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The regional tectonics of the Tasman orogenic system, eastern Australia

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and

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Abstract—From the perspective of Phanerozoic mountain belts the mostly Paleozoic Tasman orogenic system of eastern Australia is unique. For example, it has no through-going miogeocline or foreland fold and thrust belt. Except for a narrow deformed fringe along its western margin the entire system is 'suspect' in the sense that its paleogeography is uncertain through much of Paleozoic time. The tectonic evolution of the Tasman orogenic system is composed of four major phases. The first was a prolonged late Proterozoic–early Paleozoic period of variable tectonic settings characterized by generally deep-marine turbiditic sedimentation and submarine volcanism, and shifting, somewhat local, deformation, metamorphism and plutonism. The second epoch was a major mid-Paleozoic period of deformation, volcanism and plutonism that consolidated a belt of lower Paleozoic interior terranes into Australia. The third epoch was a major accretionary phase in the outer New England belt of terranes that culminated in late Paleozoic time, and continued into the early Mesozoic. The final epoch was extensional, and was due to the break-up of Gondwanaland in late Mesozoic time, continuing to the present. Tectonic evolution during the first three phases was somewhat similar to that of the remainder of the nearly 20,000 km long Pacific margin of Gondwanaland in the Andes and Antarctica, and suggests that 'absolute' motions of Gondwanaland itself prior to break-up may have influenced the tectonics of its Pacific margin.

INTRODUCTION

THE TASMAN orogenic system (Scheibner 1978a, see also Scheibner 1978b, 1986 for very useful reviews) is a mainly Paleozoic to early Mesozoic mountain belt which makes up the eastern one-third of the Australian continent (Figs. 1 and 2). It stretches over 4000 km from Tasmania in the south to Cape York in northern Queensland and is as wide as 1500 km. Considering that at least one-third of the original mountain belt has been extended and submerged beneath the Tasman Sea by late Mesozoic–Cenozoic rifting and sea-floor spreading, this orogenic edifice was a mighty one; equal, say, to the width of the North American Cordillera in western United States. Although its length today is short, when it formed it was on the extremity of an orogenic system almost 20,000 km long. This orogenic system extended along the Pacific margin of Gondwanaland from the northern Andes of South America through the Pacific margin of Antarctica and into eastern Australia.

The Tasman orogenic system lies east of the Archean and lower to middle Proterozoic cratonic crystalline basement of Australia. A narrow fringe of deformed upper Proterozoic sediments sitting on basement is locally exposed along the southwestern margin of the orogen, and a narrow belt of deformed basement intruded by Paleozoic plutons is found on the northwestern margin. Otherwise, no unequivocal exposures of this ancient crystalline basement are known anywhere within the Tasman belt. It is at least possible that none of this basement exists at depth. Instead, the Tasman orogenic system is mostly made up of fairly deep-marine Paleozoic sedimentary and volcanic rocks, and Paleozoic to lower Mesozoic volcanic and plutonic material. The amount of granitic material is extraordinary, reaching nearly one-third of the exposure in some sectors. Finally, as much as two-thirds of the Tasmanides are buried beneath mostly flat-lying upper Paleozoic to Mesozoic–Cenozoic cover, such as the vast but shallow Murray and Great Australian basins.

All of the Tasman orogenic system east of the exposed or projected Precambrian crystalline cratonic basement of Australia can be considered as made up of 'suspect terranes' (Scheibner 1985, Leitch & Scheibner 1987, Coney 1988). All this means is that if the methods of terrane analysis are rigorously followed (Jones *et al.* 1983, Coney 1989) most of the Tasman orogen emerges as composed of tectonostratigraphic terranes. This does not necessarily mean that we, or others, have concluded the Tasman is all 'exotic' to Australia or that parts of it have come from California. Although there has certainly been significant accretion, the main point is the uncertainty in paleogeography. That is to say, we are uncertain about the exact paleotectonic settings and original paleogeographic relationships between the identified terranes and the Australian craton, and between many of the various terranes themselves, through large portions of Paleozoic time.

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For our purposes the Tasman orogenic system (Fig. 2) can be perceived to consist of three major divisions (Coney 1988). The first division is that part of the Precambrian crystalline cratonic basement of Australia and its upper Proterozoic–Phanerozoic platform cover that has been locally deformed by early Paleozoic Tasman orogenesis, and now exposed as a narrow fringe along the southwestern margin of the orogen in the Adelaide–Broken Hill region of South Australia and western New South Wales, and the intruded and deformed Precambrian of the Georgetown block in Queensland. The second division is the mainly lower to mid-Paleozoic terranes of Tasmania, the Lachlan, Thompson and north Queensland portions of the Tasman orogenic system, which generally form an inner belt of tectonic elements. They were mainly deformed and consolidated into Australia by mid-Paleozoic orogeny. The third part is the Greater New England terranes, which generally lie in an outer or eastern position and are mainly of mid- to late Paleozoic age. Consolidation of the Greater New England belt started in the Carboniferous and continued into the early Mesozoic.

This report is based on regional tectonic analysis and compilations during 1987–1988 at a scale of 1:1,000,000 using 26 base maps covering eastern Australia. Sources included all available published geologic and geophysical maps from the Bureau of Mineral Resources and the various state surveys, some unpublished observations from BHP-Utah files, a considerable aeromagnetic data base manipulated at BHP-Utah, field excursions by the authors and selected outside advisors, and all the published literature thought germane to the purposes of the project. Figure 1, the tectonic assemblage map, is a much reduced, simplified and generalized summary of the regional 1:1,000,000 compilations.

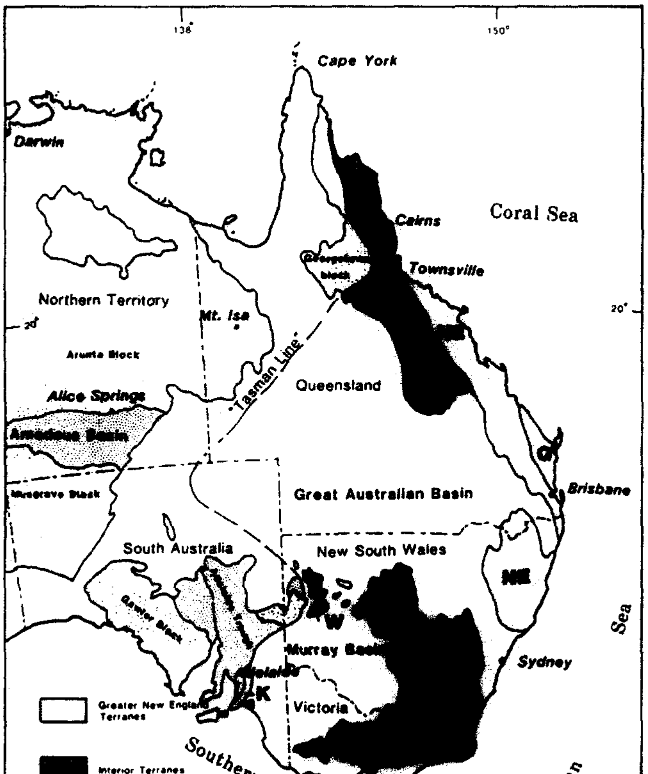

Fig. 2. Principal features of the Tasman orogenic system. The major tectonostratigraphic terranes are indicated by bold letters: T: Tasmania, L: Lachlan, K: Kanmantoo, W: Wonominta, B: Brewery (Anakie), CT: Charters Towers, H–C: Hodgkinson–Camel–Graveyard Creek, Balcooma, Sandalwood, NE: Greater New England, G: Gympie.

THE AUSTRALIAN CRATONIC MARGIN, ITS PLATFORM COVER AND THE BOUNDARY WITH THE SUSPECT TERRANES

General statement

The principal exposures of the Archean to mid-Proterozoic crystalline basement of the Australian craton and its upper Proterozoic–early Paleozoic platform cover are in the Adelaide–Broken Hill region of South Australia and far western New South Wales, the Musgrave–Amadeus–Arunta region of central Australia, the Mount Isa region of northwest Queensland, and the north Queensland Georgetown block (Fig. 2). The actual boundary between the craton and the Tasman orogenic system is only exposed in the Adelaide region and along the east side of the Georgetown block. Elsewhere the margin is widely covered by upper Paleozoic–Mesozoic–Cenozoic sedimentary basins and plains of the interior deserts of east-central Australia.

The Adelaide region

The first deposits of the platform cover upon the Archean to mid-Proterozoic crystalline basement of Australia are the upper Proterozoic Adelaidean sequences of the Flinders ranges–Adelaide region of South Australia (Parker 1986, Preiss 1987, 1988). In this region (Fig. 3) initial deposition seems to date from about 1100 Ma ago and took the form of marine to deltaic sandstones and shales, lagoonal evaporites, dolomites and other carbonates. Thicknesses and facies change rapidly both up and across sections but attain local maxima of 10,000 m. Deposition is usually interpreted to have been associated with elongate intracratonic rifts and was locally accompanied by alkaline volcanism. At about 800 Ma ago (?), there was a transition to more stable settings, and dominantly glaciogene marine shallow-water sedimentation occurred over wide areas continuing into latest late Proterozoic time. The entire assemblage takes on the aspect of the sedimentary fill of a sprawling late Proterozoic intracratonic rift which probably extended east of the Stuart shelf from the continental margin east of present-day Adelaide northward and westward into the Amadeus basin of central Australia (Von der Borch 1980, Preiss 1987, 1988).

The Adelaidean sequence is then widely transgressed by Lower Cambrian mostly shelf sediments which,

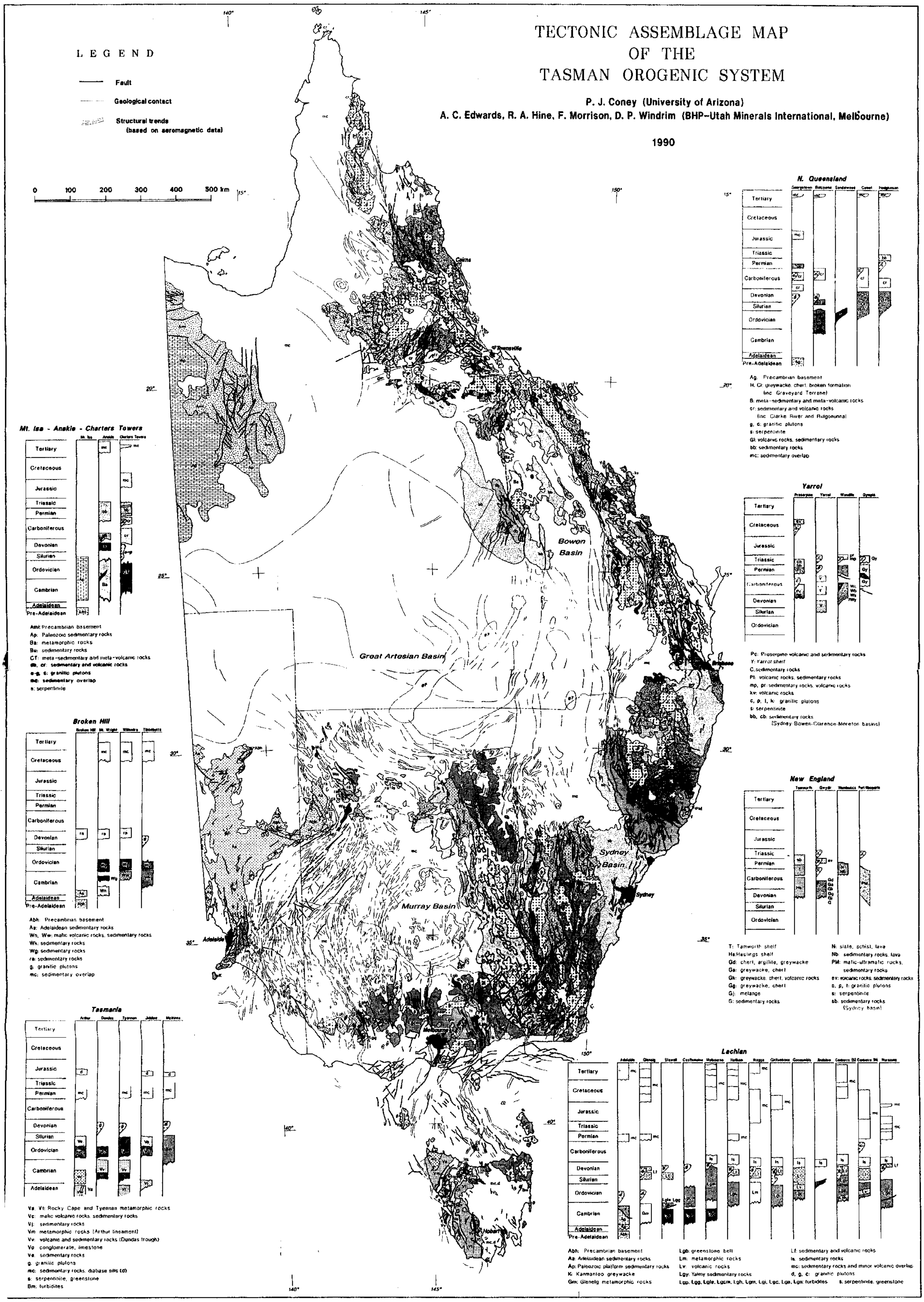

Fig. 1. Tectonic assemblage map of the Tasman orogenic system. This generalized tectonic map of eastern Australia shows the main tectonic assemblages of the Tasman orogenic system discussed in the text. Although no terrane boundaries are shown as such on the map, in general the terranes and sub-terranes are indicated by the individual columns in the margin and by capitalized lithologic symbols on the map (see also Fig. 2). Overlap assemblages and plutons are given by lower case symbols.

