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Structural style and crustal architecture of the Tasmanides of eastern Australia: Example of a composite accretionary orogen

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ABSTRACT

Deformation in accretionary orogens, such as the eastern Australian Tasmanides, is clearly partitioned either as thin-skinned thrusting or thick-skinned faulting, with structural style dependent on the nature and stratal thicknesses of the sequences involved. The thin-skinned thrust systems consist of either detachment-related folds and thrust sheets within attenuated passive margin sequences or thrust sheets of chevron-folded turbidites with leading imbricate-fan geometry that are developed within former submarine fans overlying back-arc basin oceanic lithosphere. Thick-skinned belts consist of major thrust faults that root into the seismic reflection Moho with no apparent common décollement and cause crustal-scale imbrication of former arc, forearc, submarine fan, and accretionary complex elements. The Tasmanides are a composite orogenic system made up of three distinct orogenic belts whose character and structural style have resulted from the deformation of different tectonic components; the former rifted passive margin to make the Delamerian Orogen, a turbidite fan system(s) in a back-arc setting to make the Lachlan Orogen, and an arc-subduction complex that includes some older accreted components to make the New England Orogen. The inboard Delamerian Orogen consists of an external, craton-vergent thrust belt with foreland-style, detachment-related folds and thrusts linked to a high-T/low-P metamorphic complex. The centrally located Lachlan Orogen is made up of three separate thrust systems largely developed in submarine turbidite fans and incorporates a shear-zone-bounded high-T/low-P metamorphic belt. The outermost New England Orogen is constructed from craton-vergent, fore-arc and magmatic arc sequences, subduction complexes, and ophiolite fragments.

INTRODUCTION

Accretionary orogens form as a consequence of ongoing plate convergence at continental margins that have undergone long-lived subduction accretion, with additions of turbidite fans, island arcs, ophiolite slivers, seamounts, rifted continental fragments, and oceanic plateaus (e.g., Sengor and Natal'in, 1996; Foster and Gray, 2000; Windley et al., 2001; Cawood, 2005; Gray et al., 2006a). The crustal architecture of eastern Australia reflects such lateral accretion with cratonization involving stepwise addition of three separate and distinct orogens, collectively referred to as the Tasman orogenic system or Tasmanides. Successive cratonization

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from west to east included the early Palaeozoic Delamerian Orogen (ca. 490 Ma), the middle Palaeozoic Lachlan Orogen (ca. 340 Ma), and the late Palaeozoic–early Mesozoic New England Orogen (ca. 210 Ma), with their respective peak deformations of Middle-Late Cambrian, Late Ordovician-Silurian and Permian-Triassic age (e.g., Gray and Foster, 2004a). The crustal architecture of this accretionary-style orogenic belt is markedly different to the classic accretionary-collisional Alpine orogenic system through lacking the major crustal sutures, fold-nappes, basement-involved thrust sheets, and back-folding or retro-charriage (e.g., Coward and Dietrich, 1989).

This paper reviews the structural style and crustal architecture of the Tasmanides. We have constructed orogen-wide, crustal profiles, which are constrained by deep seismic reflection profiles (e.g., Meissner et al., 1991). The structural style is mixed with both thick-skinned, crustal-scale interleaving where major faults root into the seismic reflection Moho and thin-skinned where multiple detachments produce a leading imbricate-fan thrust system. Orogenic shortening in the latter tends to be up to ~70%. Crustal-scale stacking of elements including volcanic arcs, forearc basins, subduction complexes, and ophiolites as parts of a thick-skinned structural style may be characteristic of accretionary orogen architecture.

CRUSTAL ARCHITECTURE

The continental crust of southeastern Australia is dominated by the turbidite-hosted Lachlan Orogen that occupies up to 80% of its surface area (Fig. 1). The inner parts of the Tasman orogenic system, including the craton-fringing Delamerian Orogen and the western part of the Lachlan Orogen, show pronounced curvature and structural conformity with what appear to be promontories and recesses in the old cratonic margin (e.g., Marshak and Flöttmann, 1996). Outboard of this, the central and eastern parts of the Lachlan Orogen and the New England Orogen have more continuous north-south trends that show no relationship to the former cratonic margin (Fig. 1). The Thomson Orogen to the north of the Lachlan Orogen (Fig. 1) is largely covered by younger sedimentary basins, so that relatively little is known about the crustal structure apart from data obtained in deep seis-

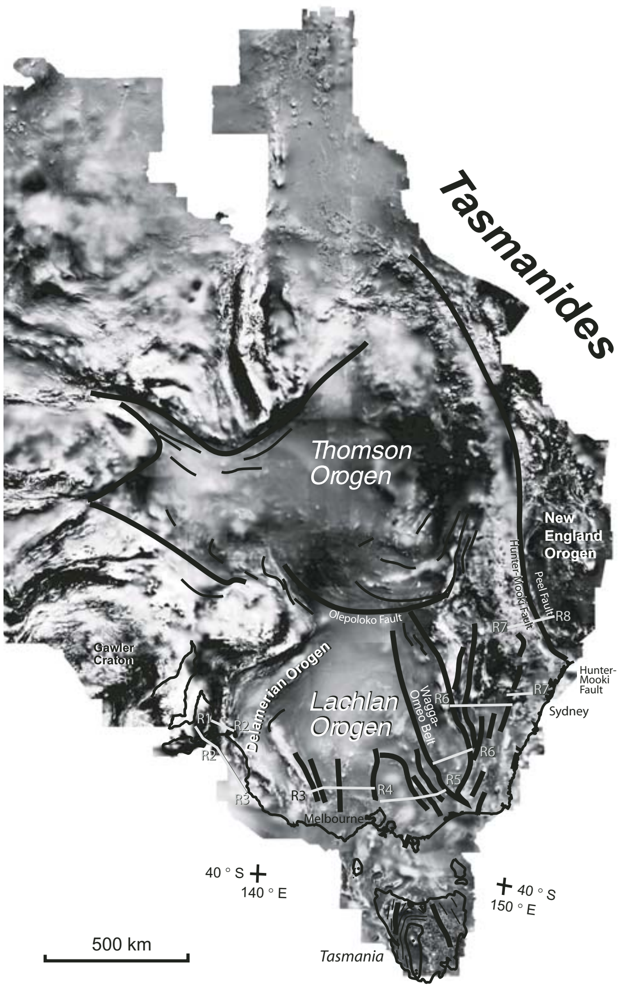


Figure 1. Aeromagnetic image of eastern Australia from Kilgour (2002) showing the broad tectonic divisions and major faults of the Tasman orogenic system, or Tasmanides (modified from Gray and Foster, 2004a). Locations of profile segments, designated R1 through R8, of the crustal profile in Figure 3 are shown.

mic reflection profiles (Korsch et al., 1997). The Thomson Orogen has an elongated ovoid form with approximately east-west trends and the major Olepoloko Fault marking the boundary with the Lachlan Orogen to the south (Fig. 2).

