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The pre-Carboniferous geology of Tasmania

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Tasmania evolved over 900 Myr as a small fragment on the margin of Gondwana. There are three episodes of passive margin sedimentation from the Mesoproterozoic to the Devonian. Tasmania rifted from the Antarctic margin as part of Rodinia breakup and was then involved in “West-Pacific-Style” tectonics along the eastern margin of Gondwana through the Paleozoic. Arc-continent collision led to ophiolite obduction in the Cambrian. Much of this geological history can be recognised from the excellent coastal exposures along the north coast of Tasmania.

Introduction

This paper provides a broad overview of the complex geological history of Tasmania, with particular emphasis on the north coast (Figure 1). The paper relies upon supporting data that cannot be included in this short review and the reader should refer to Burrett and Martin (1989) for a pre-1998 view of the geological history. More recent papers on the geology of Tasmania are Black et al. (2004, 2005), Calver and Walter (2000), Meffre et al. (2000) and Berry et al. (2007) and a major detailed review of the geology is about to become available (Corbett et al., 2012). Biostratigraphic correlations for the Cambrian follow the review in Figure 3 of Corbett (2002). The latest review of the tectonics is in Cayley (2011).

Tasmanian is usually separated into a Western Tasmanian Terrane (WTT) and an Eastern Tasmanian Terrane (ETT). The Nd isotopes reported from the WTT indicate that the lower crust was extracted from the mantle in the late Paleoproterozoic (c. 1700 Ma; Berry et al., 2008). Only Paleozoic rocks are exposed in the ETT and the deep basement is probably late Neoproterozoic–Cambrian ocean crust (Black et al., 2010).

Tectonic Overview

Australia and most of East Antarctica were combined into a continental fragment by 1100 Ma (Betts and Giles, 2006), which from 1100–780 Ma formed part of Rodinia (Li et al., 2008). The Neoproterozoic Australia/Antarctic continental fragment retained the same geometry until the Mesozoic (Veevers, 2000) and this geometry is well constrained from modern ocean structure. A major continent, possibly Laurentia or South China, rifted away from East Gondwana at c. 780 Ma (Li et al., 2008; Wingate et al., 2002). However, the separation of the WTT from the Australian craton probably

occurred during a second rift phase at 580 Ma (Calver and Walter, 2000; Direen and Crawford, 2003; Meffre et al., 2004).

The position of Tasmania in Cambrian reconstructions remains controversial. Detailed Mesozoic reconstructions (Royer and Rollett, 1997) put Tasmania outboard of the Ross Orogen (Figure 2). Paleomagnetic data support the interpretation that Tasmania was near this position by the late Cambrian (Li et al., 1997). Despite this position as an isolated microcontinent E of the Ross-Delamerian Orogen, the Western Tasmanian Terrane shares many features of its Neoproterozoic depositional history with the Adelaide Fold Belt (Calver and Walter, 2000). Berry et al. (2008) concluded that the Western Tasmanian Terrane rifted away from the Transantarctic Mountains at c. 580 Ma (Figure 3). It remained isolated from Antarctica and from the whole evolving Gondwanaland margin from at least 540 Ma until the end of the Cambrian (Figure 4).

At the end of the early Cambrian, the WTT collided with an oceanic island arc (Figure 4b; Berry and Crawford, 1988; Crawford and Berry, 1992) and Tasmania was accreted back onto the craton margin in the middle to late Cambrian. The formation of an Ordovician arc to the E of Tasmania (Figure 4) trapped a section of ?Cambrian oceanic crust which formed the rigid lower crust for the Selwyn Block (Cayley, 2011) including NE Tasmania and the Melbourne Trough.

Figure 1 Space time chart for Tasmania.

Figure 2 Tasmanian position outboard of the Ross Delamerian Orogeny based on Mesozoic reconstruction of Royer and Rollett (1997).

Figure 3 Possible position for Tasmania near the Transantarctic Mountains before rifting at 580 Ma.