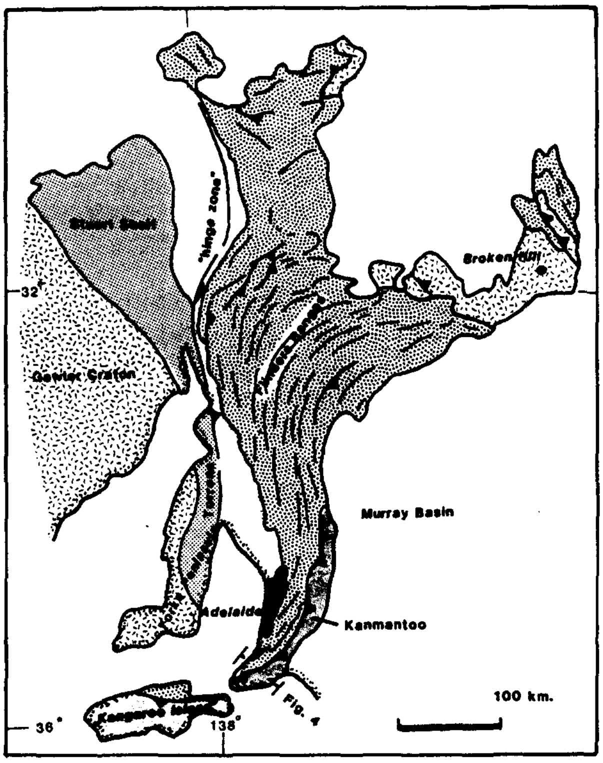

Fig. 3. Main features of the Adelaide–Broken Hill region. Dash pattern: Precambrian basement. Heavy stipple: Adelaidean trough and Stuart shelf late Proterozoic sediments. Dark shading: Cambrian Kanmantoo greywackes.

where last seen east and southeast of Adelaide, suggest facies trends towards deeper water. Then, in an arcuate strip along the southeastern extremity of the known Adelaidean and its Cambrian cover are the very thick deep-water greywacke sands and muds of the Cambrian Kanmantoo Group (Parker 1986, Preiss 1987, 1988). They stretch over a distance of nearly 500 km from northeast of Adelaide to Kangaroo Island. These rocks are now intensely folded and thrust against, and locally upon, the Adelaidean shelf (Fig. 4) We seem here to be in some sense at the edge of cratonic Australia in Cambrian time and in the strict sense the Kanmantoo is the first suspect terrane outboard of cratonic Australia. Most of its contacts with the Adelaidean–Lower Cambrian platform are faulted. But many workers argue, based on facies relationships and a very few local exposures of depositional contacts, that the Kanmantoo is simply the distal deep-water equivalent of the upper Lower to lower Middle Cambrian shelf sequences of the platform. The question then is: What produced the sudden influx of detrital Kanmantoo sediment and what produced the basin in which to deposit and preserve it? There seems to be no consensus. It could have been a major rifting of the Australian margin shelf. Another possibility was perhaps the arrival, or obduction, of an allochthon somewhere to the east of present exposures in Middle Cambrian time. This could have flexed the margin down to receive the enormous piles of Kanmantoo sand and mud from the interior of Australia.

The abrupt juxtaposition of very disparate facies seen today, however, took place during Late Cambrian–Early Ordovician Delamerian orogeny. This orogeny placed allochthonous sheets of duplexed NW-vergent deformed Kanmantoo Group over the Adelaidean shelf (Jenkins in press), folded the shelf into classic foreland folds and detachment style thrusts, and generated scattered granites which intrude the Kanmantoo Group as well as the Adelaidean shelf itself (Fig. 1). The Delamerian orogeny has been correlated with the Ross orogeny typical of the Transantarctic Mountains in East Antarctica (Craddock 1982, Bradshaw *et al.* 1985).

The Tasman line

From the Adelaide–Broken Hill region northward to the Georgetown block, a distance of over 2000 km, the boundary between the Australian craton and the various generally deep-water Paleozoic terranes of the Tasman orogen is obscured by variable widths of younger overlapping sediments (Fig. 2). In places the width of cover is less than 100 km, such as east of the Broken Hill salient, but elsewhere it is hundreds of kilometers between exposures of cratonic Australia and the suspect terranes. The supposed boundary has been referred to as the "Tasman line" (Hill 1951) and its trace has been guided by proposed lineaments, geophysical trends and limits of outcrop or drill data.

The Georgetown block

In the Georgetown block, however, the Precambrian

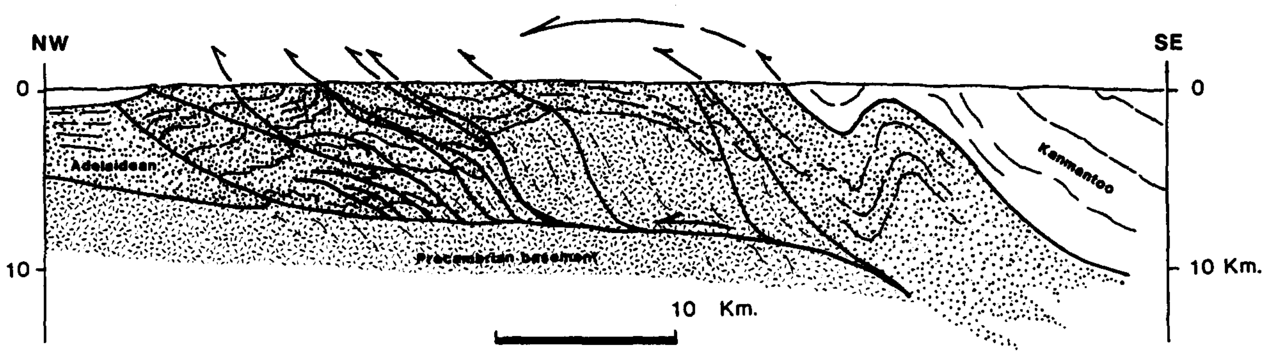

Fig. 4. Diagrammatic structure-section of the Adelaide region. Section shows the southern end of the Adelaide fold belt just south of Adelaide with the folded Adelaidean sequence (stippled) over Precambrian basement (dashed). The Kanmantoo (dark shading) is shown thrust northeastward over both (after Jenkins in press).

basement is abruptly juxtaposed against lower Paleozoic intensely deformed generally deep-marine rocks of the Hodgkinson and Camel terranes, or is separated from them by a narrow slice of the Balcooma terrane. The boundary is everywhere faulted and/or mylonitized, and the faults appear steep and remarkably straight over large distances.

Summary

In summary, a remarkable fact here is the apparent abrupt juxtaposition of the lower Paleozoic suspect terranes of the Tasman orogen, which for the most part display deep-marine aspects, directly against the platform-like margin of the Australian Precambrian craton. Although widely obscured by younger cover, where exposed the juxtaposition is either across major faults, or sometimes across narrow belts of poor exposure. Unlike Phanerozoic mountain belts in North America, for example, which preserve well-developed miogeoclinal 'transitional' facies from the cratonic platform into the orogen, the Tasman orogenic system has no obvious through-going miogeoclinal prism (Coney 1988). This raises an important question as to what the nature of the transition was from craton to the suspect terranes. It has become popular to consider all such boundaries as rifted continental margins, and this may indeed be correct here (Scheibner 1985), but upon reflection not all margins can be rifted ones for eventually one runs out of available displaced equivalents. An alternative might be that the so-called Tasman line might have been in part simply a Precambrian accretionary margin that always faced an ocean. Local margin-parallel strike-slip faulting and/or extensional attenuation could have modified it considerably. Because of Gondwanaland's great size its 'freeboard' might have been anomalously high (Hay *et al.* 1981, Dickinson 1988), thus inhibiting 'transitional' facies. This type of continental margin has not been discussed very much and needs to be elaborated.

LOWER TO MID-PALEOZOIC TERRANES OF THE INTERIOR TASMAN OROGEN

General statement

The grouping of lower to mid-Paleozoic interior terranes (Fig. 2) of the Tasman orogenic system is made up of nine tectonostratigraphic terranes, most of the larger ones being best considered as composite (i.e. subdivided into sub-terranes). Included would be the larger composites of Tasmania, Lachlan, Wonominta, Brewery (Anakie inlier), Charters Towers and Hodgkinson–Camel terranes, then the smaller Glenelg, Balcooma and Sandalwood terranes (Fig. 1). These terranes display a remarkable heterogeneity in lithologic associations. The exact original paleogeographic relationships between these terranes and the Australian craton are not obvious, nor often are the paleogeographic relationships between the terranes themselves.The thread that binds them together is they all for the most part are composed of lower to mid-Paleozoic rocks, the majority of which are of deep-marine aspect, and they seem to have been consolidated into Australia by widespread early to mid-Paleozoic orogeny.

The Glenelg terrane

The Glenelg terrane (Gibson 1988) lies in westernmost Victoria and is a poorly exposed region of weakly to moderately metamorphosed unfossiliferous slate, phyllite, greywacke, minor basalt and carbonate intruded by post-metamorphic Upper Cambrian–Lower Ordovician (Delamerian) granite (Figs. 1 and 5). These rocks have long been tentatively correlated with the Kanmantoo Group of South Australia 300 km to the northwest. This is, of course, an interpretation, but scattered outcrops of assumed Delamerian granite across the plains between the Glenelg region in western Victoria and the Kanmantoo Group in South Australia perhaps support the correlation. If the correlation is correct, and if the Kanmantoo is in fact depositionally tied to cratonic Australia, the Glenelg is not a 'suspect' terrane. Also, the recorded early Paleozoic Delamerian orogeny makes the Glenelg somewhat different from most of the other interior terranes. The boundary between the Glenelg terrane and the large composite Lachlan terrane to the east is problematical and obscured by overlap of thick Devonian Grampians Group continental sediments. Also problematical is the fact that the westernmost exposures of Lachlan greywackes are unfossiliferous. The boundary is probably a fault of unknown character (Gray 1988). In any event, the grade of metamorphism is generally lower in the Lachlan terrane just to the east, and there are no known Delamerian granites.

The Lachlan terrane

The vast Lachlan terrane (Cas 1983, Scheibner 1985, 1987, Degeling *et al.* 1986, Ramsay & VandenBerg 1986, Gray 1988) spreads for almost 800 km across Victoria and extends some 500 km northwards into central New South Wales (Figs. 1 and 5). It certainly underlies at least the eastern part of the Murray basin and a significant part of the south-central part of the Great Australian basin as well. Because of its size and enigmatic character, the Lachlan is a major element in any eventual comprehension of the Tasman orogenic system. Although best considered a composite terrane, and in spite of its size, a remarkable commonality in certain lithotectonic associations and general structural style extends across the entire expanse of the Lachlan terrane.

The Lachlan terrane consists of three major lithotectonic associations which range from Cambrian to Upper Devonian–Early Carboniferous in age (Fig. 1). The associations are Cambrian greenstones, widespread mainly Ordovician to Lower Silurian greywackes, and a very complex mostly Silurian to Devonian volcanic–sedimentary package associated with a multitude of Silurian–Devonian granites. No unequivocal Precambrian rocks are known anywhere in the Lachlan fold belt.

The oldest dated rocks known in the Lachlan are the Lower to Middle Cambrian 'greenstone belts' (Cas 1983, Crawford *et al.* 1984, Crawford 1988) whose exposure is actually confined to the western half of the terrane (Fig. 5). They occur generally in three N-trending elongate fault-bounded narrow bands, which are from west to east the Stavely, Heathcote and Mt Wellington greenstone belts. Composition of the greenstones is quite variable and includes 'calc-alkaline andesite', particularly in the Stavely belt, boninites, subalkaline tholeiitic basalts, dolerites and gabbro, with serpentinized or silicified peridotites commonly occurring in shear zones and along faults. Contacts of the greenstones with adjacent mostly Ordovician greywackes are usually faulted, but in the Heathcote belt the submarine volcanics are overlain depositionally by Upper Cambrian shales and chert, which conformably underlie Lower Ordovician shales and greywackes. The basement to the greenstones, whatever it might have been, has never been seen.

Several very important questions surround these distinctive rocks. What in fact do they represent? Do they underlie all or part of the Lachlan as a continuous 'sheet', or are they confined to the belts in which they are today exposed (Cas 1983)? Symptomatic of the problem is the fact that the greenstone belts have been placed in almost every conceivable plate tectonic setting imaginable in the recent literature, but the enigma remains as to what they represent. Most recent work (Crawford 1988) concludes the association represents a submarine arc, or arcs, perhaps modified by intra-arc rifting, but it must be recalled that no associated 'trench assemblage' has ever been recognized (Cas 1983). As a result, the facing, or polarity, of the proposed arc, or arcs, is unknown. Another important observation is that if the depositional relationship of the greenstones with Upper Cambrian through to Ordovician sediments seen in the Heathcote belt is correct, the belts did not deformationally 'see' the Late Cambrian–Early Ordovician Delamerian orogeny of the Kanmantoo–Adelaide and Glenelg domains just to the west.