The Delamerian Orogen (Figs. 1 and 2) is an arcuate, craton-vergent thrust belt that shows transitional character from fold-dominated in the north to thrust-dominated in the south (Marshak and Flöttmann, 1996), much like the transition from foreland parts of the Central to Southern Appalachians of the eastern U.S. (e.g., Kulander and Dean, 1986). The lithostratigraphy consists of deformed Neoproterozoic Adelaidean intracratonic rift sequences of marine to deltaic sandstones and shales, lagoonal evaporites, dolomites and limestone, transgressed by lower Cambrian shelf sediments transitional into deep-water sandstones and mudstones

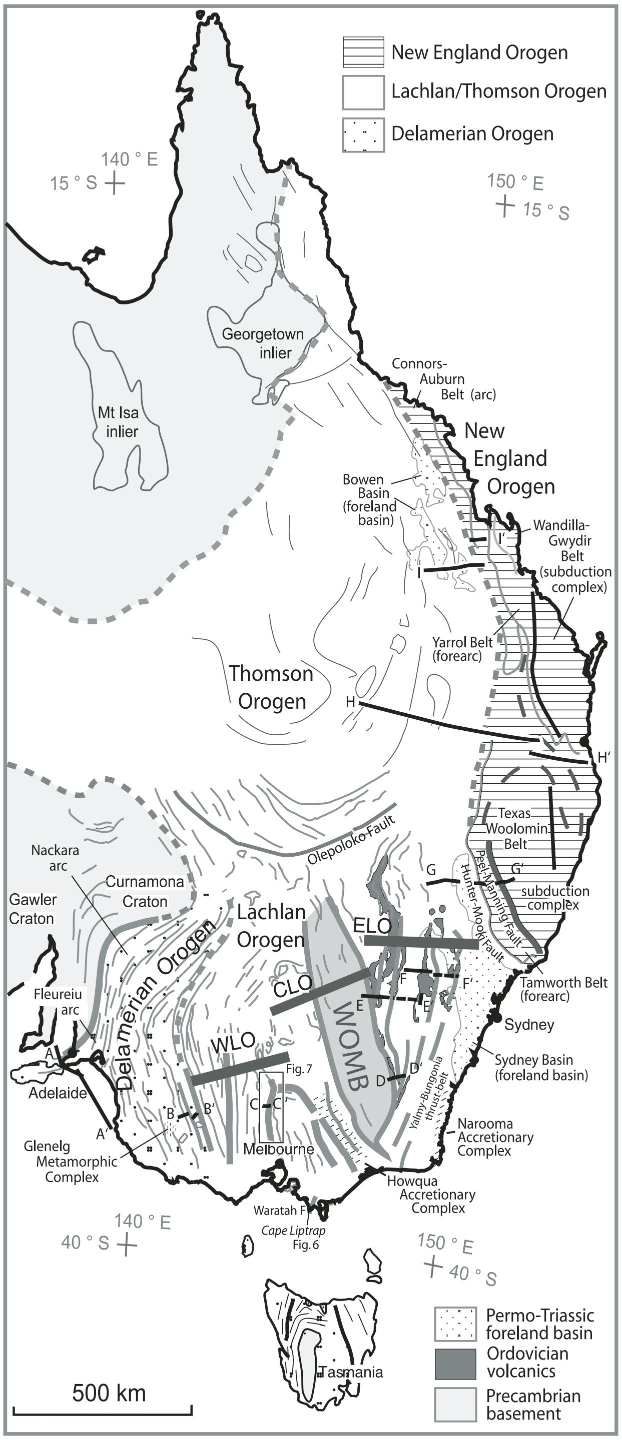


Figure 2. Map of eastern Australia showing the subdivisions of the composite Tasman orogenic system, including the Delamerian, Thomson-Lachlan, and New England Orogens, the locations of the deep crustal seismic reflection profiles, as well major faults and key geologic elements. Seismic line A-A´ is shown in Figure 4; lines B-B´ and C-C´ in Figure 5; lines D-D´, E-E´, and F-F´ in Figure 8; and lines G-G´, H-H´, and I-I´ in Figure 9. WLO: western Lachlan Orogen; CLO: central Lachlan Orogen; ELO: eastern Lachlan Orogen; WOMB: Wagga-Omeo Metamorphic Belt.

(Preiss, 1987). Foreland-style detachment-related folds cored by diapiric breccias characterize the northern fold-dominated part (e.g., Clarke and Powell, 1989; Marshak and Flöttmann, 1996), whereas basement involved culminations and discretely spaced major mylonitic shear zones dominate the southern part (e.g., Flöttmann et al., 1994; Marshak and Flöttmann, 1996). Amphibolite grade metamorphism, with local development of kyanite-sillimanite assemblages and polyphase deformation, is associated both spatially and temporally with intrusion of syn-tectonic granites in the southeasternmost part (e.g., Sandiford et al., 1992; Foden et al., 1990; Foden, 1999).

The Lachlan Orogen shows groupings of thrust faults that define three thrust systems of distinct tectonic vergence in the western, central, and eastern parts (Gray 1997; Gray and Foster, 1998, 2004b). Thrust systems in the western and central Lachlan and the central Lachlan are characterized by imbricated, chevron-folded turbidites (Fig. 3) with overall leading imbricate-fan geometry (e.g., Gray and Foster 1998; Spaggiari et al., 2004), where maximum throw occurs on the frontal or leading fault. The western Lachlan Orogen is an east-vergent thrust belt, whereas the central Lachlan Orogen is a southwest-vergent thrust-belt linked to a fault-bounded metamorphic complex (the Wagga-Omeo Metamorphic Belt, or WOMB, of Figs. 2 and 3). The eastern Lachlan Orogen is an east-directed thrust system (Glen and VandenBerg, 1987; Fergusson and VandenBerg, 1990) within inverted Siluro-Devonian extensional basins in an older Ordovician arc (Glen, 1991; Glen et al., 1992, 1994). In the southeast and the easternmost part, this east-vergent thrust system overrides an older (Late Ordovician), subduction-related accretionary complex (Narooma accretionary complex of Fig. 2). The lithostratigraphy across the western and central parts of the Lachlan Orogen consists of predominantly subgreenschist to greenschist grade quartz-rich turbidites overlying oceanic lithosphere and possible microcontinental fragments (e.g., Tasmania-Selwyn block of Cayley et al., 2002) in the western Lachlan Orogen and central Lachlan Orogen, with numerous syn- and post-tectonic plutonic and volcanic rocks (Foster and Gray, 2000).