The Paleozoic history of this block is tied to the evolution of the Tasman Fold Belt with a final orogenic event in the Devonian.

Mesoproterozoic

The oldest rocks of the WTT are found on King Island. They are low amphibolite grade metasedimentary rocks and minor amphibolites. Chemical U-Th-Pb dating of monazite indicates a metamorphic event at 1290 Ma (Berry et al., 2005), whereas detrital zircon dating shows that these rocks were deposited after 1350 Ma (Black et al., 2004). Several types of mafic rocks intrude this succession (Cox, 1989). The oldest are discontinuous, concordant to subconcordant bodies of metamorphosed low K tholeiites emplaced prior to D_1 . Polyphase deformation has affected the Mesoproterozoic metasediments. However only the first major deformation phase (D_1), tight folds with a penetrative axial surface cleavage defined by muscovite, is considered to have formed at 1290 Ma. This event is very restricted in distribution and its significance is still debatable. There are no obvious correlates in SE Australia.

Neoproterozoic (760–750 Ma; Black et al., 1997) biotite granites intrude the King Island succession (Cox, 1989; Turner et al., 1998). The granites have strongly deformed aureoles but are not linked to any larger scale deformation features. This event is known as the Wickham Orogeny. Holm et al. (2003) argued the King Island granitoids are related to rifting and the breakup of Rodinia.

Neoproterozoic sedimentary rocks

This summary of the Neoproterozoic sedimentary record largely follows Calver et al. (2012a). The early Neoproterozoic stratigraphy of NW Tasmania (Figure 1) is dominated by shallow water siliciclastics (Rocky Cape Group in the NW, and correlates in the S and E) and turbidites (Oonah Formation in the N). The age of these units is poorly constrained. All have similar detrital zircon patterns (Black et al., 1997), with the youngest zircons dated at 1000 Ma. Calver and Walter (2000) argued that parts of the unconformably overlying succession are 750 Ma old. The Oonah Formation contains dolerite sills (Cooee Dolerite) that have a 725 ± 35 Ma minimum age (Crook 1979). Calver et al. (2012a) argue this sequence is older than 760 Ma but no Neoproterozoic granites have been found in the widely exposed units. It is possible this sequence was deposited after the Wickham Orogeny and before 700 Ma.

The Rocky Cape Group is a thick sequence of siliciclastic sedimentary rocks deposited in a marine shelf (passive margin) environment (Calver et al., 2012a). The Pedder River Siltstone, Balfour Subgroup and Irby Siltstone were deposited in an open shelf environment between storm wave base and fair-weather wave base. They are dominated by mudstone and siltstone-sandstone. The sandstones are commonly wave rippled and cross-lamination and locally gutter casts and swaley and hummocky cross-stratification have been identified. Small synsedimentary clastic dykes are common in many pelite beds that probably formed as 'diastasis cracks'. The Cowrie Siltstone and Emmetts Creek Shale are predominantly fine-grained and plane-laminated, indicating deposition in a low-energy, offshore shelf environment, shallowing to storm wave base at times. Supermature quartz arenites of the Lagoon River Quartzite, Detention Subgroup and Jacob Quartzite probably formed in a shallow marine, tide-dominated setting. Fining-upward cycles in the Lagoon River Quartzite may represent prograding tidal flats. Carbonate is rare in

Figure 4 Cartoon showing tectonic evolution of Tasmania, 520–440 Ma. Modified from Cayley (2011).

the Rocky Cape Group, but local oolites and stromatolites, in combination with wave ripple cross lamination indicate a shallow marine depositional setting. Carbonate units are more common in equivalent sequences in SE Tasmania. All of these rocks have been metamorphosed to prehnite-pumpellyite grade (Chester 2006).

