I. and Baldwin, S., 1995b. Thermal and structural evolution of the intracratonic Arltunga Nappe Complex, central Australia. Tectonics, 14: 1182-1204.

Eisenlohr, B.N., Tompkins, L.A., Cathles, L.A., Barley, M.E. and Groves, D.I., 1994. Mississippi Valley-type deposits: Products of brine expulsion by eustatically induced hydrocarbon generation? An example from northwestern Australia. Geology, 22: 315-318.

Embleton, B.J.J., 1981. A review of the paleomagnetism of Australia and Antarctica. In: McElhinny, M.W. and Valencio, D.A., (Eds), Paleoreconstruction of the continents. Geodynamics Series, 2: 77-92.

Embleton, B.J.J., 1984. Continental palaeomagnetism. In: Veevers, J.J. (Ed), Phanerozoic earth history of Australia. Oxford Geological Sciences Series 2, Clarendon Press, Oxford: 11-16.

Enkin, R., Yang, Z.Y., Chen, Y. and Courtillot, V., 1992. Palaeomagnetic constraints on the geodynamic history of China from the Permian to the Present. Journal of Geophysical Research, 97: 13953-13989.

Etheridge, M.A. and O'Brien, G.W., 1994a. Structural and tectonic evolution of the Western Australian margin basin system. The PESA Journal, 22: 45-63.

Etheridge, M.A. and O'Brien, G.W., 1994b. Structural and tectonic evolution of the Western Australian margin basin system. APEA Journal, 34: 906-908.

Exon, N.F. and Colwell, J.B., 1994. Geological history of the outer North West Shelf of Australia: a synthesis. AGSO Journal of Australian Geology & Geophysics, 15: 177-190.

Exon, N.F. and von Rad, U., 1994. The Mesozoic and Cainozoic sequences of the Northwest Australian margin, as revealed by ODP core drilling and related studies. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 181-199.

Fein, J.B. and Jurdy, D.M., 1986. Plate motion controls on back-arc spreading. Geophysical Research Letters, 13: 456-459.

Fergusson, C.L. and Leitch, E.C., 1993. Late Carboniferous to Early Triassic tectonics of the New England Fold Belt, eastern Australia. In: Flood, P.G and Aitchinson, J.C., (Eds), New England Orogen, Eastern Australia, University of New England: 53-59.

Flood, P.G. and Aitchison, J.C., 1992. Late Devonian accretion of the Gamilaroi terrane to eastern Gondwana: Provenance linkage suggested by the first appearance of Lachlan Fold Belt-derived quartzarenite. Australian Journal of Earth Sciences, 39: 539-544.

Forman, D.J. and Shaw, R.D., 1973. Deformation of the crust and mantle in central Australia. Bureau of Mineral Resources, Bulletin, 144, pp20.

Frotzheim, N. and Manatschal, G., 1996. Kinematics of Jurassic rifting, mantle exhumation, and passive - margin formation in the Austroalpine and Penninic nappes (eastern Switzerland). Geological Society of America Bulletin, 108: 1120-1133.

Gehrels, G.E. and Saleeby, J.B., 1987. Geologic framework, tectonic evolution, and displacement of the Alexander Terrane. Tectonics, 5: 151-173.

Giddings, J.W., Théveniaut, H. and Klootwijk, C.T., 1994. Late Palaeozoic APWP. AGSO94: 105-106.

Goleby, B.R., 1981. Early Palaeozoic palaeomagnetism in South East Australia. In: McElhinny, M.W., Khramov, A.N., Ozima, M. and Valencio, D.A. (Eds), Global reconstruction and the geomagnetic field during the Palaeozoic. Advances in Earth and Planetary Sciences, 10: 11-21.

Goscombe, D.B., Findlay, R.H., McClenaghan, M.P. and Everard, J., 1994. Multi-scale kinking in northeast Tasmania: crustal shortening at shallow crustal levels. Journal of Structural Geology, 8: 1077-1092.

Gradstein, F.M., 1992. Legs 122 and 123, Northwestern Australian margin - A stratigraphic and paleogeographic summary. In: Gradstein, F.M., Ludden, J.N. et al., Proceedings Ocean Drilling Program Scientific Results, 123. College Station, TX (Ocean Drilling Program): 801-816.

Gradstein, F.M. and von Rad, U., 1991. Stratigraphic evolution of Mesozoic continental and oceanic sequences: Northwest Australia and northern Himalayas. Marine Geology, 102: 131-173.

Gradstein, F.M., von Rad, U., Gibling, M.R., Jansa, L.F., Kaminski, M.A., Kristiansen, I-L., Ogg, J.G., Röh, U., Sarti, M., Thurow, J.W. and Wiedmann, J., 1992. Stratigraphic and depositional history of the Mesozoic continental margin of Central Nepal. Geologisches Jahrbuch, Reihe B, 77: 3-141.

Hall, R., 1996. Reconstructing Cenozoic SE Asia. In: Hall, R. and Blundell, D. (Eds), Tectonic evolution of Southeast Asia. Geological Society Special Publication, 106: 153-184.

Harrington, H.J. and Korsch, R.J., 1985. Deformation associated with accretion of the Gympie terrane in eastern Australia. Geological Society of Australia, Abstracts, 14: 104-108.

Hocking, R.M., Mory, A.J. and Williams, I.R., 1994. An atlas of Neoproterozoic and Phanerozoic basins of Western Australia. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 21-43.

Holcombe, R.J. and Little, T.A., 1994. Blueschists of the New England Orogen: Structural development of the Rocksberg Greenstone and associated units near Mt Mee, southeastern Queensland. Australian Journal of Earth Sciences, 41: 115-130.