The New England Orogen is a Permo-Triassic craton-vergent or west-directed thrust belt (e.g., Fergusson, 1991; Holcombe et al., 1997; Korsch et al., 1986, 1997) consisting of stacked magmatic arc (Connors-Auburn belt), fore-arc (Yarrol-Tamworth belt), and oceanic assemblages including subduction complexes (southern Texas-Woolomin and northern Wandilla-Gwydir belts) and ophiolite (Peel Fault and Marlborough serpentinite) that override an inboard Permo-Triassic sedimentary basin with a foreland phase (Sydney-Bowen basin; Fig. 2). Major faults in the south include: 1. the bounding Hunter-Mooki thrust fault (Fig. 1) that displaces Carboniferous arc-forearc rocks over Permo-Triassic foreland basin sedimentary successions (Glen and Beckett, 1997), and 2. the steeply dipping Peel-Manning fault system that separates fore-arc basin fill (Tamworth belt) from subduction complex rocks of trench and outer arc affinities (Tablelands Complex, Texas-Woolomin belt; Cawood and Leitch, 1985). Mafic and ultramafic rocks in the hanging wall to the Peel-Manning Fault define a disrupted ophiolite sequence with back-arc basin affinities in the north (Yang and Seccombe, 1997) and refractory island arc ophiolite in the south (Aitchison and Ireland, 1998). Occupying an outcrop length of ~300 km, the ophiolite sequence varies from <10 m to ~2 km in width and shows internal fault imbrication, loss of section, and faulted contacts between ophiolite units (Yang and Seccombe, 1997). The Peel-Manning Fault is characterized by serpentinite-matrix mélange, incorporating blocks of ophiolite and older eclogite and blueschist metamorphics (Offler and Williams, 1987; Fukui et al., 1995; Aitchison et al., 1997).

THIN-SKINNED THRUST SYSTEMS

These include the external part (Adelaide fold-thrust belt) of the Delamerian Orogen and the western, western-central and easternmost part of the Lachlan Orogen (Fig. 3). Thin-skinned thrust systems in the central and eastern Lachlan and New England Orogens that are interpreted to be former accretionary complexes are also included in this group.

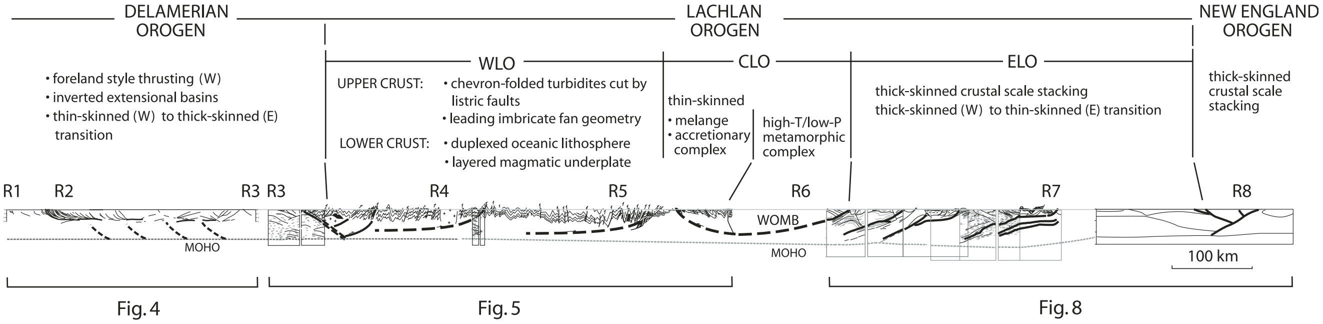


Figure 3. Composite structural profile of the composite Tasman orogenic system. Enlargements of various segments of the profile are shown in Figures 4, 5, 8 and 9. WLO: western Lachlan Orogen; CLO: central Lachlan Orogen; ELO: eastern Lachlan Orogen; WOMB: Wagga-Omeo Metamorphic Belt; W: west; E: east. Segments of the composite profiles are designated R1 through R8, with the profile locations shown on Figure 1.

Adelaide Fold-Thrust Belt, Delamerian Orogen

The Adelaide thrust belt is an arcuate, S-shaped, 600 km long, 50–150 km wide fold-thrust belt (Clarke and Powell, 1989; Mancktelow, 1990; Flöttmann et al., 1994; Marshak and Flöttmann, 1996). Maximum width of the belt is 150 km in the north where folds with ~20 km wavelengths and 400 m amplitudes dominate (Nackara arc of Fig. 2; see Marshak and Flöttmann, 1996). These folds have upright form and are cored by evaporite breccia in carbonate injected from the basal décollement, similar to the salt diapirism in the Zagros fold belt (e.g., Bahroudi and Koyi, 2003) and the Rome breccias of the southern Appalachians (Diegel, 1989).

In the south, the belt narrows to >50 km (Fleurieu arc of Fig. 2; see Marshak and Flöttmann, 1996) where Proterozoic basement, Adelaidean platformal cover, and Kanmantoo rift basin sequences are imbricated along major, gently east-southeast–dipping shear zone systems (Jenkins and Sandiford, 1992; Flöttmann et al., 1994). These zones have ~5 km spacing and involve imbricate stacking above an inferred décollement at shallow depth (Fig. 4A) interpreted either at ~4 km (see Fig. 3B of Flöttmann et al., 1994) or ~8 km (see Fig. 4 of Jenkins and Sandiford, 1992). East of a major shear zone (Williamstown-Meadows Fault), rift basin turbidites (younger Kanmantoo and Normanville Groups) are chevron-folded with an apparent thick-skinned form (Mancktelow, 1990; Flöttmann et al., 1994) but are probably floored by a décollement at ~13–14 km depth (Fig. 4).

The region to the east is largely under sedimentary cover with crustal structure reflected by the aeromagnetics (Fig. 1) with offshore seismic reflection profiling oblique to the structural trends suggesting an imbricate thrust form with faults splaying off a basal décollement at ~13–14 km depth (Fig. 4B; Flöttmann and Cockshell, 1996). The easternmost exposed part is the Glenelg Metamorphic complex in western Victoria (Fig. 2), where deep crustal seismic profiling (Korsch et al., 2002) shows largely east-dipping crustal-scale reflective zones but with both east- and west-dipping reflective zones at shallower levels (see B-B´, Fig. 5). Both east- and west-dipping structures are also seen in the easternmost part of the offshore seismic line A-A´ (Fig. 4B).

The Turbidite-Dominated Western Lachlan Orogen Thrust System

The structural style of the western Lachlan Orogen is characterized by chevron-folds (Fig. 6) cut by a series of linked fault-systems (e.g., Fergusson and VandenBerg, 1990; Gray et al., 1991; Gray and Foster, 1998; Fig. 5). This deformation has resulted in massive shortening (~60–70%) and structural thickening (~300% vertical elongation) of the overlying turbidite pile (e.g., Gray and Willman, 1991a,b; Fergusson and Coney, 1992). The deformed wedge outside the fault zones has only one phase of deformation, shown by a weak to moderately developed slaty cleavage (see White and Johnston, 1971), which is parallel to the axial surface of upright, subhorizontally plunging chevron-folds in the upper parts of thrust sheets (Gray and Willman 1991b).