The second major lithotectonic association of the Lachlan is the mostly Ordovician, but locally Silurian, widespread quartz-rich turbidites and pelagic pelites and cherts so characteristic of what we came to call the

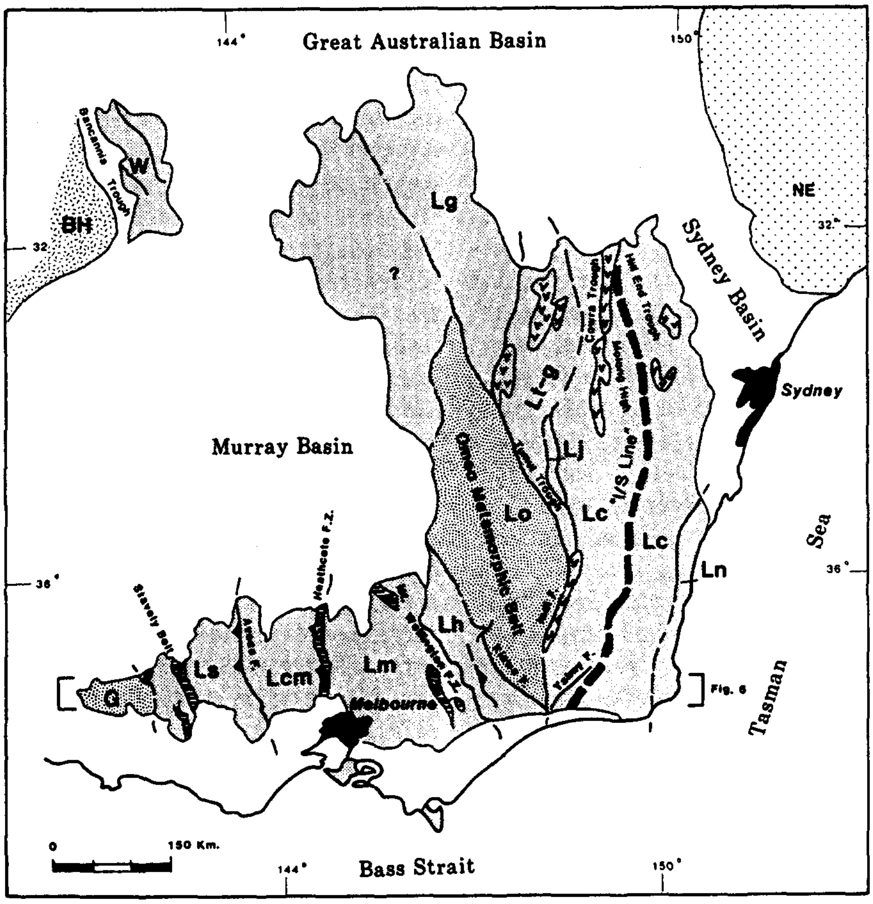

Fig. 5. The Lachlan fold belt. The main sub-terranes, or structural belts, of the Lachlan are shown. Ls: Stawell, Lcm: Castlemaine, Lm: Melbourne, Lh: Howqua, Lo: Omeo metamorphic belt, Lg: Girilambone, Lt-g: Tumut trough, Lj: Jindalee, Lc: Canberra, Ln: Narooma. The greenstone belts are shown by narrow bands of heavy close lines. The intra-Ordovician submarine volcanics are shown by the 'V' pattern. G: Glenelg terrane, BH: Broken Hill Precambrian basement, W: Wonominta terrane, NE: New England belt.

Lachlan "mud-pile" (Cas 1983, Powell 1983, Ramsay & VandenBerg 1986, Cas & VandenBerg 1988). This remarkable association dominates the Lachlan terrane and expresses an extraordinary commonality over a region which today extends almost 800 km E–W across Victoria and nearly 600 km northward into central New South Wales (Fig. 1). In the New South Wales part of the Lachlan several narrow belts of submarine andesitic, tholeiitic, and shoshonitic volcanics and volcanogenic sediments (Fig. 5) seem to be somehow embedded in the generally non-volcanogenic quartz-rich greywackes (Cas 1983, Wyborn & Chappell 1983).

Because of subsequent deformation and often poor exposure, thicknesses of the association are difficult to estimate. Measured thicknesses range from about 2 km (Cas 1983) to average estimates of as much as 5 km. In the Melbourne 'trough', where the association extends unbroken up into the Silurian and even Early Devonian, the post-Ordovician part alone approaches 10 km. The association is rather well dated by extensive collections of graptolites and conodonts (see Cas & VandenBerg 1988). Only the westernmost sub-terrane, west of the so-called graptolite or Wedderburn–Avoca fault line, is unfossiliferous and could be possibly all or in part Cambrian in age. Eastern exposures, in what we have called the Narooma sub-terrane, include minor basalt and radiolarian chert as well as greywacke and are perhaps the most 'distal' facies known.

In spite of the commonality, the Ordovician to Lower Silurian greywackes and mudstones include numerous sub-assemblages (Fig. 1), which generally are confined to fault-bounded belts (see Scheibner 1985, Fergusson *et al.* 1986). The original paleogeography remains to us quite obscure, even amidst the many separate assemblages themselves, but the association in gross may constitute a broad 'overlap' of much of the early Paleozoic Lachlan (Powell 1983). The source of the mud and greywackes, apparently from the 'south to southwest', may well have been Gondwanaland. The overall aspect suggested is an enormous complex submarine turbidite fan. The fan may have been sourced from the rising Delamerian–Ross orogen of East Antarctica and southeastern Australia, spreading out over a vast deep-marine setting complicated by off-shore arcs, transforms and other, as yet unperceived, paleotectonic environments.

Spread over most of the Lachlan terrane is the third major lithotectonic grouping, which is made up of a very complex sedimentary, volcanic and plutonic association of about Early to Middle Silurian to Late Devonian age, extending in some forms into the Early Carboniferous (Cas 1983, Powell 1984, Chappell *et al.* 1988, Marsden 1988, VandenBerg 1988). The association (Fig. 1) represents a major transition in the history of the orogen. This seems to have involved a major orogenic episode, which brought to an end the deep-marine–oceanic aspect of the Lachlan that characterized the early Paleozoic, and a progressive consolidation of the belt into a mature continental-margin mountain chain. The most striking aspect is that the widespread lower Paleozoic deep-marine basins came progressively up to and above sea level, and were deformed by complex successions of compression, transtension, transpression and extension, meanwhile exploding in a flare-up of widespread granitic intrusion and mixed bimodal, but particularly felsic, volcanism on an extraordinary scale. In our view, the crust must have been progressively and variably thickened and melted at deeper levels to explain such an outburst. This was accompanied by local to regional extensional collapse. Listric normal faulting, particularly in certain sectors, is probably much more widespread than generally appreciated. One puzzling relationship is the fact that marine conditions persisted in local troughs or basins through Silurian time, and locally into Early Devonian time. The orogen was eventually widely eroded with formation of numerous interior continental basins, and extensive detrital–fluvial sheets were shed west and north during the Late Devonian–Early Carboniferous.

The patterns and distributions of this mid-Paleozoic sedimentary and magmatic outburst are extremely complex. Most, but not all, of the mid-Silurian to Early Devonian volcanic activity was concentrated in the eastern part of the Lachlan (Fig. 1). A number of elongate troughs, or basins, either formed, or persisted, in which fairly deep-marine conditions prevailed. Adjacent 'highs' record shallow-marine to terrestrial conditions. Volcanism in the eastern Lachlan was increasingly widespread, eventually covering a present-day width of over 400 km. Facies and stratigraphic succession changes across faults are often extremely abrupt. Many bounding faults present younger on older relationships. A complex compressional–extensional plate tectonic setting is suggested (Cas 1983), similar perhaps to the Cenozoic of western North America; but as no trench has been identified, exact plate-tectonic models remain somewhat speculative. In the western Lachlan, west of the Mount Wellington fault zone, the Melbourne 'trough' persisted as a relatively deep and quiet but progressively shallowing depocenter well into Devonian time. Still further west, in western Victoria, the Rockland Rhyolites erupted in Late Silurian (?) time, associated with fluvial–lacustrine clastics of the Grampians Group.

The granitic plutons of the Lachlan (Chappell & White 1974, Chappell *et al.* 1988) are very widespread, accounting for almost one-third of existing outcrop in the exposed terrane. The volume produced is truly extraordinary. These now classic suites, for the most part of mid-Silurian to Late Devonian age, are spread across the entire present-day 800 km width of the Lachlan fold belt. For the most part the plutons are large bulbous to elongate masses which are in part syn-, but mostly post-tectonic cross-cutting bodies (Paterson *et al.* 1989). No age trends, such as younging to the east or west, are obvious in the presently known geochronologic data. Some of the youngest plutons, in fact, are in the center of the Lachlan just post-dating the folding of the Melbourne trough in mid-Devonian time. Upper Devonian caldera complexes are also found in this region.

The important discovery of the distributions of 'I'- and 'S'-type granites (Chappell & White 1974), and the distributions of distinctive 'suites' (Chappell *et al.* 1988) has important bearing on the crustal structure and tectonic meaning of the Lachlan orogen. Based on isotopic data the plutons do not seem to record any ancient Precambrian source and it seems likely that they represent largely recycled Lachlan crust. On the other hand, the Ordovician greywackes and mudstones do not seem to have been a significant contributor to the granite, so a presumably upper Proterozoic or possibly Cambrian deep-crustal sedimentary-mafic layer, which is never exposed,. must have been the source. The distinctive geochemical suites seem to map-out deep-crustal 'terranes', the boundaries of which seem to have little or no bearing on the obvious structural–stratigraphic 'sub-terrane' boundaries of the Lachlan 'super-terrane' exposed at the surface today (Chappell *et al.* 1988). The 'I–S line', which separates only I-types in the east from both I- and S-types to the west, runs down the easternmost part of the Lachlan (Fig. 5), but does not seem to mark any really distinctive discontinuity in Lachlan geology or structure. Several Lower Carboniferous plutons, similar to those found in the southern New England fold belt northeast of the Lachlan, occur in the northeasternmost corner of the Lachlan orogen in southeastern New South Wales.

Like everything else in the Lachlan orogen, the patterns and timing of deformation are extremely complex (Cas 1983, Duff *et al.* 1985, Fergusson 1987, Gray 1988). Structure seen in the greywackes and mudstones is remarkably uniform across the Lachlan (Fig. 6). Isoclinal upright folds are ubiquitous over a distance of nearly 800 km across strike. The individual sub-terranes, or belts, are usually bounded by steep faults or fault zones that have been interpreted to be thrusts or transpressional zones. In the western Lachlan some of these bounding thrust zones coincide with the greenstone belts. Vergence across the Lachlan is variable, but most of the generally upright Lachlan structure in the greywackes is portrayed as slightly E-vergent. One exception of note is the Howqua, or Tabberabbera, belt, which lies just southwest of the Omeo metamorphic complex and verges southwest.

In the center of the Lachlan, extending slightly west of north for almost 500 km, with a width of 150 km, is the fault bounded Omeo metamorphic belt (Figs. 1 and 5). The belt is characterized as largely greenschist-grade pelitic schists with local development of gneiss, and a great deal of granite. The protoliths of the schists are widely agreed to be the Ordovician muds and greywackes. Metamorphic fabrics in the Omeo belt are generally fairly steeply dipping. Otherwise, the grade of metamorphism is low throughout the remainder of the Lachlan greywackes and mudstones, but slaty cleavage is very widespread. The eastern margin of the Omeo metamorphic belt, usually referred to as the Gilmore 'suture', is a very complex structural boundary marked by wide mylonitized fault zones, ultramafic rocks and a chaos of micro-terranes of obscure origins (Basden *et al.* 1987).

The mid-Silurian to Upper Devonian sedimentary–volcanic association is usually somewhat less deformed than the Ordovician to Lower Silurian muds and greywackes. There are places where this is not seen, such as in the Melbourne trough where the Silurian to mid-Devonian sediments are conformable with the Ordovician, but for the most part an agular unconformity, often itself deformed, seems to separate the two associations. The discontinuity is usually more dramatic as the overlapping sediments and volcanics become younger. Polyphase deformational fabrics are widely described throughout the Lachlan, particularly in the older rocks (Gray 1988).

Numerous 'orogenies' have been identified for many years in various parts of the Lachlan, ranging from the Early Silurian Benambran orogeny through the Middle Silurian Quidongan, Early Devonian Browning, to the late Middle Devonian Tabberaberan orogeny (Cas 1983). Recently, an emphasis has been placed on the Early Carboniferous Kanimblan orogeny, particularly in the eastern Lachlan where even Upper Devonian sequences are broadly but markedly folded (for example, see Powell 1984, Duff *et al.* 1985). Much of the intense deformation seen in the Ordovician greywackes of parts of the eastern and central Lachlan must have taken place during Early Silurian Benambran orogeny. For example, the metamorphism and deformation seen in the Omeo metamorphic belt is attributed to this time, and as was mentioned above, the Ordovician greywackes are often reported as tightly folded beneath less deformed Silurian–Devonian volcanic and sedimentary rocks. On the other hand, the Early Devonian Bowning and/or late Middle Devonian Tabberaberan orogenies probably affected the entire Lachlan orogen in one form or another. The total spread of deformation represents a time span of almost 100 Ma. It does not seem to be certain as yet if the extensional and strike-slip faulting now widely recognized was interspersed with or somehow synchronous with the obvious compressional phases.

In published (Duff *et al.* 1985, Gray 1988) and unpublished structure-sections in the various parts across the Lachlan, the fold style alone suggests up to 50% shortening across the belt. If thrust faults, particularly low-angle interpretations, are added, the shortening could be much more. It is quite extraordinary for so much shortening to be found in such a uniform style across 800 km of cross-strike width in an orogenic system (Fig. 6). Even in spite of the metamorphic culminations, which are high temperature–low pressure assemblages perhaps better interpreted as 'regional contact aureoles' which were never very deep, the structural level seems to be about the same across the entire Lachlan belt. No deep-seated crustal rocks are brought-up on large-scale ramping thrusts in the Lachlan, as is so commonly seen in many other orogenic systems.