The Oonah Formation and correlates make up a number of inliers between the Rocky Cape and Tyennan regions and form the eastern part of the Arthur Metamorphic Complex. There is no known stratigraphic contact with the Rocky Cape Group or any of its correlates. The succession is prehnite-pumpellyite to low greenschist facies. Two lithological associations are included in the Oonah Formation.

Sedimentary structures in the dominant fine grained quartzwacke assemblage are typical of sandy turbidites (grading, cross-lamination, parallel lamination, convolute lamination, intraformational slumps, flute marks, load casts and rip-up clasts). At Sulphur Creek, coastal exposures thought to be stratigraphically high in the Oonah Formation display low-angle scours and possible hummocky cross-stratification, suggesting a shallowing of paleoenvironment to above storm wave-base. Sandy beds at or near the top of the Oonah Formation are particularly rich in coarse detrital muscovite (Turner, 1989). The turbidite package is intruded by the Cooee Dolerite and includes minor mafic pillow lavas. The second, relatively rare, lithological association is pelite and carbonate, with rare mafic volcanics and conglomerate. This association has been interpreted as a shallow water upper subdivision of the Oonah Formation (Brown, 1986).

The Togari Group (and correlates) forms the next phase of deposition. The basal units of the Togari Group rest on different stratigraphic levels of the Rocky Cape Group basement. The contact is a low angle (c. 20°) to disconformable surface (Brown, 1989). The metamorphic grades range up to low greenschist facies. The type section in NW Tasmania (Everard et al., 2007) is divided into four main lithostratigraphic units: (i) a lower dolomitic succession with basal siliciclastics and a diamictite near the top (?Marinoan glaciation), which represents a widespread phase of (c. 700–600 Ma) shallow marine shelf sedimentation; (ii) a phase of mafic rift volcanism (c. 600–570 Ma); (iii) shallow-marine carbonates (c. 570–545 Ma), and (iv) early Cambrian deep-water siliciclastics.

Stage (i) comprises a basal siliciclastic unit, the Forest Conglomerate, of variable thickness (0–120 m), followed by the Black River Dolomite (Brown, 1989) which consists of up to 800 m of interbedded dolostone, black shale and chert with a diamictite near the top. Calver (1998) correlated the stage (i) dolomitic unit with the Sturtian glaciation but, based on other constraints and the most recent dating for Neoproterozoic glaciations (Macdonald et al., 2010), a Marinoan age is assumed for the diamictite. The only direct numerical age constraint is a Re-Os date of 641 ± 5 Ma for black shale from the top of the Black River Dolomite (Kendall et al., 2009). Thus the ages of these sedimentary units remain contentious.

The second cycle of deposition, the Kanunnah Subgroup, is a 1.2 km thick succession of marine sedimentary rocks (siltstone, mudstone, volcanoclastic sandstone and diamictite) and basaltic lavas. On King Island, a ?glacial diamictite occurs near the base of this sequence (Direen and Jago, 2008; Hoffman et al., 2009). A rhyodacite lava in NW Tasmania extruded at 582 ± 4 Ma (Calver et al., 2004), and other slightly younger magmatic dates have been obtained on King Island (Meffre et al., 2004). This age suggests correlation of the diamictite with the Gaskiers glaciation (Macdonald et al. 2010) but Hoffman et al. (2009) preferred a correlation with the Marinoan

glaciation. The tholeiitic basalts, dolerite dykes and minor intrusions in this sequence are related to the 580 Ma rifting phase along the Gondwana margin.

The Kanunnah Subgroup is conformably overlain by a 1.5 km thick sequence of dolostone, the Smithton Dolomite. Strontium isotope chemostratigraphy suggests deposition at c. 570–545 Ma, consistent with the ages of units above and below. The whole sequence was deposited in shallow-marine, warm-water, occasionally evaporitic paleoenvironments (Calver et al., 2012a).