The major faults in the western Lachlan Orogen (Figs. 3 and 5) are spaced at 100 to ~120 km, have finite strike lengths on the order of 150 km (Gray and Foster, 1998; Gray et al., 2006b), and are actually zones containing what appear to be the upper parts of former Cambrian back-arc oceanic lithosphere (Crawford and Keays, 1978; Crawford et al., 1984). They contain dismembered

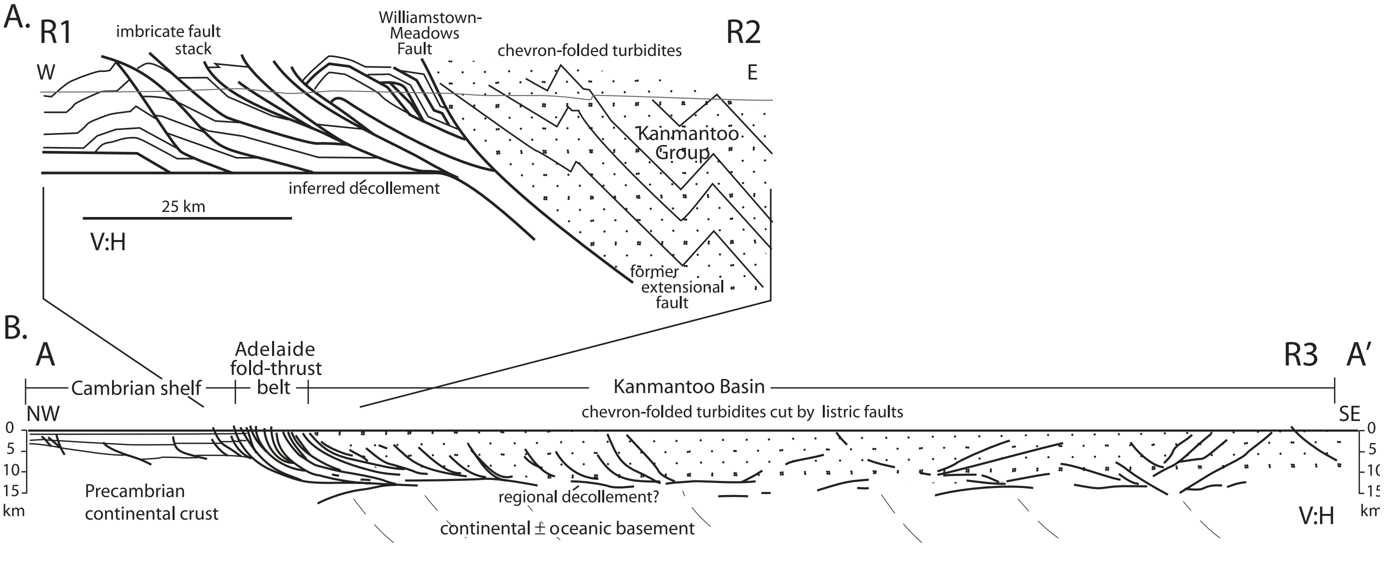


Figure 4. Geometry of the Delamerian Orogen. (A) Balanced permissible cross section of the Adelaide fold-thrust belt (modified from Figure 3 of Flöttmann et al., 1994). (B) Offshore seismic reflection profile modified from Figures 4 and 6 of Flöttmann and Cockshell (1996). Locations are shown in Figures 1 and 2.

Cambrian ophiolite slivers (Spaggiari et al., 2003a) as well as relicts of serpentinite and mud-matrix mélange incorporating blueschist knockers (Spaggiari et al., 2004). These fault zones have widths up to 4–5 km in plan view, and have duplexlike character where interconnecting faults link with bounding faults that define the fault zone proper (Fig. 7; Gray and Foster 1998; Spaggiari et al., 2004).

Major thrust fault zones within the deformed turbidite package of the western Lachlan Orogen are polydeformed zones characterized by transposition layering and crenulation cleavages (Gray and Willman 1991a,b; Gray, 1995; Morand et al., 1995; Gray and Foster 1998). They show high, noncoaxial strains, intense mica fabrics, and isoclinal folds (Gray and Willman, 1991a,b; Gray, 1995), and clearly have a different character than the brittle-ductile fault zones of classic foreland fold-and-thrust belts (see Table 1 of Gray and Foster, 1998).

Some faults within the western Lachlan Orogen thrust system (e.g., the Waratah Fault Zone; Fig. 2) consist of a deformed region up to 500 m wide with mud-matrix mélange and zones of mud meshwork veinlets and seams (Gray et al., 1999; Janssen et al., 1998). These are typical of mud diapirism in the shallower parts of the migrating and structurally thickening, subduction-accretion wedges (e.g., Moore and Byrne, 1978; Williams et al., 1984).

Thin-Skinned Eastern Lachlan Orogen

Outboard and south of an attenuated Ordovician volcanic arc and a Siluro-Devonian platformal and basinal facies in the eastern Lachlan Orogen (see p. 125) chevron folded turbidites cut by listric faults are exposed in the Yalmy-Bungonia thrust belt (Fergusson and VandenBerg, 1990; Fergusson, 1998a). Geometries of the crustal profiles in this belt are similar to those of the western Lachlan Orogen (compare Figs. 9 and 10 of Fergusson and VandenBerg, 1990). Thrust repetition has also been described farther south in this zone by Glen and VandenBerg (1987).

Remnant Accretionary Complexes of the Central and Eastern Lachlan Orogen

Relicts of accretionary complexes are contained within the Tabberabbera zone of the central Lachlan Orogen and the easternmost part of the eastern Lachlan Orogen, the Narooma accretionary complex (Fig. 2). In the Narooma accretionary complex large-scale imbrication is associated with chaotic block-in-matrix mélange, broken formation along high-strain zones, early bedding-parallel cleavage, recumbent folds in turbidites, and structural complexity in cherts. This succession has been interpreted as the outer-arc slope and imbricated zone of an accretionary wedge that was part of a Late Ordovician-Silurian subduction zone (e.g., Powell 1983, 1984; Bischoff and Prendergast 1987; Miller and Gray 1996, 1997; Offler et al., 1998; Fergusson and Fricken 2003), although Glen et al. (2004) have argued that it is part of an accreted exotic terrane.

In the Tabberabbera Zone of the central Lachlan Orogen (see Howqua Accretionary Complex, Fig. 2) an imbricated and chevron-folded, Late Ordovician-Silurian turbidite succession