Hongzhen Wang and Xuanxue Mo, 1996. An outline of the tectonic evolution of China. Episodes, 18: 6-16.

Idnurm, M., 1985. Late Mesozoic and Cenozoic palaeomagnetism of Australia 1. A redetermined apparent polar wander path. Geophysical Journal Royal Astronomical Society, 83: 399-418.

Idnurm, M., 1990. Comments on: 'A weighted least-squares fit of the Australian apparent polar wander path for the last 100 Myr' by R.J. Musgrave. Geophysical Journal International, 102: 191-193.

Idnurm, M., 1994. New Late Eocene pole for Australia, time-averaging of remanence, and palaeogeographic reference systems. Geophysical Journal International, 117: 827-833.

Irving, E., Thorkelson, D.J., Wheadon, P.M. and Enkin. R.J., 1995. Paleomagnetism of the Spences Bridge Group and northward displacement of the Intermontane Belt, British Columbia: A second look. Journal of Geophyical Research, 100: 6057-6071.

Irving, E., Wynne, P.J., Thorkelson, D.J. and Shiarizza, P., 1996. Large (1000 to 4000 km) northward movements of tectonic domains in the northern Cordillera, 83 to 45 Ma. Journal of Geophysical Research, 101: 17901-17916.

Jackson, M.J., Diekman, L.J., Kennard, J.M., Southgate, P.N., O'Brien, P.E. and Sexton, M.J., 1992. Sequence stratigraphy, basin-floor fans and petroleum plays in the Devonian-Carboniferous of the northern Canning Basin. APEA Journal, 32: 214-230.

Jones, B.G., 1991. Fluvial and lacustrine facies in the Middle to Late Devonian Pertnjara Group, Amadeus Basin, Northern Territory, and their relationship to tectonic events and climate. In: Korsch, R.J. and Kennard, J.M., (Eds), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin 236: 333-348.

Jupp, P.E. and Kent, J.T., 1987. Fitting smooth paths to spherical data. Applied statistics. 36/1: 34-46.

Kennard, J.M., Jackson, M.J., Romine, K.K., Shaw, R.D. and Southgate, P.N., 1994. Depositional sequences and associated petroleum systems of the Canning Basin, WA. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 657-676.

Khramov, A.N. and Rodionov, V.P., 1980. Paleomagnetism and reconstruction of paleogeographic positions of the Siberian and Russian plates during the Late Proterozoic and Palaeozoic. Journal of Geomagnetism and Geoelectricity, 32, Supplement III, SIII 23-SIII 37.

Khramov, A.N., Petrova, G.N. and Pechersky, D.M., 1981. Palaeomagnetism of the Soviet Union. In:

McElhinny, M.W. and Valencio, D.A., (Eds), Paleoreconstruction of the Continents. American Geophysical Union, Geodynamic Series, 2: 177-194.

Klein, G.D., Beauchamp, B., Baud, A., Chuvashov, B.I., Lopez-Gamundi, O.R., Parrish, J.T., Ross, C.A., Scholle, P.A., Scotese, C.R. and Watney, W.L., 1994. Introduction: Project Pangea and workshop recommendations. In: Klein, G.D., (Ed), Pangea: Paleoclimate, Tectonics, and Sedimentation During Accretion, Zenith and Breakup of a Supercontinent. Geological Society of America Special Paper, 288: 1-12.

Klootwijk, C.T., 1985. Palaeomagnetism of the Tasman Fold Belt: Indications of mid-Carboniferous large-scale southward displacement of the New England region. Third Circum-Pacific Terrane Conference, Geological Society of Australia. Extended Abstracts, 14: 124-127.

Klootwijk, C.T., 1980a. Early Palaeozoic palaeomagnetism in Australia 1: Cambrian results from the Flinders Ranges, South Australia. Tectonophysics, 264: 249-278.

Klootwijk, C.T., 1980b. Early Palaeozoic palaeomagnetism in Australia 2: late Early Cambrian results from Kangaroo Island, South Australia. Tectonophysics, 64: 278-293.

Klootwijk, C.T., 1980c. Early Palaeozoic palaeomagnetism in Australia 3: Middle to early Late Cambrian results from the Amadeus Basin, Northern Territory. Tectonophysics, 64: 293-332.

Klootwijk, C.T., 1984. A review of Indian Phanerozoic palaeomagnetism: Implications for the India-Asia collision. Tectonophysics, 105: 331-353.

Klootwijk, C., 1994. Late Palaeozoic palaeomagnetism of the Tamworth Belt: preliminary constraints on deformation and drift of New England. 12th Australian Geological Convention, Geological Society of Australia, Abstracts, 37: 222-223.

Klootwijk, C.T., 1995. Palaeomagnetism suggests mid-Carboniferous convergence between Greater Australia and Altaids. AGSO Research Newsletter, 22: 14-17.

Klootwijk, C.T., 1996a. Phanerozoic configurations of Greater Australia: Evolution of the North West Shelf. Part one, Review of reconstruction models. AGSO Record 1996/51, pp106.

Klootwijk, C., 1996b. Late Palaeozoic APWPs for New England and cratonic Australia: Implications for Carboniferous Gondwana-Laurasia tectonics. Geologie en Mijnbouw, under review.

Klootwijk, C.T., 1996c. Late Palaeozoic APWPs for New England and cratonic Australia: Implications for Gondwana-Laurasia relations. Annales Geophysicae, 14 Supplement 1: C140.