At the top of the Togari Group, the early Cambrian Salmon River Siltstone outcrops in the southern part of the Smithton syncline, where it is up to c. 350 m thick. The unit is composed of pale to dark grey, siliceous, thin-bedded siltstone. The contact with the Smithton Dolomite is not exposed but it appears to be conformable (Everard et al., 2007). By contrast, it probably has an unconformable contact with the overlying middle to late Cambrian Scopus Formation (Jago and Bentley, 2007).

Tyennan Orogeny Stage 1: Ophiolite emplacement

The Tyennan Orogeny in Tasmania is a complex event with rapidly changing stress patterns. Other than the forearc rocks, remnants of which survive today as widespread Cambrian mafic-ultramafic complexes, some Proterozoic rocks were also probably obducted at this time. These components include blueschist and eclogite facies metamorphic rocks that are thought to have undergone partial subduction during the collision event, followed by exhumation to high crustal level after slab breakoff. Although probably derived from the outer parts of the same passive margin as the autochthonous and parautochthonous rocks, these units are difficult to correlate, in part because of their high strain. The only allochthonous element specifically identified by Berry and Crawford (1988) was the mafic/ultramafic complexes. Other possible allochthonous elements identified since are the Forth Metamorphic Complex, Badger Head Metamorphic Complex, Port Davey Metamorphic Complex, Franklin Metamorphic Complex, Mersey River Metamorphic Complex and the Arthur Metamorphic Complex (Meffre et al., 2000), and the Wings Sandstone (Black et al., 2004). These blocks are scattered across Tasmania lying structurally above the late Neoproterozoic rift facies and are unconformably overlain by middle Cambrian and younger sedimentary rocks. The Arthur Lineament (Figure 1) forms the western limit to allochthonous blocks in Tasmania and appears to mark the maximum extent of the thrust complex. The early part of the thrust emplacement is recorded in high temperature mylonites that indicate thrusting towards the Swest. A major phase of thrusting to the S is recorded in the greenschist facies metamorphic rocks and widespread cataclasite in western Tasmania (Holm and Berry, 2002).

There are, a large number of less deformed Neoproterozoic to early Cambrian rocks loosely associated with the mafic/ultramafic complexes that are interpreted to be parautochthonous to allochthonous fault blocks. Examples along the northern Tasmanian coast are the Motton Spilite and Barrington Chert (Calver and Everard, 2012). The Barrington Chert is low in terrigenous input and is probably of oceanic origin whereas the Motton Spilite consists of pillowed and massive metabasalt and minor associated breccia of possible MORB (Mid Oceanic Ridge Basalt) affinity.

The passive margin sequence was strongly deformed and metamorphosed during this early stage of the Tyennan Orogeny. In the past these rocks have been subdivided into medium grade metamorphic rocks, high strain low grade metamorphic rocks, low strain low grade metasedimentary rocks and mélange (e.g., Turner, 1989). The high strain rocks of medium and low grade are commonly intimately interleaved by faulting and these were grouped together as metamorphic complexes by Meffre et al. (2000). Mélange units are poorly exposed (Seymour and Calver, 1995).

It is possible to subdivide the WTT into four domains (Figure 5). NW Tasmania, W of the Arthur Lineament is largely outside the Tyennan Orogen with only weak deformation except near the Arthur Lineament. Passive margin deposition continued through the middle Cambrian. The ophiolite emplacement can be recognized in this area by a progressive increase in detrital chromite, sourced from the ultramafic bodies, in the Cambrian sedimentary record.

The second domain is the External Zone (Foreland) in which relatively intact ophiolites sit on top of a very low grade continental shelf sequence dominated by thin-skinned deformation. The external zone (Figure 5) occupies the area from the Arthur Metamorphic Complex to the edge of the Tyennan Complex (or the Forth Metamorphic Complex in the N). The highest metamorphic grades are exposed along the western margin of the zone. Marginal blueschist facies rocks (Turner and Bottrill, 2001) are strongly overprinted by greenschist facies metamorphism. The mylonites at the base of the ophiolites indicate transport to the SW but all other structures indicate transport to the S. The ophiolite is unconformably overlain by middle Cambrian (506 Ma) sedimentary rocks (Turner and Bottrill, 2001).