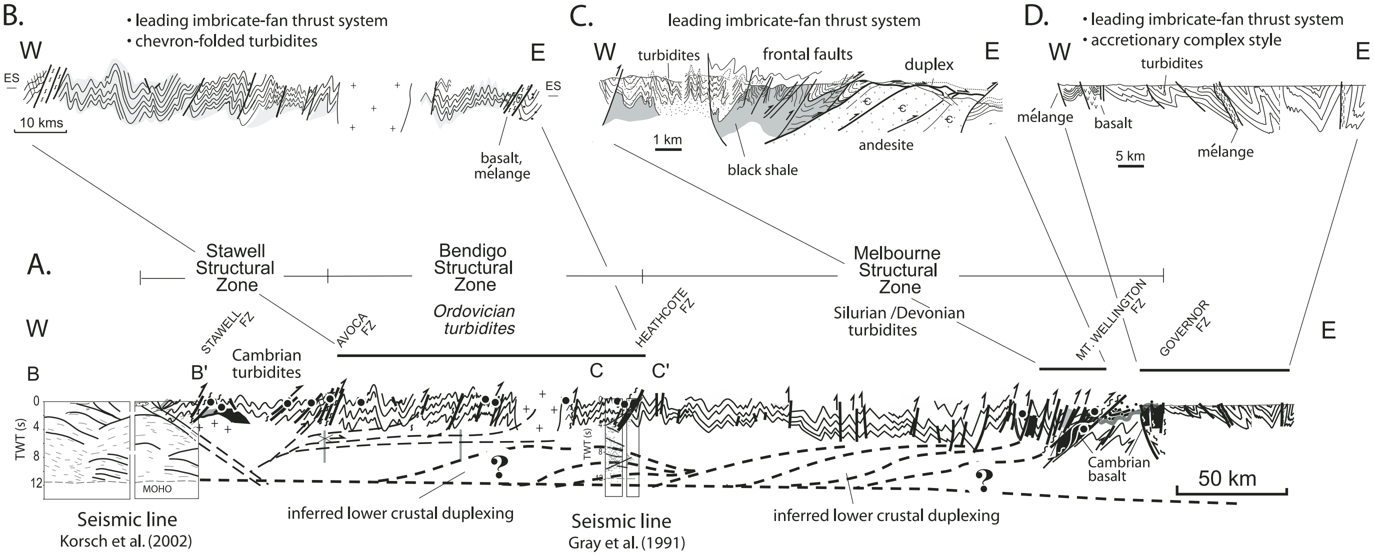


Figure 5. (A) Unbalanced structural profile across the western and central Lachlan Orogen incorporating the deep crustal seismic reflection profiles B-B´ (after Korsch et al., 2002) and C-C´ (after Gray et al., 1991), with enlargements of profile segments displayed as B, C, and D. (B) Chevron-folded western Lachlan Orogen (WLO) (modified from Gray and Willman, 1991a). (C) Frontal part of the Melbourne Structural Zone, western Lachlan Orogen incorporating the Mt. Wellington Fault zone (modified from Figure 3.45 of VandenBerg et al., 2000). (D) Structural profile of the frontal part of the Tabberabbera Zone of the CLO incorporating the Governor Fault zone (modified from Fergusson, 1998a, 2003). Location of profile shown in Figure 1.

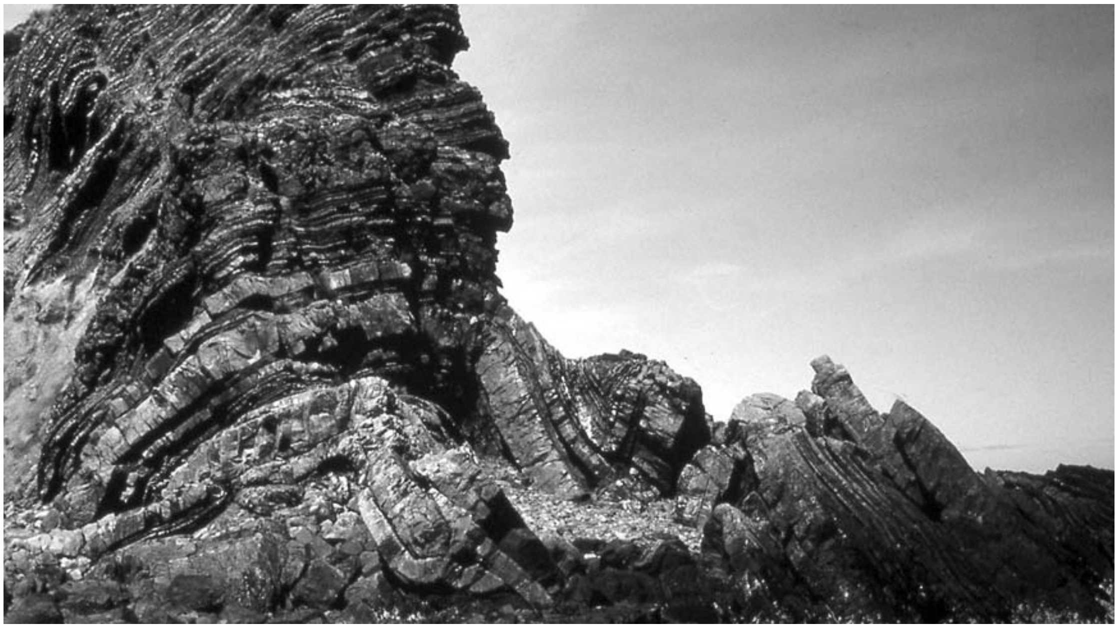


Figure 6. Photograph of chevron-folded interbedded mudstone and sandstone turbidite sequence in coastal exposure at Cape Liptrap, western Lachlan Orogen (WLO). See Figure 2 for the location. This exposure is typical of the chevron-folded sequences in the hanging walls to the leading imbricate-fan thrust systems (see Gray and Willman, 1991a,b; Gray and Foster, 1998).

contains mud-matrix and serpentinite-matrix mélanges in the frontal fault zone (Spaggiari et al., 2002a, 2002b, 2003b, 2004) as well as mud-matrix mélange along major faults within the wedge (Fergusson 1987b; Watson and Gray 2001) and a possible detached seamount (Spaggiari et al., 2003c). These have been interpreted as part of a Late Ordovician-Silurian accretionary wedge (e.g., Gray et al., 1997; Foster and Gray, 2000; Fergusson 2003).

New England Orogen Accretionary Complex Rocks

The Texas-Woolomin and Wandilla belts of the New England Orogen (Fig. 2) consist of many steeply dipping fault slices within monotonous turbidites, containing minor radiolarian chert, metabasalt and limestone, as well as broken formation and/or mélange (Cawood, 1982; Fergusson, 1984a,b; Cross et al., 1987; Fergusson et al., 1990a,b). Geometries consist of largely homoclinally and steeply dipping, structurally interleaved units of lenticular mélange, cleaved mélange, and semicoherent to coherent beds including layers of chert and basalt (see Fig. 16 of Fergusson, 1984a, and Fig. 2 of Fergusson et al., 1990a).