Klootwijk, C.T., 1996d. Australia's Late Palaeozoic APWPs: Ongoing riddle or new light on Carboniferous Gondwana-Laurasia tectonics. EOS Transactions American Geophysical Union, 77: W151.

Klootwijk, C.T., 1996e. Phanerozoic configurations of Greater Australia: Evolution of the North West

Shelf. Part three, Palaeomagnetic Data Base. AGSO Record 1996/53, pp148.

Klootwijk, C.T. and Bingham, D.K., 1980. The extent of Greater India 3: Palaeomagnetic data from the Tibetan Sedimentary Series, Central Nepal Himalaya. Earth Planetary Science Letters, 51: 381-405.

Klootwijk, C.T. and Giddings, J., 1993. Palaeomagnetic results of Upper Palaeozoic volcanics, northeastern Queensland, and Australia's Late Palaeozoic APWP. In: Flood, P.G and Aitchinson, J.C., (Eds), New England Orogen, Eastern Australia, University of New England: 617-627.

Klootwijk, C.T., Conaghan, P.J. and Powell, C.McA., 1985. The Himalayan Arc: Large-scale continental subduction, oroclinal bending and back-arc spreading. Earth Planetary Science Letters, 75: 167-183.

Klootwijk, C., Giddings, J.W. and Percival, P., 1993. Palaeomagnetic reconnaissance of Upper Palaeozoic volcanics, northeastern Queensland. AGSO Record 1993/36, pp88.

Klootwijk, C.T., Gee, J.S., Peirce, J.M. and Smith, G.M., 1991. Constraints on the India-Asia convergence: Paleomagnetic results from Ninetyeast Ridge, ODP Leg 121. In: Peirce, J., Weissel, J. et al., Proceedings Ocean Drilling Program Scientific Results, 121. College Station, TX (Ocean Drilling Program): 777-862.

Klootwijk, C.T., Gee, J. Peirce, J., Smith, G.M. and McFadden, P.L., 1992. An early India-Asia contact: Palaeomagnetic constraints from Ninetyeast Ridge, ODP Leg 121. Geology, 20: 395-398.

Klootwijk, C.T., Giddings, J., Pigram, C., Loxton, C., Davies, H., Rogerson, R. and Falvey, D. North Sepik region of Papua New Guinea: Palaeomagnetic constraints on arc accretion and deformation. Tectonophysics, in preparation.

Kodama, K. and Ogg, J.G., 1992. Motion of the Australian plate from sediment paleoinclinations, Early Cretaceous through Holocene. In: Gradstein, F.M., Ludden, J.N. et al., Proceedings Ocean Drilling Program Scientific Results, 123. College Station, TX (Ocean Drilling Program): 549-554.

Kohn, B.P. and Gleadow, A.J.W., 1994. The rise of the Snowy Mountains: when and how much: evidence from apatite fission track thermochronology. Geological Society of Australia Abstracts, 37: 226.

Korsch, R.J. and Harrington, H.J., 1987. Oroclinal bending, fragmentation and deformation of terranes in the New England Orogen, Eastern Australia - In: Leitch, E.C. and Scheibner, E., (Eds), Terrane accretion and orogenic belts. Geodynamics Series, 19: 129-139.

Korsch, R.J. and Totterdell, J.M., 1996. Mesozoic deformational events in eastern Australia and their impact on onshore sedimentary basins. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43: 308-318.

Krishnan, M.S., 1968. Geology of India and Burma. Higginbothams Limited, Madras, pp536.

Lackie, M.A. and Schmidt, P.W., 1993. Remagnetisation of strata during the Hunter-Bowen Orogeny. Exploration Geophysics, 24: 269-274.

Lackie, M.A. and Schmidt, P.W., 1996. Thermal events in the Sydney-Bowen Basin as defined by palaeomagnetism. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43: 319-328.

Laird, M.G., 1996. Mid and early Late Cretaceous break-up basins of the South Island, New Zealand. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43: 329-336.

Lemoine. M., 1983. Rifting and early drifting: Mesozoic Central Atlantic and Ligurian Tethys. In: Sheridan, R.M., Gradstein, F.M. et al., Initial Reports DSDP,76: Washington (U.S. Government Printing Office): 885-895.

Lemoine, M., 1984. Mesozoic evolution of the Western Alps. Annales Geophysicae, 2: 171-172.

Lemoine, M., Bas, T., Arnaud-Vanneau, A., Arnaud, H., Dumont, T., Gidon, M., Bourbon, M., de Graciansky, P.-C., Rudkiewicz, J.-L., Megard-Galli, J. and Tricart, P., 1986. The continental margin of the Mesozoic Tethys in the Western Alps. Marine and Petroleum Geology, 3: 179-199.

Li, Z.X., Chen, Z. and Powell, C.McA., 1993. New Late Palaeozoic palaeomagnetic results from cratonic Australia, and revision of the Gondwanan apparent polar wander path. Exploration Geophysics, 24: 263-268.

Li, Z.X., Powell, C.McA., Chen, Z., Baillie, P. and Balme, B.E., 1994a. Revision of the Palaeozoic apparent polar wander path for Gondwanaland, and implications for rapid continental drift. Geological Society of Australia, Abstracts, 37: 246-247.

Li, Z.X., Zhang, L. and Powell, C.McA., 1994b. Were the East Asian continental blocks part of Rodinia? Geological Society of Australia, Abstracts, 37: 248-249.

Li, Z.X., Zhang, L. and Powell, C.McA., 1996a. Roles of the major East Asian cratonic blocks in the assembly and breakup of supercontinent Rodinia. Geological Society of Australia, Abstracts 41: 249.