The third domain is the Internal Zone (Figure 5), which is dominated by strongly folded metasedimentary rocks of low to medium grade which are thrust into a complex structural sequence lacking recognisable systematic zonation. In most parts of the Tyennan and Forth regions the earliest deformation phase (D_1) produced isoclinal to tight folds and commonly a bedding-parallel foliation. The second phase (D_2) produced isoclinal folds in some areas and open folds in other areas (Turner, 1989). The differentiated crenulation cleavage associated with D_2 is the dominant surface in most pelitic rocks. Mylonitic fabrics and the common occurrence of faults which are subparallel to the axial surfaces of isoclinal to tight folds, or which form the boundaries of major lithological units, indicate that widespread low angle faulting occurred in the early deformation. The juxtaposition of metamorphic blocks drawn from different crustal levels in the orogenic pile almost certainly occurred during D_{1-2} as part of the arc-continent collision. On structural and metamorphic grounds it is possible to separate the Tyennan region into three distinct subdomains (Figure 5):

- i) a northern subdomain dominated by E-W fold trends;
- ii) a SW subdomain characterised by fault bounded slices of medium and low grade metamorphic rocks;
- iii) a SE subdomain of low grade rocks dominated by N-S folds.

The Eastern Province (Figure 5) of thin skinned deformation and very low-grade metamorphism is the fourth domain. The northern section, near Beaconsfield, has higher ductile strain and more similarities with the Internal Zone but is included here on the basis of the presence of ophiolites, a small fault slice of marginal blueschist facies rocks and the limited distribution of medium grade rocks. The southern area is very similar to the External Zone. In Oman, low

Figure 5 Geology of the Western Tasmania Terrane relevant to the Tyennan Orogeny (simplified from Berry, 2012).

grade areas E of the Internal Zone are interpreted to be the equivalents of the External Zone, which were trapped behind the rapidly uplifting metamorphic rocks of the Internal Zone after slab breakoff (Searle et al., 2004) and this interpretation matches the few constraints known in Tasmania.

All indications are that the first stage of the Tyennan Orogeny was very short. The ophiolite contains a gabbro that intruded at 514 ± 5 Ma (Black et al., 1997). The age of the highest grade metamorphism is defined by U-Pb zircon and chemical U-Th-Pb monazite dating with the best estimate for the age of peak metamorphism at c. 511 Ma (Berry et al., 2007). The white mica ages reported by Foster et al. (2005) indicate that the Forth Metamorphic Complex cooled below the Ar/Ar white mica blocking temperature by 508 Ma. Detrital metamorphic minerals and metamorphic clasts in the post-collisional sediments suggest that the high pressure metamorphic rocks were unroofed by 506 Ma (Turner et al., 1998; Turner and Botttrill, 2001). The entire obduction stage of the Tyennan Orogeny took less than 10 Myr.

The rapid transition from high P metamorphism to exhumation indicates that collision occurred at plate tectonic speeds. The evolution is very similar to that modelled by Cloos et al. (2005) for West Irian (see also Davies, 2012). After slab breakoff, the buoyancy of the continental margin drives the metamorphosed continental margin back towards the surface and the slab falls away. The removal of the slab and rapid isostatic uplift drives extensional collapse at the surface. Lithospheric delamination can lead to an influx of asthenospheric mantle that controls the development of post-collisional volcanism. In western Tasmania, the post-collisional Mt Read Volcanics erupted into a Dundas Trough by 505 Ma and represent voluminous post-collisional volcanism (Crawford and Berry, 1992).