All the above has some implications for crustal structure and evolution in the Lachlan orogenic system (Fig. 7). The present crustal thickness seems to range from about 50 to 30 km, with the thickest crust beneath the eastern Lachlan. It seems likely that this crust has been thinned by extension, first during the mid-Silurian–Late Devonian interval, perhaps in complex coeval patterns with telescoping and strike-slip faulting (Fergusson *et al.* 1986, Packham 1987), then again during the late Mesozoic–Cenozoic break-up of Gondwanaland. This means the Lachlan crust was once thicker than it is today. The observation that the Lachlan never seems to have risen to high elevations above sea level as a result of shortening and crustal thickening, particularly during Middle Silurian to Late Devonian time, if correct, might be explained in one or both of two ways. If no Precambrian crystalline continental basement existed in the deeper Lachlan crust, a relatively high mean crustal density would have kept elevations low. Also, a dense tectonically overthickened mantle–lithosphere 'root' produced during crust–lithosphere shortening could have kept the Lachlan surface at or near sea level. Given the known or estimated thicknesses of exposed Lachlan rocks, combined with the isotopic data from the granites, and accepting the estimates of shortening, it is seemingly impossible to generate 40–60 km of Lachlan crust from telescoping what we see at the surface today (Cas 1983). This also suggests the Ordovician greywacke was not deposited on oceanic crust, which is implicit in many tectonic models of early Paleozoic Lachlan evolution. Something else must have lain beneath the exposed Lachlan rocks, at least by the time of the mid-Paleozoic telescoping. From the calculations, the thickness of this presumed substrate is roughly constrained to no more than about 15–25 km. This constraint is provided by the crustal budget discussed above, but also by the Ordovician turbidites. Calculations suggest that one could not deposit such a thick deep-marine turbidite fan on any non-oceanic substrate more than about 20 km thick. You cannot sink a ship by filling it with sawdust. The question then is: What was this substrate? It could have been attenuated 'continental material', perhaps upper Proterozoic 'Pan African' metamorphic basement. The Lachlan could have been deposited on this thin quasi-continental substrate, or perhaps thrust upon it in mid-Cambrian time. It could also have been all or in part a vast upper Proterozoic distal submarine fan deposit, perhaps equivalent to the Adelaidean intracratonic rift deposits on the Australian shelf. This enigma of Lachlan deep-crustal structure remains as a major outstanding problem with this remarkable orogenic belt.

The paleogeography and paleotectonic setting for all this is not obvious (see an excellent discussion in Cas 1983). Numerous settings have been proposed, many of which are quite reasonable, but they have been difficult to prove. The lack of definitive trench assemblages for the Cambrian greenstones, the Ordovician submarine volcanics, and the widespread magmatic patterns of the Silurian–Devonian are major obstacles to paleotectonic interpretations. What is clear is the progressive consolidation of the Lachlan crust into cratonic Australia dur-

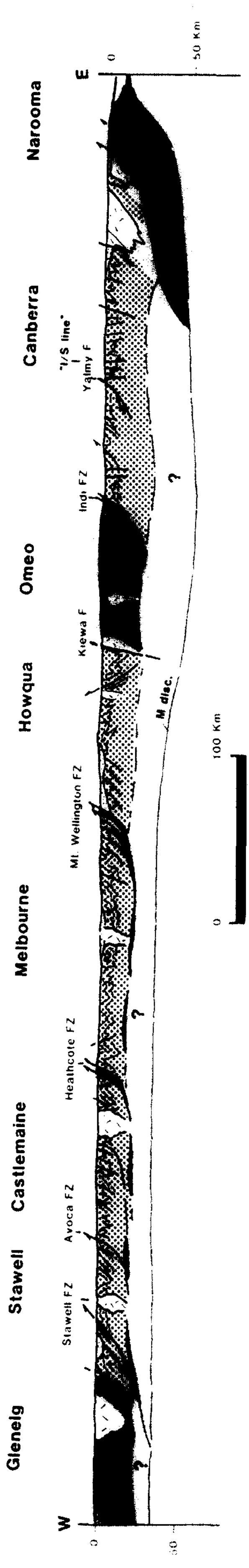

Fig. 6. Diagrammatic structure-section across the Lachlan fold belt (after Fergusson *et al.* 1986). The queried shaded area at depth is the unexposed 'basement' discussed in the text.

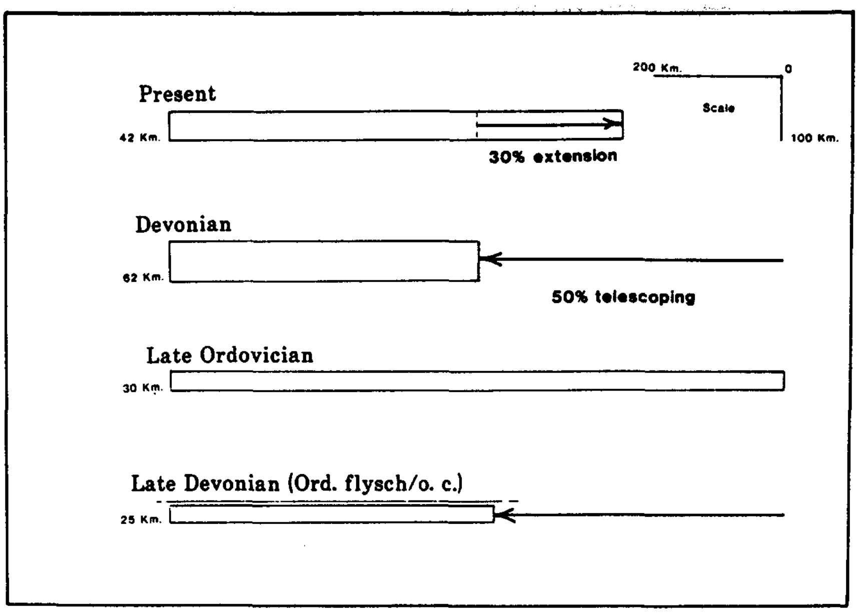

Fig. 7. Possible crustal thickness evolution of the Lachlan fold belt. The section labeled 'Present' shows actual crustal thickness as result of 30% extension since the mid-Paleozoic. The Devonian section below shows the crust after 50% shortening in mid-Paleozoic time. The Late Ordovician section suggests the crust after deposition of the mainly Ordovician 'mud pile'. The section labeled Late Devonian (Ord./o.c.) shows what the crustal thickness would be at the end of mid-Paleozoic deformation if the Ordovician to Devonian sediments had been deposited on oceanic crust. See text for discussion.

ing Silurian–Devonian time. This must have taken place in an overall convergent environment, the exact paleotectonic setting of which still remains obscure.

Tasmania

The island of Tasmania (Collins & Williams 1986, Berry & Crawford 1988) lies about 300 km south of the Victoria coast (Fig. 1). It is heavily forested and access is often difficult. The geology is known to be very complex and is relatively poorly understood. Furthermore, we have space for only a cursory treatment. Its importance, however, cannot be overemphasized. In most reconstructions of Gondwanaland it clearly lies very close to southeastern Australia and ties with the Lachlan and Adelaide region are obvious. It also lies close to Northern Victoria Land in Antarctica and to the West Nelson region of South Island, New Zealand. Tasmania shares certain lithotectonic characteristics with all of these (Stump *et al.* 1986), and it will certainly eventually prove to be a key to understanding the early Paleozoic tectonic evolution of the Tasman orogenic system.

Tasmania consists of two major tectonic subdivisions (Fig. 8). The first is the western two-thirds of the island which is a complex composite terrane (Van Diemens) made up of Precambrian metamorphic basement overlain structurally at least by lower Paleozoic local ultramafic, and more widespread complex Cambrian to Devonian volcano-sedimentary packages, all intruded by mainly Devonian plutons and deformed several times, but mainly during the Devonian Tabberaberan orogeny. The second part is the Mathinna beds, or Bassian terrane, a thick pile of lower Paleozoic muds and greywacke best exposed in the northeastern corner of the island. The Mathinna beds were also deformed in Devonian time and intruded by Devonian granites. A long-recognized major discontinuity, the Tamar River 'fracture zone', separates the two major terranes of Tasmania. Much of Tasmania is overlapped by flat-lying upper Paleozoic–lower Mesozoic sediments intruded by widespread Jurassic dolerite sills.

There are two major exposures of the metamorphic 'basement' of western Tasmania. These are the Rocky Cape region in the northwest corner of the island, and the generally higher grade Tyennan complex which

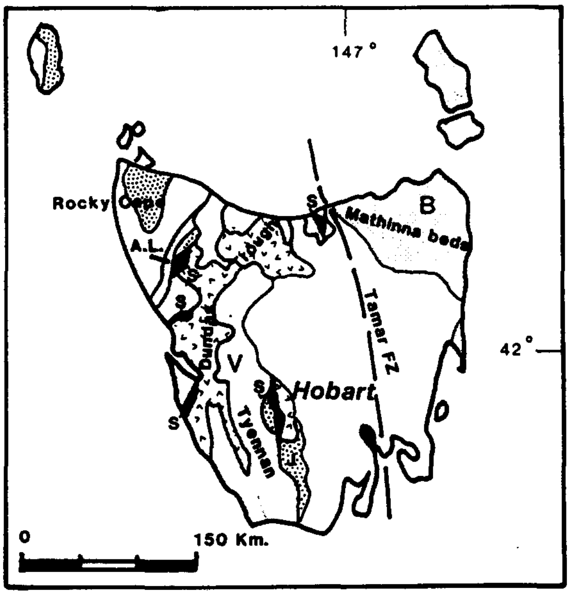

Fig. 8. Principal features of Tasmania. The Tamar 'fracture zone' divides the island into the two 'super terranes' Van Diemens (V) and Bassian (B). The Rocky Cape and Tyennan 'basement' is shown by shading. The upper Proterozoic–lower Paleozoic cover is shown by heavy stipple. The ultramafic bodies are labeled 's'. The Dundas and related troughs are shown by the 'V' pattern. AL is the Arthur 'lineament'.

forms an elongate domal core in southwestern Tasmania. Several other small exposures of metamorphic rock occur along the north coast. The Rocky Cape block is made up of quartzite, slate, carbonate and minor alkali basalt and tuff, all variably folded and slightly metamorphosed. A distinct puzzling band of higher grade metamorphic rocks 10–15 km wide, the Arthur lineament, crosses the region in a northeast direction. Geochronology (Adams *et al.* 1985) suggests that the deformation and metamorphism in The Rocky Cape area took place about 700–800 Ma in what has been termed the 'Penguin orogeny'. Less deformed upper Precambrian to Cambrian dolomite, sandstone and turbiditic volcaniclastics with interbedded basalt locally overlie the Rocky Cape 'basement'. The higher grade Tyennan metamorphic complex consists of greenschist-grade pelite, quartzite, dolomitic marble and minor meta-basalt, all polydeformed apparently near 800 Ma. It is locally similarly overlain by Upper Precambrian to Lower Cambrian sediments. The Rocky Cape and Tyennan metamorphic culminations are separated by the very complex fault-ridden Dundas 'trough' of mainly Cambrian through to Devonian volcanics, sediments and ultramafic rocks.

The ultramafic complexes (Berry & Crawford 1988) include serpentinite, peridotite, dunite, gabbro, occasional low-Ti basalt and boninite, mylonitized amphibolite, banded chert and argillite-greywacke. These rock bodies are usually fault-bounded, and are interpreted to be tectonically juxtaposed with either the Rocky Cape and Tyennan basement and/or their Upper Precambrian–Early Cambrian cover. Contacts with younger rocks of the Dundas trough are also usually faulted but some depositional contacts with Upper Cambrian rocks are known. It has been recently proposed that the ultramafic complexes were obducted across the Tyennan basement and onto the edge of the Rocky Cape basement in mid-Cambrian time (Berry & Crawford 1988). The Dundas trough itself can be perceived to be made up of two major packages. The first is a very complex volcano-sedimentary array of rhyolite–dacite lavas, pumiceous and crystal-rich volcaniclastics, and associated flanking marine sediments of mid- to Late Cambrian age. Overlying this is an apparently overlapping transgressive sequence over 3000 m thick of basal conglomerate followed by platform limestone of Ordovician age. This Ordovician marine package is widely interpreted to be the proximal near-shore equivalent to the Ordovician Lachlan greywacke and mudstone. Silurian to Lower Devonian shallow marine sandstones and mudstones almost 2000 m thick lie conformably above. The entire region was then intensely folded and faulted during mid-Devonian 'Tabberaberan' orogeny and intruded by Devonian granites.

The Mathinna beds, or Bassian terrane, includes thick turbiditic interbedded mudstone, siltstone and quartz wacke, apparently shed from the west. Fossils are rare but include Early Ordovician and Early Devonian graptolites. Folds trend NW with a slight NE-vergence, and the terrane is intruded by Devonian granites. These rocks are dramatically different from coeval Ordovician–Devonian rocks in western Tasmania but similar to the Lachlan greywackes.

What should we make of all this, and what bearing does it have on the adjacent Lachlan? The metamorphic basement exposed in Tasmania is of particular interest because it tempts one to consider Tasmania as a 'window' into the basement of the Lachlan. The recent proposal that the ultramafic complexes of Tasmania were obducted over this basement in mid-Cambrian time is a provocative and attractive model (Berry & Crawford 1988). This would suggest the greenstones of the western Lachlan, which are all pre-Middle Cambrian in age, might have been obducted also. This event would correlate with the Middle Cambrian Kanmantoo detrital flood, discussed earlier, deposited on, and just off the edge of, the Adelaidean shelf. On the other hand, the Middle to Upper Cambrian 'arc-like' volcanics of the Dundas trough have no known correlative in the Lachlan. From Ordovician through to Devonian, correlations across to Victoria are quite reasonable, and the abrupt transition from the Late Cambrian 'convergent' volcanism into the basal Ordovician conglomerates in the Dundas trough could be a distal record of the Delamerian–Ross orogeny nearby in Antarctica and South Australia. Cas (1983) and Cas & VandenBerg (1988) have suggested a similar cause for the onset of greywacke deposition in the Lachlan.

The Wonominta terrane

The Wonominta composite terrane (Leitch *et al.* 1987) lies poorly exposed just east of the Broken Hill salient of the Adelaidean shelf in western New South Wales (Figs. 1 and 5). Like the Tasmanian composite terrane, it is of interest because older metamorphic rocks are exposed here apparently beneath lower to middle Paleozoic sedimentary and volcanic rocks somewhat similar in aspect to those found in the Lachlan terrane nearby to the southeast.