Li, Z.X., Zhang, L. and Powell, C.McA., 1996b. East Asia in Rodinia: Accretion and Breakup. EOS Transactions American Geophysical Union, 77: W19.

Lipski, P., 1994. Structural framework and depositional history of the Bedout and Rowley Sub-basins. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 769-777.

Lisk, M. and Eadington, P., 1994. Oil migration in the Cartier Trough, Vulcan Sub-basin. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 301-312.

Little, T.A., Holcombe, R.J. and McWilliams, M., 1993a. $^{40}Ar/^{39}Ar$ thermochronology of epidote-blueschists and granitoids from the North D'Aguilar block, Queensland: implications for the timing of metamorphism and unroofing in the New England Orogen. In: Flood, P.G and Aitchinson, J.C., (Eds), New England Orogen, Eastern Australia, University of New England: 549-564.

Little, T.A., Holcombe, R.J. and Sliwa, R., 1993b, Extensional exhumation of blueschist-bearing sepentinite-matrix melange in the New England Orogen of southeastern Queensland, Australia, Tectonics,12: 536-549.

Lock, J. and McElhinny, M.W., 1991. The Global Paleomagnetic Database: Design, Installation and Use with Oracle. Surveys in Geophysics, 12: 317-491.

Malcolm, R.J., Pott, M.C. and Delfos, E., 1991. A new tectonostratigraphic synthesis of the North West Cape Area. APEA Journal, 31: 154-176

McConachie, B.A., Bradshaw, M.T. and Bradshaw, J., 1996. Petroleum systems of the Petrel Sub-basin - An integrated approach to basin analysis and identification of hydrocarbon exploration opportunities. APPEA Journal, 36: 248-268.

McCracken, S., 1994. Timing of hydrocarbon migration into the Admiral Bay Fault Zone, Canning Basin. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 739-751.

McElhinny, M.W. and Lock, J., 1993. Global Paleomagnetic Database Supplement Number One: Update to 1992. Surveys in Geophysics, 14: 303-329.

McElhinny, M.W. and Lock, J., 1994. New Updates made to Paleomagnetic Databases. EOS Transactions American Geophysical Union, 75: 428.

McElhinny, M.W. and Lock, J., 1996. IAGA Paleomagnetic Databases with ACCESS. Surveys in Geophysics, 17: 575-591.

Metcalfe, I., 1990. Allochthonous terrane processes in Southeast Asia. Philosophical Transactions of the Royal Society of London, A331: 625-640.

Metcalfe, I., 1996. Pre-Cretaceous evolution of SE Asian terranes. In: Hall, R. and Blundell, D., (Eds), Tectonic evolution of Southeast Asia. Geological Society Special Publication, 106: 97-121.

Metcalfe, I. and Nicoll, R.S., 1994. Early-Middle Palaeozoic reconstructions of the India-NW Australian Gondwanaland margin. In: Proceedings of Symposium on "Gondwana Dispersion and Asian Accretion" IGCP Project 321, 22-27 August 1994, Seoul, Korea.

Miller, L.R. and Smith, S.A., 1996. The development and regional significance of rift-related depositional systems in the Dampier Sub-basin. APPEA Journal, 36: 369-384.

Monger, J.W.H. and Price, R.A., 1996. Comment on "Paleomagnetism of the Upper Cretaceous strata of Mount Tatlow: Evidence for 3000 km of northward displacement of the Eastern Coast belt, British Columbia" by P.J. Wynne et al., and on " Paleomagnetism of the Spences Bridge Group and northward displacement of the Intermontane Belt, British Columbia: A second look" by E. Irving et al. Journal of Geophysical Research, 101: 13793-13799.

Moore, M.E., Gleadow, J.W. and Lovering, J.F., 1986. Thermal evolution of rifted continental margins: new evidence from fission tracks in basement apatites from southeastern Australia. Earth and Planetary Science Letters, 78: 255-270.

Mory, A.J., 1988. Regional geology of the offshore Bonaparte Basin. In: Purcell, P.G and R.R., (Eds), The North West Shelf, Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988: 287-309.

Mory, A.J. and Beere, G.M., 1988. Geology of the onshore Bonaparte and Ord Basins in Western Australia. Geological Survey of Western Australia, Bulletin 134, pp183.

Mossakovsky, A.A., Ruzhentsev, S.V., Samygin, S.G. and Kheraskova, T.N., 1994. Central Asian Fold Belt: Geodynamic Evolution and Formation History. Geotectonics, 27: 445-474.

Musgrave, R.J., 1989. A weighted least-squares fit of the Australian apparent polar wander path for the last 100 Myr. Geophysical Journal, 96: 231-243.

Nicoll, R.S., 1995. Reworked Ordovician conodonts lead to an enhanced mineral and hydrocarbon potential in the southern Petrel Sub-basin, Western Australia. AGSO Research Newsletter, 23; 13-15.

Nie Shangyou, 1991. Paleoclimatic and paleomagnetic constraints on the Paleozoic reconstructions of South China, North China and Tarim. Tectonophysics, 196: 279-308.

Nie Shangyou, Rowley, D.B. and Ziegler, A.M., 1990. Constraints on the locations of Asian microcontinents in Palaeo-Tethys during the Late Palaeozoic. In: McKerrow, W.S. and Scotese, C.R., (Eds), Palaeozoic Biogeography and Palaeogeography, Geological Society of London Memoir, 12: 397-409.