Tyennan Orogeny Stage 2: Post collisional volcanism and extension

The late middle Cambrian (Guzhangian) is dominated by extension and post-collisional volcanism. The extension reached a maximum with the emplacement of the Henty Dyke Swarm towards the end of the middle Cambrian. Complex volcanic and sedimentary sequences, the Mt Read Volcanics, were deposited across much of Tasmania in the middle Cambrian (Corbett and Vicary, 2012). The main depocentre of Middle Cambrian rocks was a rift wrapping around the western and northern margins of the Tyennan Block. This zone is referred to as the Dundas and Fossey Mountain troughs (Figure 6). A new cycle of deposition (?sag phase) was coeval with the late middle Cambrian (Guzhangian) Tyndall Group. This extensional phase was very

short lived (c. 5 Myr) and a new phase of tectonism began in the late Cambrian.

The rhyolitic to basaltic rocks are all marine and include coherent lavas, intrusives and volcanoclastics. The four major volcanic suites identified by Crawford et al. (1992) are:

- Suite 1: A voluminous group of transitional medium- to high-K calc-alkaline rocks of felsic to andesitic composition.
- Suite 2: Mainly hornblende phyric andesitic rocks, which are more P- and light REE- enriched than Suite 1 and have high-K calc-alkaline affinities.
- Suite 3: Basaltic to andesitic rocks with strong to extreme light REE- and P- enrichment indicating medium- to high-K calc-alkaline to shoshonitic affinities.
- Suite 4: Scattered tholeiitic basaltic and andesitic lavas and doleritic intrusives.

Crawford et al. (1992) suggested that volcanism evolved from the medium- to high-K calc-alkaline to the high-K calc-alkaline

Figure 6 Cartoon showing the extensional basin structure during the middle Cambrian (after Berry, 2012). Major volcanic complexes lie close to the eastern margin of the Dundas Trough.

strongly light REE-enriched shoshonitic basalts, then rapidly to the Suite 4 tholeiites at maximum extension. Volcanism reverted to the Suite 1 felsic volcanism at c. 500 Ma.

East of the Dundas Trough, middle Cambrian generally E-W trending folding has been widely recognised. Along the southern margin of the Fossey Mountain Trough there is tight ENE folding in the volcanic sequence and more open folding in the late Cambrian Owen Group. There are sufficient unconformities exposed to indicate that these folds were initially formed in the Cambrian and have been tightened during the Devonian. The E-W folding is probably a continuation of the tight E-W folding in the Tyennan block, with Cambrian N-S compression of the area E of the Dundas Trough continuing to push the ophiolite sheet to the S in the Adamsfield area (Figure 6), while the Dundas Trough was already filling with post-collisional volcanic rocks 100 km further west.

Tyennan Orogeny Stage 3: Late Cambrian Basin Inversion

Volcanism declined dramatically in the late Cambrian, and the Proterozoic rocks of the basin margin became the dominant source of sediments. The nature of the post-volcanic stage of the Tyennan Orogeny can be deduced from the widespread and complex

unconformities within the Owen Group. The syn-orogenic Owen Group and correlates are highly variable and restricted to discrete tectonically active basins.

The nature of late Cambrian tectonism is controversial. There is a pre-Middle Ordovician N-S fold phase in the Dundas Trough which is probably synchronous with Owen Group deposition. However, there is also local evidence of syn-depositional normal faults (Noll and Hall, 2006) and of syn-depositional reverse faults (Arnold and Carswell, 1990). The bulk of existing evidence suggests that the late Cambrian was a period of compressional tectonics with open upright folds and W-dipping thrusts. Holm and Berry (2002) correlated the D₃ event in NW Tasmania with pre-Ordovician N-S folding in the Dundas Trough. Berry et al. (2008) correlated this event with the accretion of the WTT to East Antarctica at the end of the Ross-Delamerian Orogeny (Figure 4).

Ordovician–Devonian

Following the late Cambrian basin inversion, western Tasmania was peneplaned and a new cycle of deposition began in the Middle Ordovician. Contrasting Ordovician–early Devonian histories are seen in the Western and Eastern Tasmania Terranes. In the WTT, a widespread intertidal to shallow marine tropical carbonate succession (Gordon Group) is overlain by a Silurian–early Devonian shallow marine siliciclastic sequence (Tiger Range Group). At the same time, the Mathinna Supergroup was deposited in NE Tasmania. A major fault system separates the two terranes. The summary below is based on the latest review of this sequence (Calver et al., 2012b).