On the Broken Hill salient Proterozoic basement rocks of cratonic Australia are overlain by typical quartzites, dolomite, chert and minor basalt, sandstones and glaciogene sediments of the late Proterozoic Adelaidean shelf. The Wonominta terrane itself is exposed just to the east in low hills which follow the concave-west arcuate shape of the Broken Hill salient. At least two major fault systems subdivide the Wonominta terrane itself, and the lowland separating the Wonominta terrane from the Broken Hill block is the presumably fault-bounded Bancannia trough, up to 7 km deep. This is filled with Upper Devonian terrestrial sediments which also overlap both the Broken Hill salient and the Wonominta terrane.

The oldest rocks of the Wonominta terrane are apparently what we have termed the Nootumbulla, Grassmere and Kayrunnera assemblages. These are complex mixtures of generally penetratively deformed slaty siltstones, micaceous sandstones and altered mafic to felsic lavas, which may range from late Proterozoic to Early Cambrian in age. The three assemblages are separated one from another by the two major fault systems mentioned above. Overlying these older rocks are more simply deformed prograding deltaic terrestrial to shallow-marine packages of Upper Cambrian to Lower Ordovician conglomerate, sandstone, shale and minor limestone, which we have termed the Gnalta assemblage. The Gnalta assemblage could be correlated as more proximal equivalents with the Ordovician greywacke of the Lachlan. All this is followed by local Silurian andesites and sediments, a few scattered Silurian–Lower Devonian granites, then by the widespread Upper Devonian Ravensdale terrestrial conglomerates and sandstones, which overlap both the Broken Hill block and the Wonominta terrane and fill the Bancannia trough. These rocks are very similar to the Upper Devonian–Lower Carboniferous detrital sheets typical of the Lachlan belt to the east. The Ravensdale assemblage is important since it seems to definitively tie the Lachlan terrane, Wonominta terrane and the Australian craton together by Late Devonian time. Some of the latest movements on the major faults, however, has affected the Upper Devonian rocks.

The Thomson belt (Brewery and Charters Towers terranes)

The next grouping of the interior lower Paleozoic terranes of the Tasman orogenic system is what is usually termed the Thomson fold belt (Murray & Kirkegaard 1978, Murray 1986). This vast region is mostly concealed beneath the interior basins of central eastern Australia, but comes to the surface in the Anakie inlier and Charters Towers block in east-central Queensland (Figs. 1 and 11). The boundary, if any, between the Thomson belt and the Lachlan is buried and quite speculative, but is usually placed along E–W-trending, slightly concave-north aeromagnetic and gravity trends in south Queensland–north New South Wales.

The Brewery terrane, or Anakie inlier (Murray 1986), is a NNW-trending, poorly exposed and understood, band of low to moderate-grade metamorphic sedimentary and volcanic rocks surrounded by upper Paleozoic to Mesozoic deposits of the interior basins. The oldest rocks are apparently mafic meta-lavas, including pillows, overlain by muscovite schist, quartzite and phyllite all quite intensely deformed into northeast trends. The age of these rocks and their deformation is not known but Ordovician K–Ar ages are known from metamorphic rocks and massive granodiorite intrusive into schist. The large pluton at the south end of the inlier has yielded mid- to Late Devonian K–Ar ages. In the northern part of the inlier, the Lower to Middle Devonian Ukalunda beds unconformably overlie isoclinally folded micaceous sandstone and siltstone.

The Charters Towers terrane (Henderson 1986, Murray 1986) forms the northern part of the Thomson fold belt and is usually termed the Lolworth–Ravenswood block. Its northern margin is abruptly truncated by the NE-trending Clarke River fault zone. The terrane consists of Precambrian (?) to lower Paleozoic marine sediments and volcanics, metamorphic sedimentary and volcanic rocks, and several large composite batholiths of Ordovician to Devonian age. Early Ordovician marine fossils have been found in some of the sedimentary and volcanic sequences. The general aspect is one of variably thick, fairly deep-marine, detrital to pelitic conditions with associated thick accumulations of generally felsic submarine volcanic rocks. Deformation has been intense and complex. Many structural trends are E–W. Both the Brewery and Charters Towers terranes are overlapped regionally by much less deformed Late Devonian–Early Carboniferous terrestrial sedimentary and volcanic sequences of the Drummond basin–Clarke River assemblages.

The remainder of the Thomson belt is buried beneath cover but about 45 petroleum exploration wells have penetrated basement and cores have been studied. Murray (1986) reports that basement lithology is remarkably similar over a wide area and includes fine- to medium-grained turbiditic quartzose sandstone and mudstone, all regionally metamorphosed to largely greenschist grades and steeply dipping. Early Paleozoic protolith ages are suggested by sparse fossil remains and regional correlations (Gatehouse 1986). Locally, in several buried 'basins' in southern Queensland, Lower to Upper Devonian thick continental acid to intermediate volcanics and associated fluvial to marine sediments are known from drilling. There are very scattered outcrops of granite and a number of granites have been encountered by the drill. Geophysical trends suggest other large buried granitic plutons. Where dated, these bodies, have yielded Silurian–Devonian apparent ages. In many ways, all these features are at least marginally similar to exposed Lachlan and/or Brewery geology.

The Hodgkinson and Broken River provinces of north Queensland

The last group of early to mid-Paleozoic terranes to be discussed is found in the Hodgkinson–Broken River province of north Queensland (Murray 1986, Henderson 1987). Included are the Hodgkinson, Camel and Graveyard Creek terranes and the Sandalwood and Balcooma terranes (Fig. 1). These terranes are abruptly juxtaposed against the Precambrian cratonic Georgetown block along the Palmerville, Burdekin River and other fault zones (Fig. 9). The Camel and Graveyard Creek terranes are abruptly juxtaposed against the Charters Towers terrane to the south along the Clarke River fault zone. All of these fault zones are major complex discontinuities and display remarkably straight traces over large distances.

The Hodgkinson and Camel terranes are separted by extensive Carboniferous and Permian overlap assemblages and numerous Carboniferous plutons, but they probably are tied in the sub-surface and are best considered as subterranes. The Hodgkinson terrane lies east of the Georgetown block across the Palmerville Fault. The Camel terrane lies in the open eastern end of the sharp triangular wedge between the NE-trending Bur-

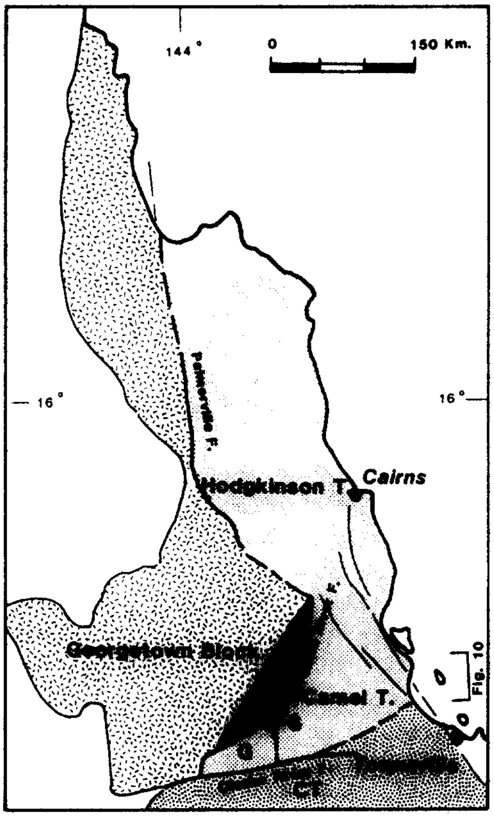

Fig. 9. Principal features of North Queensland. The dash-pattern is the Precambrian basement. CT: Charters Towers terrane, G: Graveyard Creek terrane, B: Balcooma terrane, S: Sandalwood terrane.

dekin River fault zone and the more easterly trending Clarke River fault zone. They are both made up of mainly Silurian to Devonian extensive, thick, flysch-like sediments, which are intensely deformed and include structures of broken formation character. As well as the dominant 'flysch', there are scattered mafic volcanics and banded radiolarian cherts. Along the western margin of the terranes are complex narrow bands of slumped or fault-bounded slices of limestone, turbiditic clastics, megabreccias, cherts and basalts. Fossils in the limestone bodies range from Late Ordovician to Early to mid-Devonian in age. Easternmost exposures in the Hodgkinson terrane, along the coast north of Cairns, are metamorphic rocks probably derived from the Hodgkinson flysch. South of Cairns are higher grade metamorphic rocks that may be older than the Hodgkinson (Murray personal communication 1989).

The Graveyard Creek terrane lies in the hairpin-like elbow of the Burdekin River–Clarke River fault zones and is separated from the Camel terrane by the Gray Creek fault zone. The Graveyard Creek terrane is quite distinct from the Camel terrane and includes a simply deformed stack of Lower Silurian–Devonian marine conglomerates, sandstones, turbidites and Lower to mid-Devonian limetones at the top. In general the facies thin and become more distal south and east. They sit unconformably on Ordovician quartz-rich flysch deposits and mafic volcanic rocks and are associated with a mafic–ultramafic complex of possible late Proterozoic (?) age. All this is overlain slightly unconformably by Upper Devonian–Carboniferous conglomerates. The Graveyard Creek rocks could be proximal equivalents to the Camel terrane flysch facies.

The Balcooma terrane is a long narrow slice of variably deformed often mylonitized meta-felsic volcanics, quartzite, pelite, semipelitic gneiss and mafic amphibolite which lies fault-bounded against the Georgetown block on the northwest and the Camel–Sandalwood terranes to the southeast. Ages and lithologies have led to suggestions that it is a slice of the Charters Towers terrane. The Sandalwood terrane is a complex elongate slice of serpentinite, gabbro, amphibolite and other metamorphic rocks jammed between the Graveyard Creek–Balcooma terranes and the Camel terrane.

This entire region, including the Georgetown block, is widely overlapped by continental deposits and associated volcanic rocks of the Clarke River and Bulgonunna assemblages of latest Devonian through to Carboniferous–Permian age (Fig. 1). The array of terranes is also stitched across by widespread Carboniferous plutons. This suggests the region was finally consolidated from deep-marine conditions into cratonic Australia in mid- to Late Devonian time. The overall aspect of the Camel and Hodgkinson terranes appears to us to represent a vast deep-marine–oceanic turbiditic assemblage that must have been progressively accreted against inboard Australia during Silurian–Devonian time (Fig. 10). The implication here is that, like the Lachlan, no crystalline pre-upper Proterozoic Precambrian Australian continental crust lies below the Hodgkinson–Camel terranes. We know of no exposures of such rocks in the Hodgkinson–Camel terranes, with the possible exception of the metamorphic rocks south of Cairns discussed above. On the other hand, there is some suggestion that the Hodgkinson–Camel accretionary material was actually thrust beneath the Georgetown block. On the Georgetown block itself there are scattered plutons of presumed Paleozoic (Devonian ?) age, although no evidence of a Silurian–Devonian volcanic 'arc' is recognized as such, nor is its presence obvious in the detrital modes of the adjacent flysch. It is possible that considerable margin-parallel strike-slip faulting has disrupted original paleogeography, whatever it might have been.

It is worth pointing out at this stage that the Hodgkinson–Camel terranes, juxtaposed as they are directly against the Precambrian craton of the Georgetown block, expose no evidence of widespread pre-Silurian rocks like that described for the Lachlan and Thomson belts. If the early Paleozoic Lachlan–Thomson trends ever passed through this region they seemingly must have been removed by rifting or strike-slip disruption, or lie structurally below and are rarely exposed.

Summary remarks

The interior terranes of the Tasman orogenic system, although lithotectonically variable, are characterized by widespread lower Paleozoic mainly deep-marine facies dominated by quartz-rich greywacke and mud often with

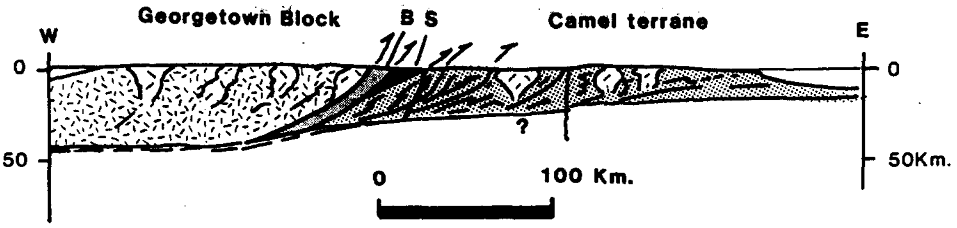

Fig. 10. Diagrammatic structure-section across North Queensland. The section shows possible relations between the Precambrian Georgetown block (dashed pattern), Balcooma terrane (B), Sandalwood terrane (S) and the broken formations of the Camel terrane (stipple).

intercalations with, or juxtapositions against, submarine volcanic rocks of both mafic and more felsic types. Locally, older upper Proterozoic material of general 'Pan African' and/or 'Adelaidean' aspect is known, particularly in westernmost exposures in areas close to the present edge of known Archean–early to middle Proterozoic cratonic Australia. The lower Paleozoic facies seem to have been progressively and variably consolidated into 'mature' Australian continental crust during complex Paleozoic 'orogeny' by voluminous magmatism, accretion, telescoping, disruption, and collapse culminating in Middle to Late Devonian time. This process produced a 'new' continental margin for Australia against and upon which the mid- to late Paleozoic–early Mesozoic New England orogen formed.

THE GREATER NEW ENGLAND TERRANES

General statement

The Greater New England terranes (Leitch 1974, 1975, Cawood & Leitch 1985, Murray *et al.* 1987, Flood & Aitchison 1988) of the Tasman orogenic system are found in easternmost Australia stretching in an elongate belt almost 2000 km long and up to 500 km wide between Townsville, Queensland, and Sydney, New South Wales (Figs. 1 and 11). The belt is traditionally divided into two parts: the New England orogen proper in the south between Brisbane and Sydney, and the Queensland portion from Brisbane to Townsville. The Greater New England orogen is separated from the lower Paleozoic interior terranes of the Tasman orogenic system by the upper Paleozoic–Mesozoic Sydney and Bowen basins, which are often pictured as 'foreland basins' to the Greater New England orogen. The two parts of the Greater New England belt are separated by the Surat and Clarence-Moreton basins. Some of the original New England belt is probably submerged to the east as a result of late Mesozoic rifting which formed the Tasman sea.