Oaks, Jr.,R.Q., Deckelman, J.A., Conrad, K.T., Hamp, L.P., Philips, J.O. and Stewart, A.J., 1991. Sedimentation and tectonics in the northeastern and central Amadeus Basin, central Australia. In: Korsch, R.J. and Kennard, J.M., (Eds), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin 236: 73-90.

O'Brien, G.W., 1993. Some ideas on the rifting history of the Timor Sea from the integration of deep crustal seismic and other data. The PESA Journal, 21: 95-113.

O'Brien, G.W. and Woods, E.P., 1995. Hydrocarbon-Related Diagenetic Zones (HRDZs) in the Vulcan

Sub-basin, Timor Sea: Recognition and exploration implications. APEA Journal, 35: 220-252.

O'Brien, G.W., Lisk, M., Duddy, I., Eadington, P.J., Cadman, S. and Fellows, M., 1996. Late Tertiary fluid migration in the Timor Sea: A key control on the thermal and diagenetic histories? APPEA Journal, 36: 399-427.

O'Sullivan, P.B., Foster, D.A., Kohn, B.P. and Gleadow, A.J.W., 1995. Fission track data from the Bathurst Batholith: evidence for rapid middle Cretaceous uplift and erosion within the Eastern Highlands of Australia. Australian Journal of Earth Sciences, 42: 597-607.

O'Sullivan, P.B., Coyle, D.A., Gleadow, A.J.W. and Kohn, B.P., 1996. Late Mesozoic to Early Cenozoic thermotectonic history of the Sydney Basin and the Eastern Lachlan Fold Belt, Australia. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43: 424-432.

Ogg, J.G. and von Rad, U., 1994. The Triassic of the Thakkhola (Nepal) II: Paleolatitudes and comparison with other Eastern Tethyan margins of Gondwana. Geologische Rundschau, 83: 107-129.

Ogg, J.G., Kodama, K. and Wallick, B.P., 1992. Lower Cretaceous magnetostratigraphy and palaeolatitudes off Northwest Australia, ODP Site 765 and DSDP Site 261, Argo Abyssal Plain, and ODP Site 766, Gascoyne Abyssal Plain. In: Gradstein, F.M., Ludden, J.N. et al., Proceedings Ocean Drilling Program Scientific Results, 123. College Station, TX (Ocean Drilling Program): 523-548.

Opdyke, N.D., Claoué-Long, J., Roberts, J. and Irving, E., 1996a. Preliminary magnetostratigraphic results from the Carboniferous (Kiaman) of eastern Australia. Annales Geophysicae, 14 Supplement 1: C142.

Opdyke, N.D., Roberts, J., Irving, E. and Claoué-Long, J., 1996b. The magnetic stratigraphy of the Middle and Upper Carboniferous of the Rocky Creek and Werrie Syncline areas, N.S.W., Australia. EOS, 77: W27.

Parry, J.C. and Smith, D.N., 1988. The Barrow and Exmouth Sub-basins. In: Purcell, P.G and R.R., (Eds), The North West Shelf, Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988: 129-145.

Pigram, C.J. and Panggabean, H., 1984. Rifting of the northern margin of the Australian continent and the origin of some microcontinents in Eastern Indonesia. Tectonophysics, 107: 331-353.

Pigram, C.J. and Davies, H.L., 1987. Terranes and the accretion history of the New Guinea Orogen. BMR Journal of Australian Geology & Geophysics, 10: 193-211.

Pogson, D.J. and Hitchins, B.L., 1973. New England 1:500,000 Geological Sheet. Geological Survey of New South Wales, Sydney.

Pogue, K.R., DiPietro, J.A., Khan, S.R., Hughes, S.S., Dilles, J.H. and Lawrence, R.D., 1992. Late Palaeozoic rifting in northern Pakistan. Tectonics, 11: 871-883.

Powell, C.McA., 1984. Terminal fold-belt deformation: Relationship of mid-Carboniferous megakinks in the Tasman Fold Belt to coeval thrusts in cratonic Australia. Geology, 12: 546-549.

Powell, C.McA., Cole, J.P. and Cudahy, T.J., 1985. Megakinking in the Lachlan Fold Belt, Australia. Journal of Structural Geology, 7: 281-300.

Powell, C.McA., Roots, S.R. and Veevers, J.J., 1988. Pre-breakup continental extension in East Gondwanaland and the early opening of the eastern Indian Ocean. Tectonophysics, 155: 261-283.

Purcell, P.G. and Purceel, R.R., 1994. The sedimentary basins of Western Australia: An introduction. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 3-18.

Ramsay, D.C. and Exon, N.F., 1994. Structure and tectonic history of the northern Exmouth Plateau and Rowley Terrace: outer North West Shelf. AGSO Journal of Australian Geology & Geophysics, 15: 55-70.

Rangin, C., Jolivet, L., Pubellier, M. and the Tethys Pacific working group, 1990. Simple model for the tectonic evolution of Southeast Asia and the Indonesian region for the past 43 m.y. Bulletin de la Société Géologique de France, 6: 889-905.

Richardson, A.N. and Blundell, D.J., 1996. Continental collision in the Banda Arc. In: Hall, R. and Blundell, D. (Eds), Tectonic evolution of Southeast Asia. Geological Society Special Publication, 106: 47-60.

Roberts, J., 1981. Control mechanisms of Carboniferous brachiopod zones in eastern Australia. Lethaia, 14: 123-134.

Roberts, J., Engel, B. and Chapman, J., 1991. Geology of the Camberwell, Dungog and Bulahdelah 1:100,000 Sheets 9133,9233,9333. New South Wales Geological Survey, Sydney: pp382.