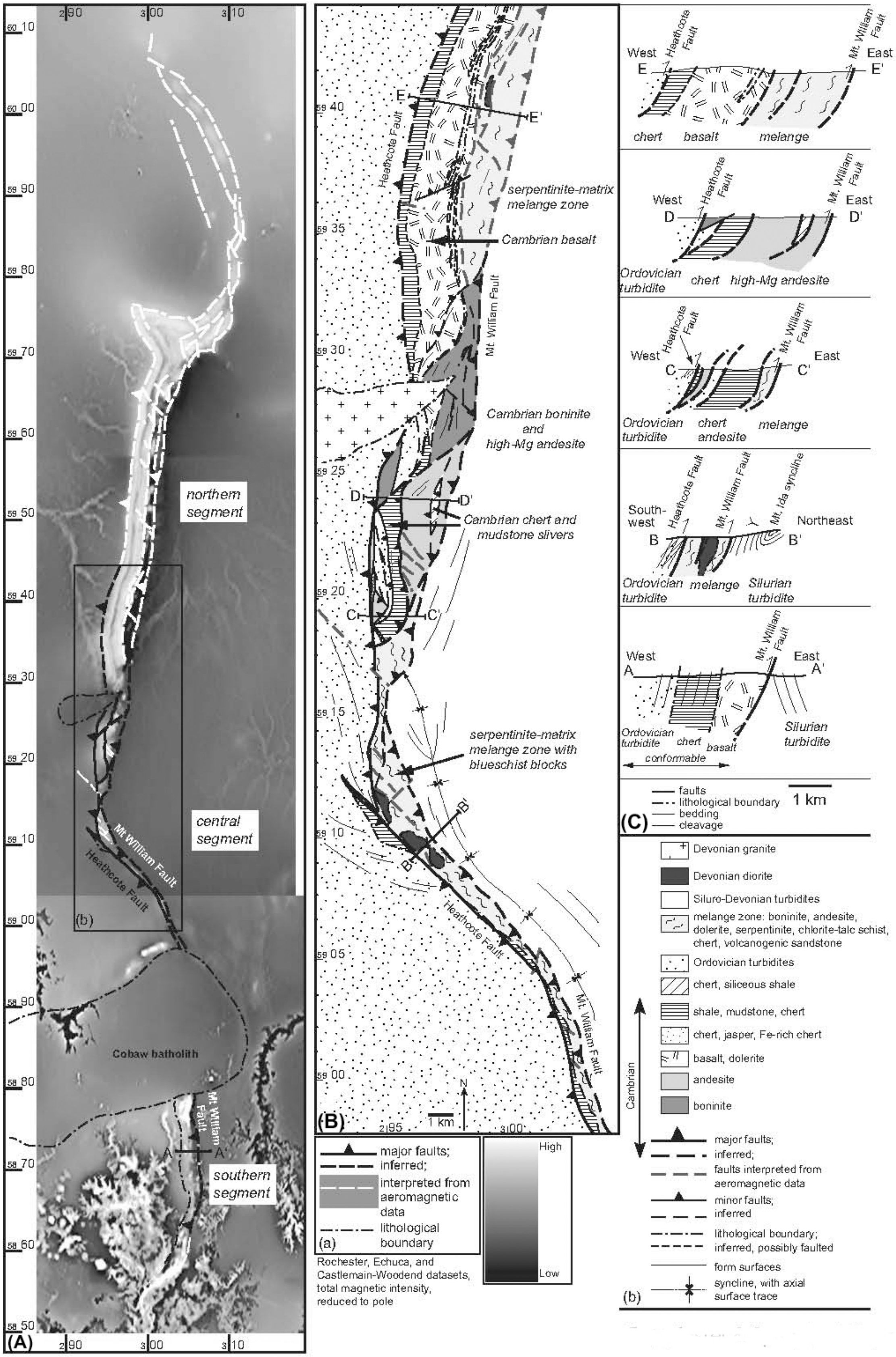
THICK-SKINNED FAULT SYSTEMS

Deep crustal seismic reflection profiles show that the western part of the eastern Lachlan Orogen and the New England Orogen have classic thick-skinned crustal architecture where major faults extend to the seismic reflection Moho and show no décollement system.

The Eastern Lachlan Orogen

Originally interpreted as an east-vergent, thin-skinned thrust system (e.g., Fig. 11 of Glen, 1992), recent deep crustal seismic data show, however, that the eastern Lachlan Orogen is made up of several major, west-dipping fault zones that penetrate to the Moho (i.e., thick-skinned deformation; Glen et al., 2002). These faults cause crustal-scale imbrication of Ordovician volcanic arc rocks, coeval quartz-rich turbidites and inferred Cambrian MORB (midocean ridge basalt) volcanic rocks (Fig. 8; Glen et al., 2002). They have crustal spacings of 10–15 km and continuous 100–150 km length segments in profile (see E-E′ and F-F′, Fig. 8).

Younger west-dipping faults evolved from Silurian-Devonian extensional faults that were reactivated as thrusts during the mid-Devonian and the Carboniferous (Glen, 1992; Glen et al., 1992, 2002). As a consequence, the former extensional basins (e.g., Cowra and Hill End troughs) have antithetic (i.e., west-directed) thrust faults defining their western margins (Fig. 8). At the scale of the crust the major, through-going faults are west-dipping, but at shallow crustal levels there are both east- and west-dipping younger thrust fault systems. Structure of the Wagga-Omeo Metamorphic belt (see WOMB of Fig. 3) is dominated by a series of


(A)
northern segment
central segment
southern segment
Mt William Fault
Heathcote Fault
Cobaw batholith
(b)
A A'
290 300 310
6010 6000 5990 5980 5970 5960 5950 5940 5930 5920 5910 5900 5890 5880 5870 5860 5850
(B)
Heathcote Fault
Mt. William Fault
serpentinite-matrix melange zone
Cambrian basalt
Cambrian boninite and high-Mg andesite
Cambrian chert and mudstone slivers
serpentinite-matrix melange zone with blueschist blocks
E E' D D' C C' B B'
5940 5935 5930 5925 5920 5915 5910 5905 5900
295 300
N
1 km
(a)
major faults; inferred;
interpreted from aeromagnetic data
lithological boundary
Rochester, Echuca, and Castlemain-Woodend datasets, total magnetic intensity, reduced to pole
High
Low
(C)
West E Heathcote Fault Mt. William Fault East E'
chert basalt melange
West D Heathcote Fault Mt. William Fault East D'
Ordovician turbidite chert high-Mg andesite
West C Heathcote Fault Mt. William Fault East C'
Ordovician turbidite chert andesite melange
South-west B Heathcote Fault Mt. William Fault Mt. Ida syncline Northeast B'
Ordovician turbidite melange Silurian turbidite
West A Mt. William Fault East A'
Ordovician turbidite chert basalt Silurian turbidite
conformable
faults
lithological boundary
bedding
cleavage
1 km
Devonian granite
Devonian diorite
Siluro-Devonian turbidites
melange zone: boninite, andesite, dolerite, serpentinite, chlorite-talc schist, chert, volcanogenic sandstone
Ordovician turbidites
chert, siliceous shale
shale, mudstone, chert
chert, jasper, Fe-rich chert
basalt, dolerite
andesite
boninite
Cambrian
major faults; inferred;
faults interpreted from aeromagnetic data
minor faults; inferred
lithological boundary; inferred, possibly faulted
form surfaces
syncline, with axial surface trace
(b)

antithetic thrust faults that nucleate or propagate off the major west-dipping shear zone that defines the eastern margin of the belt (Fig. 8). The arc rocks show hanging wall crustal-scale antiforms that may reflect subsurface ramping off these west-dipping faults.