In the WTT there is a thick post-orogenic succession of dominantly shallow-marine siliciclastics and carbonates, consisting of the Gordon Group (Ordovician–lowest Silurian) and the Eldon Group (Silurian–Lower Devonian). The predominantly limestone Gordon Group overlies the upper Cambrian–lower Ordovician syn-orogenic coarse-grained siliciclastics (Owen Group) or rests unconformably on older basement.

The lower siliciclastics of the Gordon Group in western Tasmania consist of a fining-upward succession, with siliceous conglomerate, bioturbated quartz sandstone and siltstone. This is a diachronous, transgressive succession, up to 750 m thick, that overlies the Owen Group disconformably or unconformably. In the early Middle Ordovician, limestone was deposited in shallow-marine conditions offshore of the basal siliciclastic unit. By the late Middle Ordovician micritic peritidal tropical carbonate sedimentation dominated most of the WTT. The youngest part of the Gordon Group is a 250 m thick siltstone-dominated marine sequence that coarsens upwards.

The Gordon Group is overlain conformably or disconformably by a shallow-marine siliciclastic succession with subordinate limestone, the Eldon Group that ranges from early Silurian–Early Devonian and is up to 2.3 km thick in the Queenstown area.

In the ETT, the Ordovician–Early Devonian succession is a thick sequence of deep-marine sandy turbidites known as the Mathinna Supergroup, with strong similarities to the lower Paleozoic turbidites of the Lachlan Fold Belt of Victoria and especially the Melbourne Trough (Cayley, 2011). No older rocks are exposed in the ETT, and basement to the succession is unknown. The geochemistry and zircon inheritance of Devonian granites in this area indicate that the basement is young and probably late Neoproterozoic to Cambrian oceanic crust unlike the Proterozoic continental crust of Western Tasmania (Black et al., 2010).

Figure 7 Schematic cross-section across the WTT-ETT boundary. Based on Reed *et al.* (2002), Patison *et al.* (2001) and Seymour *et al.* (2011).

The summary below comes from Seymour *et al.* (2011). The Mathinna Supergroup is separated into a lower Tippogoree Group and an upper Panama Group. Before 2001 these two groups were considered to be conformable but Reed (2001) argued the recumbent folding in the Tippogoree Group formed during the Benambran Orogeny (Silurian) and predated the deposition of the Panama Group. Recent mapping (Seymour *et al.*, 2011) has demonstrated a faulted relationship between the two groups. An angular unconformity has not yet been found, but circumstantial evidence for the Benambran Orogeny in NE Tasmania is accumulating.

The lower section of the Tippogoree Group is dominated by thick (>1 m), graded beds of medium to fine-grained sandstone typical of proximal turbidites (Stony Head Sandstone c. 1 km thick). There is a fairly sharp transition at the top into the dark Turquoise Bluff Slate. Powell *et al.* (1993) interpreted the slate as pelagic and hemipelagic shale and marl. The Turquoise Bluff Slate contains Early–Middle Ordovician graptolites.

The Panama Group (Silurian–Early Devonian) is split into four formations. The Yarrow Creek Mudstone is a thin-bedded grey mudstone, with minor quartz-rich siltstone beds interpreted as distal turbidites. The Retreat Formation contains medium to fine-grained quartz-rich sandstone with minor mudstone. It was probably deposited in a series of submarine fan complexes. The Lone Star Siltstone (late Silurian) is a sequence of laminated siltstone and shale. Beds of quartz-rich sandstone become more common towards a transitional contact with the overlying Sideling Sandstone. The Early Devonian Sideling Sandstone contains quartz-rich, fine to medium-grained sandstone with minor siltstone. It was deposited in a marine passive margin

setting, probably as sandy submarine fan complexes.