Roberts, J., Jones, P.J. and Jenkins, T.B.H., 1993. Revised correlations for Carboniferous marine invertebrate zones of eastern Australia. Alcheringa, 17: 353-376.

Roberts, J., Claoué-Long, J.C. and Jones, P.J., 1995a. Australian Early Carboniferous Time. In Geochronoloy Time Scales and Global Stratigraphic Correlation, SEPM Special Publication, 54: 23-40

Roberts, J., Claoué-Long, J., Jones, P.J. and Foster, C.B., 1995b. SHRIMP zircon age control of Gondwanan sequences in Late Carboniferous and Early Permian Australia. In: Dunay, R.E. and Hailwood, E.A., (Eds), Non-biostratigraphic Methods of Dating and Correlation. Geological Society Special Publication, 89: 145-174.

Roberts, J., Claoué-Long, J.C. and Foster, C.B., 1996. SHRIMP zircon dating of the Permian System of eastern Australia. Australian Journal of Earth Sciences, 43: 401-421.

Romine, K.K., Southgate, P.N., Kennard, J.M. and Jackson, M.J., 1994. The Ordovician to Silurian phase of the Canning Basin WA: Structure and sequence evolution. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 677-696.

Romine, K.K., Cassim, G. and Survey 136 Shipboard Party, 1995. High resolution seismic survey of the Northern Carnarvon Basin, North West Shelf, Australia: Survey 136 post-cruise report. AGSO Record 1995/17, pp47.

Schmidt, P.W., Embleton, B.J.J., Cudahy, T.J. and Powell, C.McA., 1986. Prefolding and pre-megakinking magnetization from the Devonian Comerong Volcanics, New South Wales, Australia, and their bearing on the Gondwana Pole Path. Tectonics, 5: 135-150.

Schmidt, P.W., Embleton, B.J.J. and Palmer, H.C., 1987. Pre- and post-folding magnetizations from the Early Devonian Snowy River Volcanics and Buchan Caves Limestone, Victoria. Geophysical Journal Royal Astronomical Society, 91: 155-170.

Schmidt, P.W., Powell, C.McA., Li, Z.X. and Thrupp, G.A. 1990. Reliability of Palaeozoic palaeomagnetic poles and APWP of Gondwanaland. Tectonophysics, 184: 87-100.

Schmidt, P.W. and Lackie, M.A., 1993. Permian remagnetisations and the deformation of the New England Fold Belt. In: Flood, P.G and Aitchinson, J.C., (Eds) New England Orogen, Eastern Australia, University of New England: 299-307.

Schmidt, P.W., Clark, D.A. and Rajagopalan, S., 1993. An historical perspective of the Early Palaeozoic APWP of Gondwana: New results from the Early Ordovician Black Hill Norite, South Australia. Exploration Geophysics, 24: 257-262.

Scotese, C.R., 1984. Paleozoic paleomagnetism and the assembly of Pangea. In: Van der Voo, R., Scotese, C.R. and Bonhommet, N., (Eds), Plate Reconstruction from Paleozoic Paleomagnetism. Geodynamic Series, 12: 1-10.

Scotese, C.R. & Barrett, S.F., 1990. Gondwana's movement over the South Pole during the Palaeozoic: evidence from lithological indicators of climate - In: McKerrow, W.S. and Scotese, C.R., (Eds) Palaeozoic Palaeogeography and Biogeography. Geological Society of London Memoir, 12: 75-85.

Scotese, C.R. and McKerrow, W.S., 1990. Revised World maps and introduction. In: McKerrow, W.S. and Scotese, C.R., (Eds), Palaeozoic Biogeography and Palaeogeography, Geological Society of London Memoir, 12: 1-21.

Šengör, A.M.C., 1984. The Cimmeride Orogenic System and the Tectonics of Eurasia. Geological Society of America Special Paper, 195: pp82.

Şengör, A.M.C., 1985. Die Alpiden und die Kimmeriden: Die verdoppelte geschichte der Tethys. Geologische Rundschau, 74: 181-213.

Şengör, A.M.C., 1987. Tectonics of the Tethysides: Orogenic collage development in a collisional setting. Annual Reviews of Earth and Planetary Sciences, 15: 213-244.

Şengör, A.M.C., Demir Altmer, Altan Cin, Timur Ustaomer and Hsü, K.J., 1988. Origin and assembly of the Tethyside orogenic collage at the expense of Gondwanaland. In: Audley-Charles, M.G. and Hallam, A. (Eds), Gondwana and Tethys, Geological Society Special Publication, 37: 119-181.

Şengör, A.M.C., Natal'in, B.A. and Burtman, V.S., 1993. Evolution of the Altaids tectonic collage and Palaeozoic crustal growth. Nature, 364: 299-307.

Şengör, A.M.C., Natal'in, B.A. and Burtman, V.S., 1994. Tectonic evolution of the Altaides. Russian Geology and Geophysics, 35: 33-47.

Shaw, R.D., 1991. The tectonic development of the Amadeus Basin, central Australia. In: Korsch, R.J. and Kennard, J.M., (Eds), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin 236: 429-461.

Shaw, R.D., Etheridge, M.A. and Lambeck, K., 1991a. Development of the Late Proterozoic to mid-Palaeozoic intracratonic Amadeus Basin in central Australia: A key to understanding tectonic forces in plate interiors. Tectonics, 1991. 688-721.

Shaw, R.D., Sexton, M.J. and Zeilinger, I., 1994. The tectonic framework of the Canning Basin, W.A., including the 1:2 million structural elements map of the Canning Basin. AGSO Record 1994/48, pp89.