The New England Orogen

Crustal thickening to form crust of ~30–35 km thickness in the New England Orogen (NEO) has involved crustal-scale imbrication on both west- and east-dipping major faults that extend to the seismic reflection Moho. The New England Orogen however, shows transitional character along its length. In the north (profile I-I´, Fig. 9), the orogen consists of stacked, crustal-scale thrust-slices of volcanic arc (Connors belt), forearc (Yarrol belt), ophiolite (Marlborough ophiolite), and subduction complex (Wandilla belt) with all faults and thrust slices dipping east away from the craton (Fergusson, 1991; Korsch et al., 1997). These major thrust faults extend to the Moho and do not appear to link to a common thin-skinned style décollement (see Fig. 14 of Korsch et al., 1997). In the south (profiles G-G´ and H-H´, Fig. 9) the boundary between the forearc basin (Tamworth belt) and the accretionary complex (Tablelands Complex) is a major west-dipping fault that extends to the Moho (Korsch et al., 1997).

In all of the seismic profiles through the New England Orogen components, the upper crustal levels appear to have overridden Lachlan-Thomson crust, although in the southern profiles (profiles G-G´ and H-H´, Fig. 9) accretionary wedge rocks appear to extend below Lachlan Orogen lower crust (see Fig. 8 in Korsch et al., 1997). In the north, the New England Orogen has classic tapered, craton-vergent thrust-wedge form, but in the southern part it shows doubly vergent character (e.g., Beaumont et al., 1994), with the arc and forearc basin rocks defining a triangular wedge (triangle zone or pop-up) with both synthetic, or pro-wedge, (eastward thrusting) and antithetic, or retro-wedge, (westward thrusting) thrust components on the western and eastern sides respectively (e.g., Korsch et al., 1997; Korsch, 2004).

The thrust-style in the northern New England Orogen is highlighted by the Jellinbah and Gogango fold-thrust zones (Fig. 9A). The Jellinbah thrust with subsidiary Yarrabee thrust as a splay (Finlayson, 1993; Goleby et al., 1994) within the Permo-Triassic foreland basin sequence (Bowen Basin coal measures) is colinear with, or appears to become, the major interface between the Thomson and New England Orogens (Fig. 9A) as this structure or equivalent structure extends to the seismic reflection Moho. The Gogango thrust zone consists of highly cleaved and isoclinally folded equivalents of Early Permian Bowen Basin rocks, which appear imbricated at the crustal-scale by multiple faults spaced at ~2–2.5 km (Fergusson, 1991; Holcombe et al., 1997; Korsch et al., 1997). These faults are truncated by a late out-of-sequence thrust that emplaced the Marlborough ophiolite (see Fig. 15 of Korsch et al., 1997).

FAULT MECHANICS AND ACCRETIONARY OROGENS

Observations from the eastern Australian seismic profiles suggest that faulting in accretionary orogenic systems consists of:

1. Thin-skinned, décollement-related fault systems associated with chevron-folded turbidites overlying fault-bounded, duplexed, and dismembered oceanic lithosphere. These fault systems tend to have leading imbricate fan geometry (Gray and Foster, 1998).
2. Thick-skinned fault systems that extend to the Moho and do not involve links to subhorizontal décollements or detachment faults. The thick-skinned sections seem to have other elements involved, such as arcs and related granites, as well as older, perhaps previously accreted ophiolitic components (e.g., parts of the New England Orogen).

Thin–skinned fault systems appear to have developed in a back-arc basin tectonic environment facilitated by having ~6–10 km thickness oceanic crust that can break between the upper and lower crustal sections, helping drive imbricate-style thrusting with just a thin chert layer and turbidites on top; that is, no other components are involved (e.g., Kimura and Ludden, 1995; see Section 5.1 and Figs. 12 and 13 of Spaggiari et al., 2004). This process may be preceded by long wavelength buckling of the oceanic lithosphere (e.g., Royer and Gordon, 1997; Gerbault, 2000), as well as possible subduction initiation, or oceanic underthrusting, due to forced convergence across oceanic transform/fracture zones (e.g., Hall et al., 2003).

Thick-skinned fault systems appear to relate to: 1. inversion of former extensional faults in attenuated continental crust (eastern Delamerian Orogen) or arcs (western part of the eastern Lachlan Orogen), or 2. crustal-scale stacking of arc, forearc, and subduction elements adjacent to former subduction zones (e.g., New England Orogen). Such behavior and thick-skinned, crustal-scale stacking is reflected in thermomechanical laboratory modeling experiments of arc behavior during intraoceanic convergence, particularly during closure of back-arc basins (see Boutelier et al., 2003). Major interfaces between the components extend to the base of the crust.

Figure 7. (Facing page) (A) Aeromagnetic image of typical fault zone of the western Lachlan Orogen (WLO) and of accretionary style orogens. The image shows fault-bounded suprasubduction zone basalts that define the Heathcote Fault zone (modified from Spaggiari et al., 2004). Aeromagnetic datasets from Geoscience Australia and the Geological Survey of Victoria. (B) Map of part of the northern and central segments of the Heathcote Fault Zone showing major structures and lithologies (modified from Spaggiari et al., 2004). (C) Profiles across the southern (A-A´), central (B-B´, C-C´, D-D´), and northern (E-E´) segments (modified from Spaggiari et al., 2004).

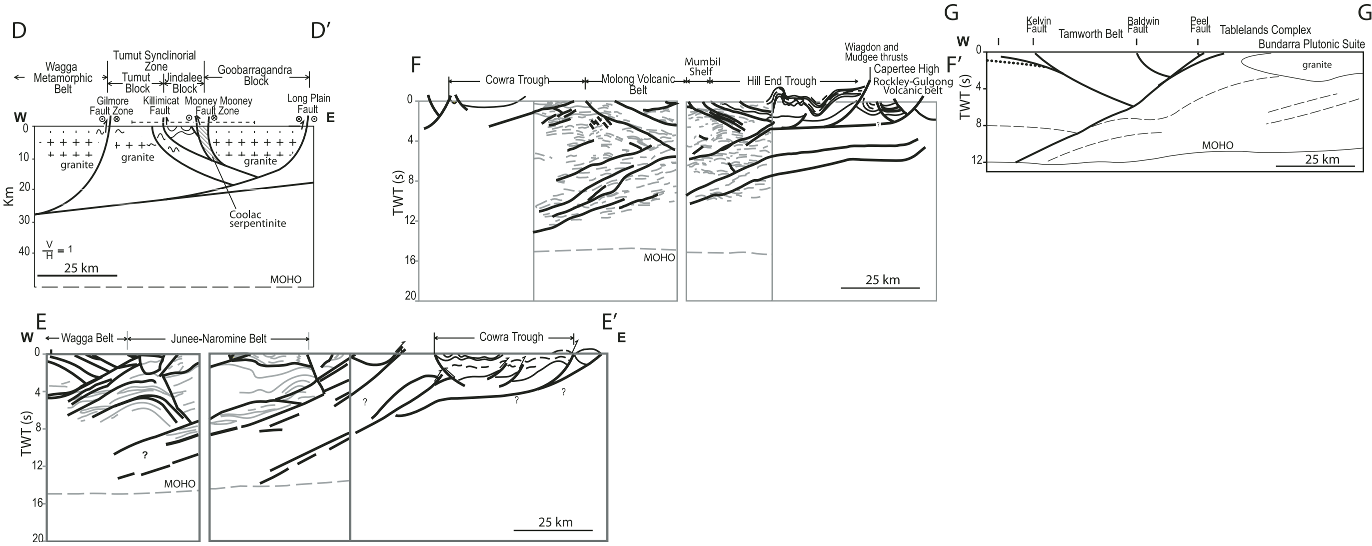


Figure 8. Composite crustal profile across the eastern Lachlan Orogen (ELO) based on deep crustal seismic reflection profiling. Profile D-D´ from Leven et al. (1992), profiles E-E´ and F-F´ from Glen at al. (2002), and profile G-G´ from Korsch et al. (1986, 1997). All profiles are at the same scale. For locations, see Figure 2.