The Tabberabberan Orogeny, (390 Ma; Black *et al.*, 2004) occurred throughout Tasmania and is characterised by the complexity of fold orientations, explained, in large part, by reactivation of older structures. In many areas the fold geometry is controlled by the Cambrian fold trends, which were tightened during the Devonian. This led to Devonian cleavage orientations that transect the axial planes of the folds with which they are associated. In the Fossey

Figure 8 Pre-Carboniferous geology of Tasmania. Simplified from 1:250,000 digital geological map of Tasmania (Brown *et al.*, 1995).

Mountain Trough, E-W Cambrian folds are tightened. In the Dundas Trough, N-trending Cambrian folds are tightened with an associated NNW-striking Devonian cleavage. The orientation of NNE-trending folds, N of Tullah, is controlled by reactivation of the Henty Fault.

A later N-S compression reactivated NNE-striking faults with sinistral strike slip movement. Detailed structural studies at the Renison Mine suggest that this event is the same age as granite-related mineralisation (Kitto, 1992). The closest dated granites to Renison have 360 Ma crystallisation ages (Black et al 2004), and this is the best evidence that this late deformation is much younger than the Tabberabberan Orogeny. Local reactivation of E-W thrust faulting occurred during this event.

In NE Tasmania the earliest phase of deformation thrust the passive margin E across the deep water section resulting in recumbent folds in the Georgetown area. However, this event is apparently restricted to the older units and may be due to the Benambran Orogeny. It was followed by back thrusting, which was especially strong in the Beaconsfield zone (Figure 7). A late stage of N-S compression produced strike slip movement on some faults and large scale kinks (Goscombe et al., 1994).

The regional metamorphic grade associated with the Devonian orogeny in the WTT is prehnite-pumpellyite with local zones of greenschist facies in the vicinity of late syn- to post-orogenic granites except in SE Tasmania where metamorphism was very low grade metamorphism (Burrett, 1992). The Mathinna Supergroup is very similar with very low grade metamorphism limited to the E coast at Scamander (Patisson et al., 2001).

Voluminous granite intrusion in NE Tasmania (Figure 8) started before the Devonian deformation and continued until the early Carboniferous (400–375 Ma; Black et al., 2005). In western and NW Tasmania, their age range is 375–350 Ma, with the youngest known granite on King Island. Most of these granites are intruded at high level and have narrow contact aureoles.

Summary

Tasmania forms an enigmatic province within the Neoproterozoic history of Australia. The WTT probably rifted from the East Antarctic margin at 580 Ma and was trapped outboard of the Cambrian Ross-Delamerian Orogen. It was accreted back to the Gondwana margin in the late Cambrian. The earliest rocks form a Mesoproterozoic shallow water sequence that was deformed at 1290 Ma. They were intruded by rift related granites at 760 Ma. The granites may be related to Rodinia breakup. A new cycle of passive margin sedimentation continued through the late Neoproterozoic but was interrupted by extensive rift tholeiites at 580 Ma.

An arc-continent collision in the early to middle Cambrian initiated the Tyennan Orogeny. This resulted in the emplacement of numerous allochthonous blocks, including obducted mafic and ultramafic slices in western and northern Tasmania. Post-collisional felsic volcanism and extension dominated the late middle Cambrian (Guzhangian). In the late Cambrian Tasmania was dominated by basin inversion and at this stage was accreted back onto the Gondwana margin.

Shallow water deposition dominated the WTT from the Ordovician to the Devonian. The oldest rocks of the ETT are Ordovician turbidites. These may have been deformed in the Benambran Orogeny before the deposition of more deep water clastic rocks. The first granites intruded this sequence at 400 Ma before the

onset of the Tabberabberan Orogeny. This thrust the ETT over the WTT terrane. Granite intrusion continued until 350 Ma.

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