The New England orogen is characterized by largely middle to upper Paleozoic and lower Mesozoic marine to terrestrial sedimentary and volcanic rocks which were consolidated into Australia by Carboniferous to early

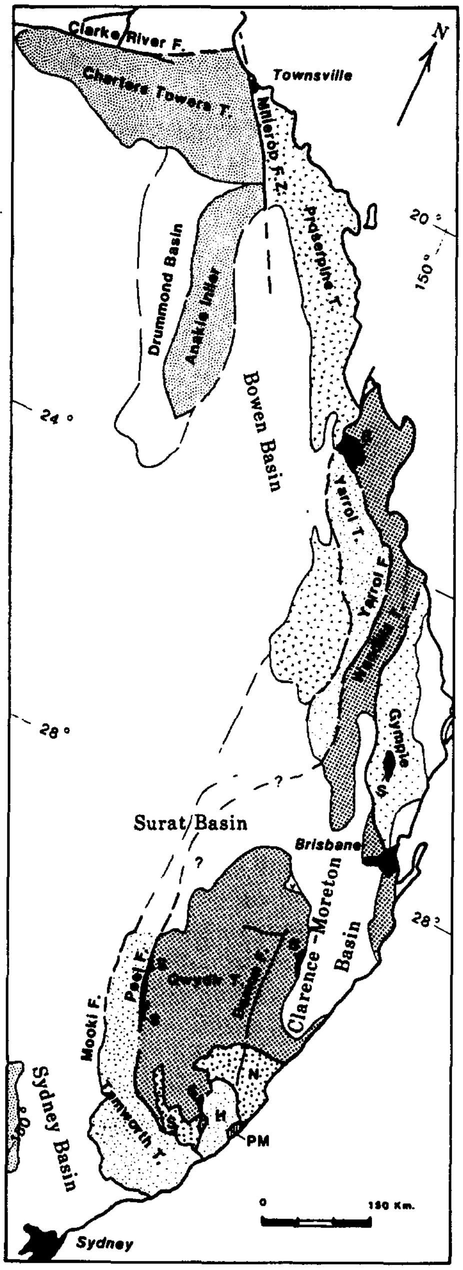

Fig. 11. Main features of the Greater New England terranes. The figure shows the Thomson fold belt (Anakie Inlier–Charters Towers) and adjacent terranes of the Greater New England composite terrane. The 'V' pattern is the Proserpine 'arc'. The Yarrol and Tamworth 'fore-arc' shelves are shown by irregular stipple. The Gwydir–Wandilla 'trench' is shaded. S: serpentinite, H: Hastings terrane, N: Nambucca terrane, PM: Port Macquarie terrane.

Mesozoic accretion, telescoping and disruption. The consolidation was accompanied by widespread Carboniferous to Mesozoic magmatism which spread across the New England orogen itself, and into the lower Paleozoic terranes of the interior Tasman to the west. Of all the terranes of the Tasman orogenic system, all or parts of the Greater New England terranes are the most 'suspect' and are probably accretionary. The western members of the group, however, may have formed on or adjacent to the outer edge of the Lachlan–Thomson belts, but they may have been tectonically juxtaposed all or in part as well.

The Greater New England belt is divided into four major lithotectonic subdivisions (Fig. 1). From west to east, they are the Proserpine (Connors–Auburn) magmatic belt, the Yarrol–Tamworth marine shelf belt, the Wandilla–Gwydir deep-marine accretionary belt and the Gympie terrane. It has been traditional to consider the Connors–Auburn magmatic belt as an arc, the Yarrol–Tamworth belt as a fore-arc and the Wandilla–Gwydir belt as a subduction complex, all active and paleogeographically tied in Devonian–Early Carboniferous time. The upper Paleozoic–Triassic Gympie terrane is widely accepted as a probable Triassic 'exotic' accretion.

The Proserpine terrane

The Proserpine terrane, or Connors–Auburn belt (Murray *et al.* 1987), is an Upper Devonian–Lower Carboniferous tract of largely subaerial andesitic, dacitic, rhyolitic and basaltic flows, tuffs and sedimentary rocks, with associated mid-Carboniferous granitic plutons (Fig. 1). The belt extends for over 700 km with an exposed width of up to 150 km along the western margin of the Queensland part of the New England orogen. The western margin of the terrane is either the Permian–Triassic overlapping Bowen basin, or in the north, the so-called Milleroo fault zone. This NNW-trending fault zone, or lineament-discontinuity, places the Proserpine terrane against the Charters Towers terrane, and also seems to separate Proserpine volcanic and sedimentary rocks from coeval, and it must be said somewhat similar rocks of the Drummond basin–Clarke River assemblages which widely overlap the interior early Paleozoic terranes of the Thomson–Hodgkinson–Camel terranes. Also, as was mentioned earlier, mid- to Upper Carboniferous plutons are widespread west of the Milleroo discontinuity intruding Charters Towers, Hodgkinson–Camel terranes and the Precambrian Georgetown block as well. They seem to be mainly younger than the Proserpine 'arc'. Whether they can be geochemically or temporally tied as a later trend to the apparently earlier Proserpine magmatism must await necessary studies.

The existence of the Proserpine 'arc' southward into the southern part of the New England belt is uncertain. If it did extend southward, it is now buried beneath the Sydney basin, or perhaps tectonically overridden by the Tamworth belt (Scheibner personal communication 1989). Analysis of detrital modes, however, in the Tamworth 'fore-arc' suggests the presence of volcanic sources to the west during deposition.

The Yarrol–Tamworth terranes

The Yarrol–Tamworth terranes (Cawood & Leitch 1985, Scheibner 1985, Murray *et al.* 1987) are a distinct belt of marine volcanogenic sedimentary deposits of mostly Devonian–Lower Carboniferous age with a shelf-like aspect deepening to the east away from volcanic sources to the west (Fig. 1). The Yarrol belt is in the northern, or Queensland sector, while the Tamworth belt is in the southern, New England, sector. Although the two are separated by the Surat–Clarence–Moreton basins, they are sufficiently similar to warrant the usual assumption that they once formed a single belt. Both have been long interpreted as classic fore-arc basins. In places the total thickness of the deposits is known to approach 10,000 m.

The Yarrol terrane is distinctive in that it locally exposes a 'basement' below the typical Devonian–Carboniferous shelf deposits. These rocks are the so-called Calliope 'arc', a sequence of Upper Silurian–Middle Devonian submarine to terrestrial andesitic to dacitic volcanics and associated sediments. Chemistry suggests an 'oceanic' setting. Although an angular unconformity is usually recognized separating the Calliope rocks from overlying Upper Devonian–Lower Carboniferous fore-arc shelf, recent work (Morand 1989, Fergusson personal communication 1989) has recognized no break in the transition in the northern Yarrol province. If this observation proves correct, it has paleographic implications, since it would suggest the New England terranes did not 'see' the widespread mid- to Late Devonian deformation typical of the interior lower Paleozoic terranes just to the west. The Yarrol terrane is also distinctive in that volcanic intercalations are common along the western margin of the Upper Devonian–Lower Carboniferous shelf deposits.

The Tamworth terrane forms an arcuate 'fish-hook'-shaped belt along the western and southern margin of the New England orogen. It has very similar lithologic characteristics to the Yarrol belt just described. The Hastings block (Lennox & Roberts 1988), a fault-bounded entity unto itself, forms the end of the 'hook', but its facies link it to the Tamworth terranes. How it was rotated or displaced into its present anomalous position is vigorously debated. Both the Yarrol and Tamworth terranes have distinctive repeated Lower Carboniferous oolitic limestones in the section that seem to have been shed from carbonate banks in the west toward deeper basins in the east (Murray 1986).

Both terranes are fault-ridden, but folding is generally quite open and cylindrical. Vergence seems to be generally westward. The eastern margin of both terranes is marked by a profound discontinuity termed the Yarrol–Peel fault system. This zone is marked by ultramafic slices and slabs, intense deformation, and glaucophane schist; and it generally places the Yarrol–Tamworth belts abruptly against the deep-marine accretionary complexes of the Wandilla–Gwydir terranes to the east. The fault zone is usually portrayed as steeply to shallowly E-dipping. In the Tamworth belt, however, recent work (Blake & Murchey 1988) records a complex history of movement, the most recent of which moved hanging wall rocks down to the east, presumably from extensional collapse. The ultramafic rocks have been interpreted as slices of the floor, or basement, of the Tamworth shelf. Unlike the Yarrol belt, which is riddled with Permo-Triassic plutons, the Tamworth belt has very few. One such pluton, however, does cut the Peel Fault.

The Wandilla–Gwydir terranes

The Wandilla–Gwydir terranes (Korsch & Harrington 1981, Fergusson & Flood 1984, Cross *et al.* 1987, Murray *et al.* 1987, Blake & Murchey 1988) represent a very thick vast composite of smashed turbiditic greywacke, siltstone, mudstone, banded radiolarian chert, ophiolitic slices, glaucophane schist and eclogite particularly along and just east of the Peel Fault, minor mafic and intermediate volcanics, and importantly, oolite-bearing greywackes that are correlated in age with the Lower Carboniferous oolitic beds of the Yarrol–Tamworth shelf. Recent radiolarian biostratigraphic work (Aitchison 1988b, Ishiga *et al.* 1988a) seems to confirm that most of these rocks are of Late Devonian–Early Carboniferous age, coeval with the Yarrol–Tamworth shelf. Both the Wandilla and Gwydir (for example, see Flood & Aitchison 1988) have been subdivided into numerous fault-bounded sub-terranes most of which are dismembered internally. Structures are very complex and polydeformed, but melange-like and broken formation fabrics are very common (Fergusson 1988, Fergusson *et al.* 1988). Vergence is chaotic, but some sections are strongly W-vergent with flat recumbent fold styles. Other regions present very steeply dipping upright fabrics. Zones of consistent structural geometry are usually bounded by faults which juxtapose packages with differing geometry and style. The entire terrane is apparently 'bottomless' and no basement has ever been seen. The Wandilla–Gwydir terrane is best viewed as an enormous complex accretionary structural package similar to the Franciscan composite terrane of California (Blake & Murchey 1988). What lies at depth remains a moot point, but an important one, since under the high plateaus of New England in New South Wales, the crust today may approach 50 km in thickness. If the California model is accepted, large-scale tectonic wedging and/or tectonic obduction and underplating may exist (Fig. 12). The terrane is widely intruded by granitic plutons. A few are Late Carboniferous in age, but most are Permian to Triassic.

The Gympie terrane

The Gympie terrane (Harrington 1983, Murray 1986), probably a composite, lies along the coast of southeast Queensland, north of Brisbane, for almost 400 km and is up to 100 km wide. It is a distinctive Lower Carboniferous to Permo-Triassic largely submarine sedimentary and volcanic complex with a stratigraphic and structural history quite different from the adjacent New England terranes to the west. The Permo-Triassic marine facies, for example, contrast sharply with the generally continental conditions typical of the New England provinces. Lithologies represented are metasediments and metavolcanics, submarine Permian basaltic to andesitic volcanics and volcanoclastic sediments and limestone, and fluviatile to marine Early Triassic sediments. The terrane was widely deformed in mid-Triassic time. The western exposed 'sole' of the terrane reveals glaucophanitic to amphibole grade metamorphics and serpentinite. The terrane is overlapped by Upper Triassic continental sediments which tie it to Australia by this time. If it accreted from off-shore, it presumably arrived during the mid-Triassic.

The Nambucca 'terrane'

The Nambucca 'terrane' (Leitch & Scheibner 1987) is a problematical mass of rather intensely deformed and metamorphosed distinctive pelites, wackes, diamictite, and pillow basalt of Permian age found as a block-like body over 100 km across in coastal northeast New South Wales. It is bounded on the south by the Hastings block, and on the west and north by the Gwydir terrane. Largely of difficult access and heavily forested in steep canyon country, it is poorly known and understood. Most of its margins are either known, or presumed to be, fault bounded, but some reports show depositional relationships with the Hastings sub-terrane on the south margin. Like the Gympie terrane to the north, the presence of apparently fairly deep-marine conditions in

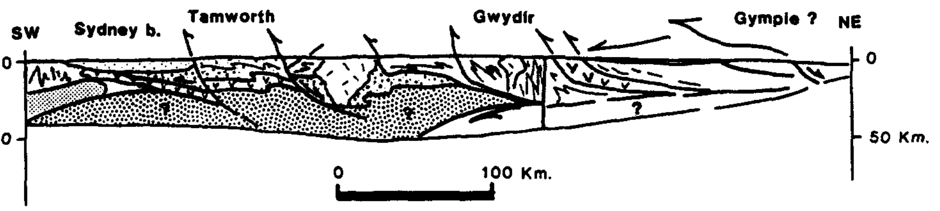

Fig. 12. Diagrammatic structure-section across the New England fold belt. This section, actually a cartoon, shows possible relationships across the southern part of the New England fold belt. The northeastern edge of the Lachlan is at the far left. The 'v' pattern is the Proserpine 'arc' below the Sydney basin and possibly below the Tamworth terrane. The Tamworth 'fore-arc' is stippled. The Gwydir accretionary mass is shaded. The 'V' pattern in the Gwydir terrane is the volcanic Keinjan sub-terrane correlated by some with the Proserpine terrane.

the Nambucca terrane during Permian time contrasts sharply with conditions elsewhere in the New England provinces. Also, the metamorphism and structural complexity in rocks so young, and in a possibly 'high' structural position, is very striking and probably important. The terrane has been interpreted as a deep extensional basin superimposed on the New England orogen and related to other smaller basins of similar age inland (Leitch 1988). It also seems to be at least worth consideration at this stage that it is an obducted oceanic realm perhaps related to the accretion of the Gympie terrane further north.