Shaw, R.D., Korsch, R.J., Wright, C. and Goleby, B.R., 1991b. Seismic interpretation and thrust tectonics of the Amadeus Basin, central Australia, along the BMR regional seismic line. In: Korsch, R.J. and Kennard, J.M., (Eds), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin 236: 385-408.

Shaw, R.D., Tyler, I.M., Griffin, T.J. and Webb, A., 1992a. New K-Ar constraints on the onset of subsidence in the Canning Basin, Western Australia. BMR Journal of Australian Geology & Geophysics, 13: 31-35.

Shaw, R.D., Zeitler, P.K., McDougall, I. and Tingate, P.R., 1992b. The Palaeozoic history of an unusual intracratonic thrust belt in central Australia based on ^{40}Ar-^{39}Ar, K-Ar and fission track dating. Journal of the Geological Society, London, 149: 937-954.

Shaw, R.D., Wellman, P., Gunn, P., Whitaker, A.J., Tarlovski, C. and Morse, M., 1995. 'Australian crustal elements' map: A geophysical model for the tectonic framework of the continent. AGSO Research Newsletter, 23: 1-3.

Snyder, D.B., Milsom, J. and Prasetyo, H., 1996. Geophysical evidence for local indentor tectonics in the Banda Arc east of Timor. In: Hall, R. and Blundell, D. (Eds), Tectonic evolution of Southeast Asia. Geological Society Special Publication, 106: 61-73.

Southgate, P.N., Kennard, J.M., Jackson, M.J., O'Brien, P. and Sexton, M.J., 1994. Reciprocal lowstand clastic and highstand carbonate sedimentation, subsurface Devonian reef complex, Canning Basin, Western Australia. In: Loucks, R.G. and Sarg, J.F. (Eds), Carbonate sequence stratigraphy, recent developments and applications. American Association of Petroleum Geologists, Memoir 57: 157-179.

Stagg, M.J. and Colwell, J.B., 1994. The structural foundations of the Northern Carnarvon Basin. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 349-364.

Stephens, C.J., Holcombe, R.J., Fielding, C.R. and Gust, D.A., 1996. Tectonic evolution of the eastern Gondwanaland margin during the Late Palaeozoic and Early Mesozoic. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43: 517-518.

Stewart, A.J., Oaks, Jr.,R.Q., Deckelman, J.A. and Shaw, R.D., 1991. 'Mesothrust' versus 'megathrust' interpretations of the structure of the northeastern Amadeus Basin, central Australia. In: Korsch, R.J. and Kennard, J.M., (Eds), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin 236: 361-383.

Struckmeyer, H.I.M., Yeung, M. and Pigram, C.J., 1993. Mesozoic to Cainozoic plate tectonic and palaeogeographic evolution of the New Guinea region. In: Carman, G.J. and Carman, Z. (Eds), Petroleum Exploration in Papua New Guinea: Proceedings of the Second PNG Petroleum Convention, PNG Chamber of Mines and Petroleum: 261-290.

Symonds, P.A., Collins, C.D.N. and Bradshaw, J., 1994. Deep structure of the Browse Basin: Implications for basin development and petroleum exploration. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 315-331.

Symonds, P.A., Colwell, J.B., Struckmeyer, H.I.M., Willcox, J.B. and Hill, P.J., 1996. Mesozoic rift basin development off eastern Australia. In: Mesozoic 96, Geological Society of Australia, Extended Abstracts, 43:528-542.

Teichert, C., 1939. The Mesozoic transgressions in Western Australia. Australian Journal of Science, 2: 84-86.

Teichert, C., 1951. The marine Permian faunas of Western Australia. Zeitschrift für Palaeontologie, 24: 76-90.

Teyssier, C., 1985. A crustal thrust system in an intracratonic tectonic environment. Journal of Structural Geology, 7: 689-700.

Théveniaut, H., Klootwijk, C., Foster, C. and Giddings, J. Newcastle Coal Measures, AGSO95, in press.

Torsvik, T.H. and Smethurst, M.A., 1995. GMAP for Windows (version 3.0). Geographic mapping and palaeoreconstruction package: Software description and examples of Palaeoreconstruction. Norges Geologiske Undersøkelse Report: pp73.

Van der Voo, R., 1993. Palaeomagnetism of the Atlantic, Tethys and Iapetus Oceans. Cambridge University Press, Cambridge: pp411.

Veevers, J.J., 1984. Phanerozoic earth history of Australia. Oxford Geological Sciences Series, 2. Clarendon Press, Oxford, pp418.

Veevers, J.J., 1988. Morphotectonics of Australia's northwestern margin - A review. In: Purcell, P.G and R.R., (Eds), The North West Shelf, Australia: Proceedings of Petroleum Exploration Society Australia Symposium, Perth, 1988: 19-27.

Veevers, J.J., 1989. Middle/Late Triassic (230±5 Ma) singularity in the stratigraphic and magmatic history of the Pangean heat anomaly. Geology, 17: 784-787.

Veevers, J.J., 1990. Antarctica-Australia fit resolved by satellite mapping of oceanic fracture zones. Australian Journal of Earth Sciences, 37: 123-126.

Veevers, J.J. and Li, Z.X., 1991. Review of seafloor spreading around Australia. II. Marine magnetic anomaly modelling. Australian Journal of Earth Sciences, 38: 391-408.

Veevers, J.J., Powell, C.McA. and Roots, S.R., 1991. Review of seafloor spreading around Australia. I. Synthesis of the patterns of spreading. Australian Journal of Earth Sciences. 38: 373-389.