Major crustal structure in the Tasmanides of eastern Australia can therefore be linked to tectonic setting, crustal components, and crustal thicknesses (e.g., Cawood, 2005). Transitions in some of the orogens or subprovinces, such as the west-to-east transition in the Delamerian Orogen, and the west to east transition in the eastern Lachlan Orogen must also relate to changes in the character of the basement. In the eastern Lachlan Orogen, the changes appear related to the presence of the Ordovician ancestral volcanic arc but in the eastern Delamerian Orogen to the presence of attenuated continental lithosphere or to possible previously rifted, microcontinental fragments.

In the Lachlan Orogen geometrical differences between the three thrust systems have been inferred to relate to differences in the thickness of the original turbidite fan, the residence time of the turbidite sediments on the seafloor, the tectonic position of the turbidites, either in the hanging wall or overriding plate of the subduction zone, or in the footwall, conveyered on the subducting slab, and the thickness of the mafic basement, either oceanic back-arc-basin crust or oceanic crust combined with volcanic arc crust (see Gray et al., 2006a). The western Lachlan Orogen developed within a thick turbidite fan system on stable back-arc basin oceanic lithosphere, the central Lachlan Orogen in a relatively thin turbidite fan also on part of the stable back-arc basin lithosphere but in front of a developing arc, and the eastern Lachlan Orogen from inverted basins in extended island arc crust (see Table 1 of Gray and Foster, 2004b). Oceanic plateau within the backarc basin related to segmented arcs (Crawford and Keays, 1978; Spaggiari et al., 2003b) or inferred continental fragments (Cayley et al., 2002) may also have been important in development of the final crustal architecture and structural style.

CONCLUSIONS

Accretionary orogens, such as the eastern Australian Tasmanides, show both thin-skinned thrusting and thick-skinned thrust faulting, dependent on the nature and stratal thicknesses of the sequences involved. Where elements such as arc, forearc basin, subduction complex and ophiolite are involved, the structural style is thick-skinned, crustal-scale stacking along thrust faults that root into the seismic reflection Moho. Where large volumes of turbidites in ancient submarine fans are involved, the deformation is more thin-skinned with multiple décollements and leading imbricate-fan geometry for the oceanic thrust systems. Thrust sheets within the turbidite fans are characterized by chevron-folding and thrust faulting that produced massive shortening (~65–70%) and structural thickening (~300%) of the former fans. Slivers of dismembered Cambrian ophiolites are preserved in the leading or frontal faults, incorporated as offscraped slices, imbricated fault slivers or duplexes, and as blocks in mélange. The Tasman Orogen indicates that crustal thickening to form crust of ~30–45 km thickness in accretionary orogens has to involve crustal-scale imbrication on both pro- and retro-wedge major faults that extend to the seismic reflection Moho.

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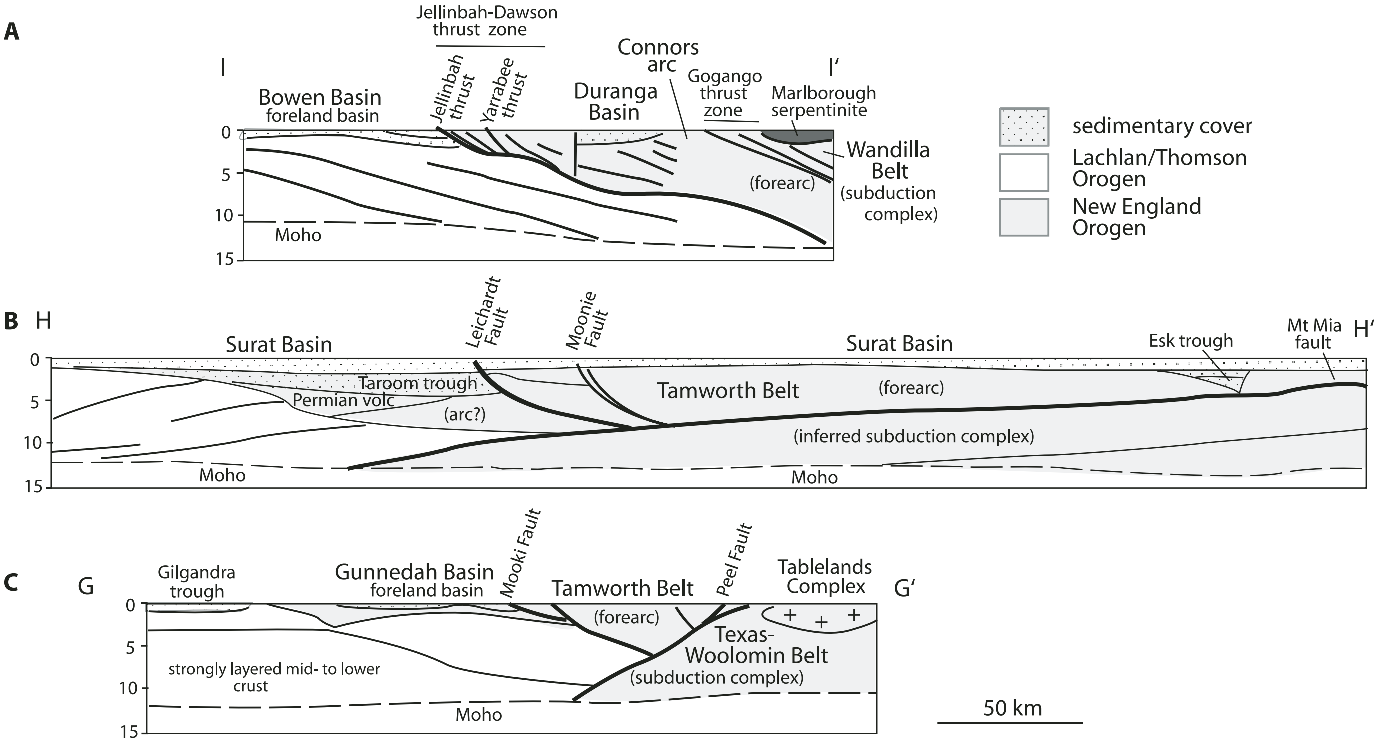

Figure 9. Deep crustal seismic reflection profiles from the New England Orogen (modified from Figure 16 of Korsch et al., 1997). The profiles have been aligned at the leading edge, or the structural front, of the New England Orogen. For locations see Figure 2.

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