Port Macquarie terrane

The Port Macquarie terrane is a small composite terrane found on the coast at Port Macquarie, New South Wales, at the northeastern corner of the Hastings block and just southeast of the Nambucca terrane. It carries a very complex and poorly understood geologic record which includes micaceous slate, volcanogenic sandstones, andesitic volcanic rocks, chert and slate sequences similar to Gwydir terrane lithologies, and a very complex association of serpentinite, gabbro, radiolarian chert, and 'melange-like' rocks with glaucophane schists. Fossil ages range from Late Silurian to Late Devonian while radiometric ages on the blueschists are Late Ordovician (Scheibner 1985, Ishiga *et al.* 1988a,b).

Summary remarks

The mid- to Late Carboniferous seems to be a major transition in the history of the Greater New England orogen. This time seems to mark the end of the conditions which controlled the evolution of the Proserpine, Yarrol–Tamworth and Wandilla–Gwydir terranes as specific, and presumably related, tectonic environments, and it appears the general accretionary history of Late Devonian–Early Carboniferous culminated in consolidation of these terranes during mid- to Late Carboniferous orogeny. Marine conditions persisted in the Gympie and Nambucca terranes, to be sure, but the remainder of the New England belt seems to have come near to, or above, sea level by Late Carboniferous time. Also, from this time forward into late Paleozoic and early Mesozoic–Cenozoic time, tectonic patterns and distributions of lithotectonic assemblages and associations progressively attain a measure of more commonality over most of the Tasman orogenic system.

UPPER PALEOZOIC TO CENOZOIC LITHOTECTONIC ASSOCIATIONS

After mid-Carboniferous time, complex magmatic, depositional and deformational patterns developed in the Tasman orogen, particularly in eastern and northern reaches (Murray 1986). Late Carboniferous mostly intermediate to felsic explosive volcanism is known on the far northeastern fringe of the Lachlan, in the Tamworth belt, and in the northern part of the New England belt in Queensland. It also spread across the eastern part of the Charters Towers terrane, over much of the Hodgkinson–Camel accretionary terranes, and across the Precambrian Georgetown block as far as Cape York in north Queensland. The volcanism was accompanied by widespread plutonism and emplacement of granites, including the Bathurst pluton in the northeastern Lachlan. Caldera complexes are widely recognized, particularly in the north. These conditions persisted through the Permian and into the Triassic, but also spread into the central part of the New England belt in southeast Queensland. By Permian time the Bowen and Sydney basins were well developed as seemingly foreland troughs and aprons west of the reactivated and rising Permo-Triassic New England provinces. Folding of the Bowen–Sydney foreland basin occurred in the mid-Triassic, perhaps somehow related to the accretion of the Gympie terrane and/or increased convergence along the Australian margin. This deformational event has been termed the Hunter–Bowen orogeny and may have been a more profound event than often perceived.

The apparent eastward 'offset' of lithotectonic trends in the northern New England province in southeast Queensland with respect to the southern part in New South Wales (Figs. 1 and 11) has prompted models proposing right strike-slip and double oroclining to explain the pattern. The most recent model is that of Murray *et al.* (1987). The model uses Cenozoic western North America as an analogue, and is based on evolving magmatic patterns in the region, arcuate structural trends in the northern Gwydir terranes, and the occurrence of serpentinite and Silurian–Devonian submarine volcanic tracts northeast of the Gwydir accretionary terranes in northeast New South Wales. Also important are isolated exposures nearby of Late Carboniferous marine sediments compared to rocks in the Yarrol–Tamworth shelf. The proposed strike-slip displacement would have occurred along a structure running west of the Yarrol terrane, then just east of the northeasternmost exposures of the Gwydir terrane. Movement would have been at least 500 km and would have caused the apparent clockwise oroclinal bending proposed for the northern part of the New South Wales sector of the New England orogen. The time of movement would be Late Carboniferous.

Through most of Jurassic time the Tasman orogenic system preserved on Australia seems to have behaved as a relatively stable cratonic region with widespread fluvial–lacustrine–continental conditions eroding uplands and slowly filling the enormous shallow interior basins (Veevers 1984, Murray 1986). If a convergent margin persisted, the evidence for it must be submerged off-shore of eastern Australia. During Early Cretaceous time, however, mostly continental calc-alkaline volcanism and associated granitic plutonism occurred along a narrow coastal strip in southeast Queensland from north of Brisbane to Townsville. These events just preceded the initiation of Gondwanaland break-up in Late Cretaceous time which produced the late Mesozoic–Cenozoic

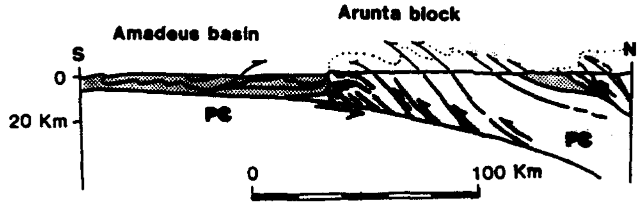

Fig. 13. Diagrammatic structure-section of the Amadeus basin–MacDonnell ranges, Central Australia. This section, after Teyssier (1985), shows the S-vergent thrusting of the Precambrian basement (shaded) over the late Proterozoic–Paleozoic Amadeus basin (stipple).

rift basins along the southern margin of Australia, isolated Tasmania, and opened the Tasman Sea, the Southern Ocean and Bass Strait. All of this also seems to have thermotectonically rejuvenated the eastern and southern part of the Tasman orogenic system producing its present relief (Jones & Veevers 1983).

Finally, we wish to call attention to late Paleozoic tectonic events in the Amadeus basin–MacDonnell ranges of central Australia (Fig. 2), usually termed the Alice Springs orogeny in mid-Carboniferous time (Shaw *et al.* 1984, Stewart *et al.* 1984, Teyssier 1985). This remarkable feature extends E–W for almost 700 km, perpendicular to the predominant N–S trends of the Tasman orogenic system, and consists of a large complex Precambrian basement uplift in the Arunta block–MacDonnell ranges along the north flank of the Amadeus basin. The orogeny actually mirrors a similar event along the south margin of the Amadeus basin in earliest Paleozoic time, and both events seem to have reactivated a late Proterozoic intracratonic rift system. In the MacDonnell ranges, Precambrian basement rocks are portrayed as thrust upwards and southwards over the basin to the south, forming crustal-scale duplexes, and folding upper Proterozoic and lower to middle Paleozoic rocks of the basin itself (Fig. 13). The mid-Carboniferous deformation is amagmatic. It obviously records a massive intraplate failure of the Australian craton. In a broad sense the Alice Springs orogeny is coeval with the mid-Carboniferous Kanimblan late compressive events in the Lachlan, the mid-Carboniferous consolidation of much of the New England orogen, and perhaps with the proposed mid- to Late Carboniferous oroclining and strike-slip disruption in the New England orogen. To date, no plate tectonic explanation for the Alice Springs orogeny has been recognized.

SUMMARY

If we could summarize the chaos described above, it is possible to perceive the history of the Tasman orogenic system as composed of four major epochs (Fig. 14). The first is a prolonged early Paleozoic period of variable and shifting 'active' tectonic settings. The period is characterized in one place or another by generally deep-marine turbiditic conditions, juxtaposition of diverse facies, local mostly submarine volcanic belts of variable aspect, and somewhat restricted and local deformations, some magmatism and metamorphism. The second epoch was a period of deformation, progressive termination of deep-marine conditions, extraordinary magmatism, crustal thickening, disruption and extensional collapse, and general consolidation from about mid-Silurian to Late Devonian time. This orogenic epoch affected the entire inner belt of terranes of the Tasman orogen. The third epoch is a major accretionary phase in the Greater New England terranes, which seems to have culminated in the mid-Carboniferous, but continued active, migrating eastward into early Mesozoic time. The final epoch is the break-up of Gondwanaland in late Mesozoic time continuing to the present. This general four-stage tectonic evolution can be traced in one form or another along most of the paleo-Pacific margin of Gondwanaland.

THE TASMAN OROGENIC SYSTEM IN THE CONTEXT OF THE PACIFIC MARGIN OF GONDWANALAND

The Paleozoic history of the Pacific margin of Gondwanaland (Fig. 15) is obscured by massive Mesozoic–Cenozoic tectogenesis in the Andes of South America and largely by ice in Antarctica. Nevertheless, the basic four-part tectonic evolution displayed in eastern Australia can be seen also in South America and Antarctica, although in detail there is much variation (Coney 1988).

Throughout most of the Andes the character of early Paleozoic geology is variable and very obscure (Lohmann, 1970, Aubouin *et al.* 1973, Irving 1975, Laubacher & Megard 1985, Ramos *et al.* 1986, Hervé *et al.* 1987, Restrepo & Toussaint 1988). As in Australia, we see no obvious through-going lower Paleozoic miogeocline or clear-cut evidence of a precursory rifted margin. Instead we have variable assemblages of mostly deep-marine muds and sands, local submarine volcanic belts, what seem to be local belts of deformation and/or magmatism, and little evidence of through-going tectonic continuity. Most of the Andean belt would have to be considered as 'suspect' in the sense that paleogeography is very obscure. Arguments continue as to whether all or part of the orogen is ensialic or ensimatic (see discussion in Dalziel & Forsythe 1985).

In Antarctica (Craddock 1982, Bradshaw *et al.* 1985, Dalziel & Grunow 1985, Gibson & Wright 1985, Wright 1985, Stump *et al.* 1986) our knowledge is dominated by the better known Transantarctic Mountains. Here, the Late Cambrian–Early Ordovician Ross orogeny has been compared with the Delamerian orogeny of South Australia (see Craddock 1982, Bradshaw *et al.* 1985). Just what lay outboard of the Ross orogen in early Paleozoic time is not very clear. On the other hand, the early Paleozoic geology of South Island, New Zealand (Sporli 1987), is very similar to the Lachlan of southeast Australia.

By the mid-Paleozoic, particularly in the Devonian–Early Carboniferous, much of the early Paleozoic geology of the Andes and Antarctica seems to have been affected by orogeny. This is especially evident in Peru,

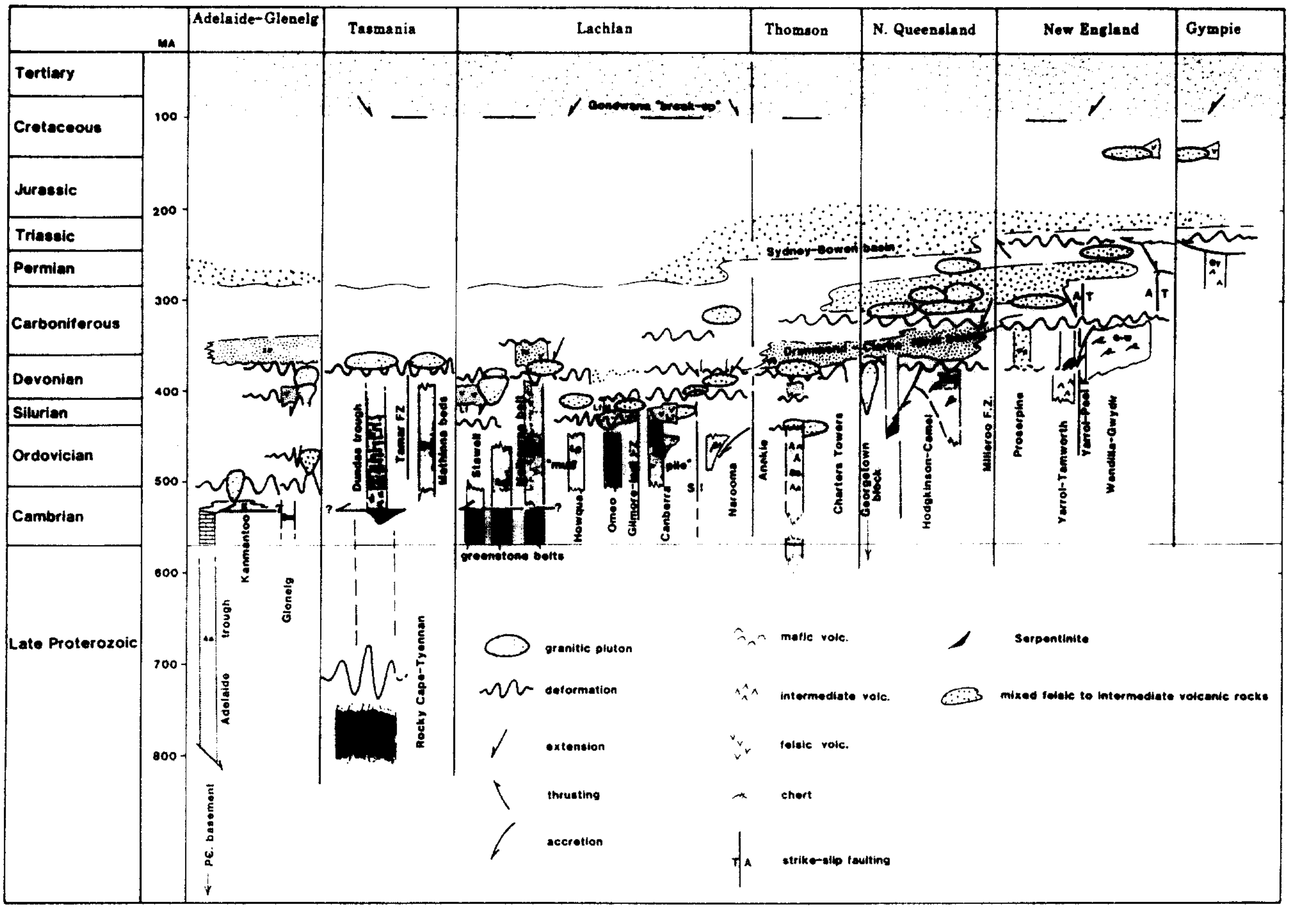

Fig. 14. Diagrammatic flow-diagram for the Tasman orogen. See discussion in text. For letter symbols within columns refer to Fig. 1. Lg = Lachlan greywacke.