Veevers, J.J., Conaghan, P.J. and Shaw, S.E., 1993. Permian and Triassic New England Orogen/Bowen-Gunnedah-Sydney Basin in the context of Gondwanaland and Pangea. In: Flood, P.G and Aitchinson, J.C., (Eds), New England Orogen, Eastern Australia, University of New England: 31-51.

Veevers, J.J., Clare, A. and Wopfner, H., 1994a. Neocratonic magmatic-sedimentary basins of post-Variscan Europe and post-Kanimblan eastern Australia generated by right-lateral transtension of Permo-Carboniferous Pangaea. Basin Research, 6: 141-157.

Veevers, J.J., Conaghan, P.J., Powell, C.McA., Cowan, E.J., McDonnell, K.L and Shaw, S.E., 1994b. Eastern Australia. In: Veevers, J.J. and Powell, C.McA., (Eds), Permian-Triassic Pangean basins and foldbelts along the Panthalassan margin of Gondwanaland. Geological Society of America Memoir, 184: 11-171.

von Rad, U., Exon, N.F. and Haq, B.U., 1992a. Rift-to-drift history of the Wombat Plateau, Northwest Australia: Triassic to Tertiary Leg 122 results. In: von Rad, U., Haq, B.U. et al., Proceedings Ocean Drilling Program Scientific Results, 121. College Station, TX (Ocean Drilling Program): 765-800.

von Rad, U., Exon, N.F., Boyd, B., Haq, B.U., 1992b. Mesozoic paleoenvironment of the rifted margin off NW Australia (ODP Legs 122/123). In: Duncan, R.A., Rea, D.K., Kidd, R.B., von Rad, U. and Weissel, J.K., (Eds), Synthesis of results from scientific drilling in the Indian Ocean. American Geophysical Union Geophysical Monograph, 70: 157-184.

Walley, A.M. and Cook, P.J., (Compilers), with contributions from Bradshaw, J., Brakel, A.T., Kennard, J.M., Lindsay, J.F., Nicoll, R.S., Olissoff, S., Owen, M., Shergold, J.H., Totterdell, J.M. and Young, G.C., 1991. The Palaeozoic palaeogeography of the Amadeus Basin region. In: Korsch, R.J. and Kennard, J.M., (Eds), Geological and geophysical studies in the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin, 236: 155-169.

Walter, M.R. and Gorter, J.D., 1994. The Neoproterozoic Centralian Superbasin in Western Australia: The Savory and Officer Basins. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 851-864.

Warris, B.J., 1994. The hydrocarbon potential of the onshore Carnarvon Basin. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 365-372.

Wells, A.T., Forman, D.J., Ranford, L.C. and Cook, P.J., 1970. Geology of the Amadeus Basin, central Australia. Bureau of Mineral Resources Geology and Geophysics, Bulletin, 100, pp222.

Wells, A.T. and Moss, F.J., 1983. The Ngalia Basin, Northern Territory: stratigraphy and structure. Bureau of Mineral Resources, Australia, Bulletin, 212, pp82.

Whittam, D.B., Norvick, M.S. and McIntyre, C.L., 1996. Mesozoic and Cainozoic tectonostratigraphy of western Zoca and adjacent areas. APPEA Journal, 36: 209-232.

Woods, E.P., 1992. Vulcan Sub Basin fault styles - Implications for hydrocarbon migration and entrapment. APEA Journal, 32: 138-158.

Woods, E.P., 1994. A salt-related detachment model for the development of the Vulcan Sub-basin. In: Purcell, P.G. and Purcell, R.R. (Eds), The sedimentary basins of Western Australia: 259-274.

Wynne, P.J., Irving, E., Maxson, J.A. and Kleinspehn, K.L., 1995. Paleomagnetism of the Upper Cretaceous strata of Mount Tatlow: Evidence for 3000 km of northward displacement of the eastern Coast Belt, British Columbia. Journal of Geophysical Research, 100: 6073-6091.

Wynne, P.J., Thorkelson, D.J., Kleinspehn, K.L., Maxson, J.A. and Irving, E., 1996. Reply. Journal of Geophysical Research, 101: 13801-13803.

Yeates, A.N., Bradshaw, M.T., Dickins, J.M., Brakel, A.T., Exon, N.F., Langford, R.P., Mulholland, S.M., Totterdell, J.M. and Yeung, M., 1987. The Westralian Superbasin: An Australian link with Tethys. In: McKenzie, K.G., (Ed), Shallow Tethys 2, Balkema, Roterdam: 199-213.

Young, D.N., Edgoose, C.J., Blake, D.H. and Shaw, R.D., 1995. Mount Doreen SF52-12 explanatory notes - 1:250 000 Geological Map Series Explanatory Notes, pp55.

Young, G.C. and Laurie, J.R., (Eds) 1996. An Australian Phanerozoic Timescale. Oxford University Press, pp279.

Zhang, L., Li, Z.X. and Powell, C.McA., 1994. Correlation of the Neoproterozoic glacigene sequences between China and Australia. Geological Society of Australia, Abstracts, 37: 483-484.

Zhao,X., Coe, R.S., Gilder, S.A. and Frost, G.M., 1996. Palaeomagnetic constraints on the palaeogeography of China: Implications for Gondwanaland. Australian Journal of Earth Sciences, 43: 643-672.

Zonenshain, L.P., Kuzmin, M.I. and Natapov, L.M., 1990. Geology of the USSR: A Plate-Tectonic Synthesis. American Geophysical Union, Geodynamics Series, 21, pp242.