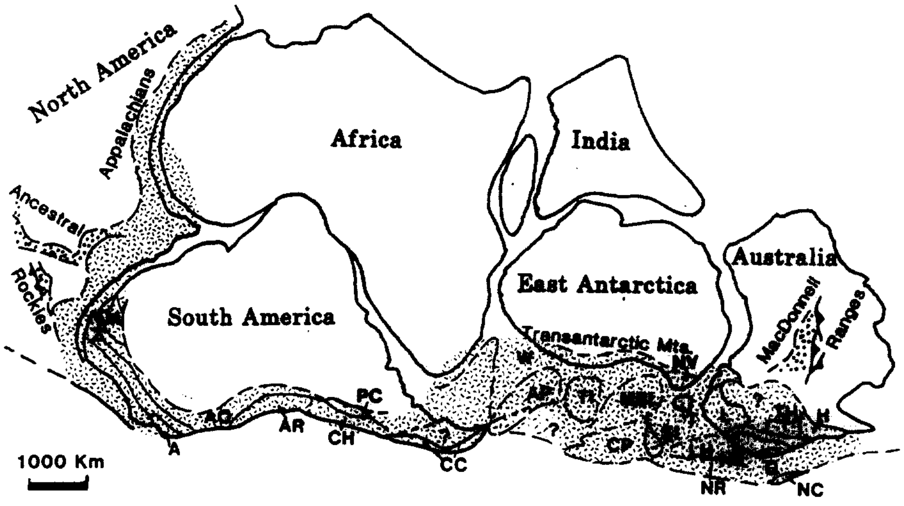

Fig. 15. The Pacific margin of Gondwanaland. This figure shows the major terranes and orogenic belts of Gondwanaland's Pacific margin and southern and eastern North America (dashed pattern) at the end of the Paleozoic when Pangaea had formed. Also shown are the Ancestral Rockies and Amadeus basin–MacDonnell ranges (heavy stipple) discussed in the text. Principal terranes are: M: Merida, Z: Zamora, A: Amatope, AO: Altiplano, AR: Arequipa, PC: Pre-Cordillera, CH: Chilena, CC: Chiloe, W: Ellsworth, AP: Antarctic Peninsula, TI: Thurston Island, MBL: Marie Byrd Land, SI: South Island, New Zealand, T: Tasmania, NV: Northern Victoria Land, LH: Lord Howe Rise, NR: Norfolk Ridge, CP: Campbell Plateau, L: Lachlan, NE: New England, G: Gympie, TH: Thomson, H: Hodgkinson–Camel, NC: New Caledonia. After D. Richards, P. Coney, F. Cole & C. Smith, University of Arizona (unpublished compilations for BHP-Utah); Dalziel & Grunow 1985, Ramos *et al.* 1986, Leitch & Scheibner 1987, Coney *et al.* this paper.

Bolivia and northern Argentina–Chile (Laubacher & Megard 1985, Hervé *et al.* 1987) where variable but widespread orogeny and magmatism occurred. In Antarctica the record is more obscure, but scattered mid-Paleozoic plutonism is reported in Marie Byrd Land and Victoria Land (Grikurov *et al.* 1982, Bradshaw 1987). The record of mid-Paleozoic orogeny is well known in New Zealand (Sporli 1987), and, when one considers the Campbell plateau, part of this large tract may have 'shielded' part of then inboard Antarctica from the mid-Paleozoic events on Gondwanaland's margin. As in Australia, much of the more interior early Paleozoic geology of the Andes and Antarctica seems to be overlapped by the mostly thin mid- to late Paleozoic shallow marine to continental rocks often referred to as the "Gondwana" series (Helwig 1972, Craddock 1982).

The late Paleozoic evolution of the Pacific margin of Gondwanaland is much more varied. One relationship, however, is worth emphasizing here. In southern Chile–Argentina a well documented late Paleozoic–early Mesozoic series of 'oceanic' accretions, termed the Chiloé terrane, occurs (Forsythe 1982, Dalziel & Forsythe 1985). There is a certain similarity here between the geology of southern Chile–Argentina and the Greater New England belt of Australia. They are similar in that both regions seemed to have been the loci of large-scale accretions of oceanic assemblages in later Paleozoic–early Mesozoic time. Inboard of both are widespread magmatic belts (Forsythe 1982, Murray 1986).

After the break-up of Gondwanaland in mid- to late Mesozoic time, the separate pieces went their several ways and commonality is lost. Even so, the late Mesozoic–Cenozoic evolution of Antarctica and Australia is similar, but the Pacific margin of South America is very different. The Andes are different because when South America finally broke free from Africa in mid-Cretaceous time it started a fairly rapid advance, in an 'absolute motion' plate tectonic framework, over Pacific Ocean lithosphere. This advance has continued to the present time. The resulting high-stress regimen produced when continental margins push their trenches ahead of them over adjacent oceans seems to explain the late Mesozoic–Cenozoic telescoping, crustal thickening and magmatism typical of the development of the Andean Cordillera (Coney 1973, Cross & Pilger 1982, Dalziel 1988, see also Isacks 1988). Australia and Antarctica, on the other hand, drifted lazily, hovering about the South Pole, and although plate convergence is recorded the predominant tectonic setting is extensional.

THE TASMAN OROGENIC SYSTEM IN THE CONTEXT OF ABSOLUTE MOTIONS OF GONDWANALAND

We have become accustomed to seek tectonic explanations in the relative motions between plates, particularly between oceanic plates and a continental margin we might be interested in. Attempting this for Paleozoic orogenic belts is fraught with insecurity in that we will never know the geometry and kinematics of plate configurations in adjacent oceans nor their interactions with a continental margin in question in any direct quantitative way. As a result, the similarity we see in tectonic evolution over a distance of 20,000 km along the Pacific margin of Gondwanaland during Paleozoic–early Mesozoic time encourages us to seek insight in the motions of Gondwanaland itself. This, of course, is also fraught with insecurity, since one must rely on relatively poorly constrained Paleozoic paleomagnetic data for Gondwanaland in order to constrain Paleozoic continental 'absolute' motions. The problem becomes doubly difficult for a large 'supercontinent' such as Gondwanaland since if the 'pole' at any given time is at one side of the continent this means large changes in longitude are possible at the other side with no record of them in the paleomagnetic data. Fully aware of the limitations discussed above, but in the spirit of trying something to see what results, we have used a recent APW path for Gondwanaland to try to reconstruct possible Gondwanaland 'absolute' motions. This APW path, right or wrong, to us seems to offer an interesting setting to contemplate the tectonic evolution of the Tasman orogenic system.

Recently, new paleomagnetic data from Africa and Australia have considerably modified previous Paleozoic Gondwanaland APW paths (Hargraves *et al.* 1987, Hurley & Van der Voo 1987, Schmidt & Embleton 1987, Li *et al.* 1988, Van der Voo 1988, Kent & Van der Voo in press). The modification is a marked excursion of the APW path from a well established position in North Africa during the Ordovician to a position near Southern Chile in the Late Silurian, then back to central Africa by the Late Devonian–Early Carboniferous. We are struck by the fact that the Silurian–Devonian orogenies of the interior terranes of the Tasman orogenic system are bracketed by this proposed APW path excursion.

In Fig. 16 we have reconstructed Gondwanaland over the South Pole in five time slices from Ordovician through to Late Carboniferous time. The reconstructions for Ordovician through to Late Devonian time are based on Van der Voo (1988) while the Carboniferous reconstructions are from Scotese & Denham (1988). Between Late Ordovician and Middle Silurian time the South Pole moves abruptly from its position in North Africa to a position near southern Chile. What effect this rapid move had on Australia's motion is difficult to constrain, but the positions shown give a sharp clockwise rotation and southward shift to Australia which might have been conducive to left-lateral transpressive shear in the Tasman orogen during Early to Middle Silurian time. This motion might correlate with the Lachlan orogen Benambran orogeny and Packham's (1987) proposed left-slip disruption in the eastern Lachlan. The Paleozoic Andes, of course, 'retreat' rapidly from the paleo-Pacific Ocean. Then, from Late Silurian to Late Devonian the South Pole shifts back into Africa, at first slowly, then more rapidly, placing it in central Africa by

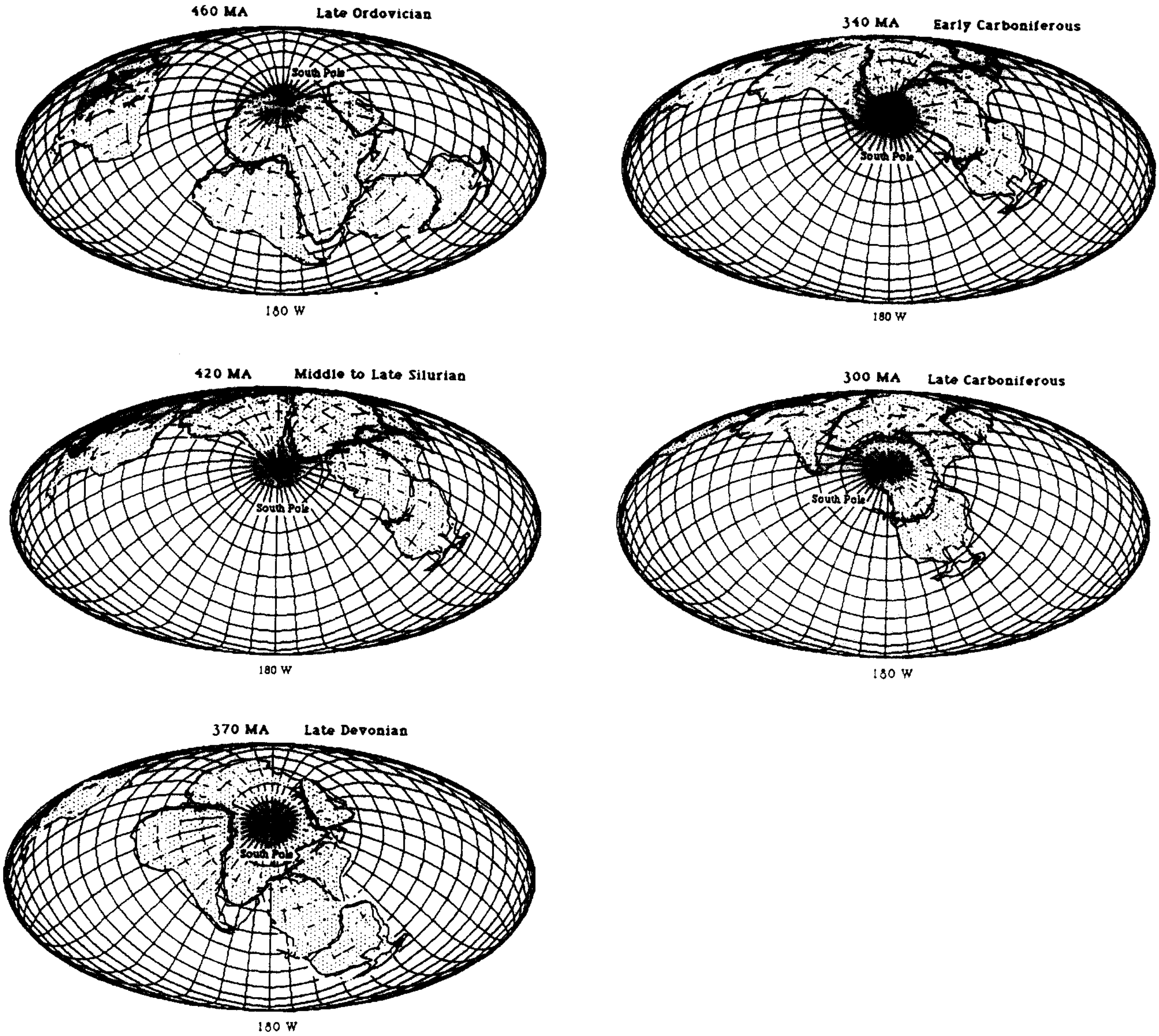

Fig. 16. Paleozoic reconstructions of Gondwanaland and the proto-Pacific Ocean. See text for discussion. The projection is orthographic full-globe centered on 65°S, 180°W. The grid is 10°.

the Late Devonian. This presumably has the effect of driving the Pacific margin of Gondwanaland over mid-Paleozoic paleo-Pacific Ocean lithosphere. This 'advance' of Gondwanaland's margin seems to coincide with the widespread mid-Paleozoic deformation and magmatism recorded in the interior terranes of the Tasman orogenand perhaps elsewhere along the Pacific margin of Gondwanaland.

After an 'elbow' in latest Devonian–Early Carboniferous, the South Pole moves across southern Africa and into Antarctica, recording the motion of Gondwanaland 'northwards' towards collision with North America during Carboniferous–Permian time to form Pangaea. In the reconstructions shown, which, of course, are not necessarily unique in terms of longitude, Gondwanaland rotates clockwise as it moves across the South Pole. This motion seems to place southern Chile–Argentina and eastern Australia in 'leading edge' positions, perhaps conducive to the late Paleozoic accretions recognized in both regions. Finally, the resulting motion of Gondwanaland, and its collision with North America starting in mid-Carboniferous time, may have wrenched the entire supercontinent. This might explain two puzzling coeval Carboniferous intraplate deformations (Coney 1988)—the Amadeus basin–MacDonnell ranges Alice Springs orogeny in central Australia (Veevers &

Powell 1984) and the Wichita–Ancestral Rockies deformation of central North America (Kluth & Coney 1981). Both of these deep-seated, amagmatic, intraplate crustal upheavals reactivated late Proterozoic intracratonic rifts.

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