EVOLUTION OF THE SOUTHERN THOMSON OROGEN:

UPDATE OF THE ARC-LINKAGE PROJECT

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INTRODUCTION

The aim of the ARC Linkage Project was to obtain geological, geochemical and isotopic information from new and legacy drillholes to understand the geological evolution of the Southern Thomson Orogen (STO) in northwestern NSW and southern Queensland. The STO is the least exposed and poorly known tectonostratigraphic element of the Tasmanides, and represents a missing link in our understanding of the geodynamic origin, evolution and growth of the eastern third of the Australian continent (Fig. 1). The geodynamic significance of the STO is both conspicuous and enigmatic in that geophysical data reveal it as a major, arcuate E-W oriented structure, extending 750 km broadly parallel to the NSW-Queensland border, truncating the predominantly north-south structural grain of the Lachlan Orogen farther south.

Major tectonic elements of eastern Australia (i.e. Delamerian, Lachlan, Thomson and New England orogens) exist in the southern Thomson Orogen region. The relationships between these elements, as well as their distribution, evolution, tectonic setting and context within the Tasmanides belt have been a matter of much debate (e.g. Burton 2010; Cayley, 2012; Glen et. al, 2013). Improved knowledge of the geology and structure of the southern Thomson Orogen can underpin further development of tectonic models and will have major implications for understanding the evolution of eastern Australia, and for refining mineralisation targets.

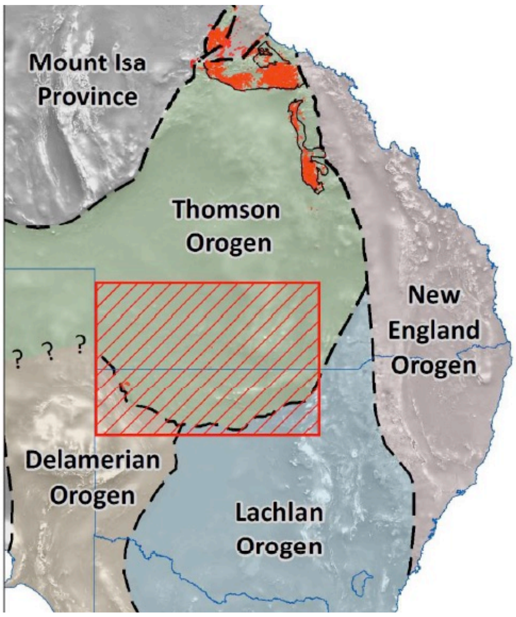

Figure 1. *Location of the Southern Thomson Orogen in the Tasmanides. Rectangle is Fig. 2.*

Geological Overview

The basement geology map (Fig. 2) has been compiled by Purdy et al. (2017). They defined trends and discontinuities in first vertical derivative and total magnetic intensity images of aeromagnetic data. Significant detail and complexity evident in areas of shallow cover were largely attributed to basement sources, allowing domains of differing magnetic character to be confidently divided. Where possible, these were matched with observations from outcrop and drill holes to tentatively define/attribute lithological units and major structures.

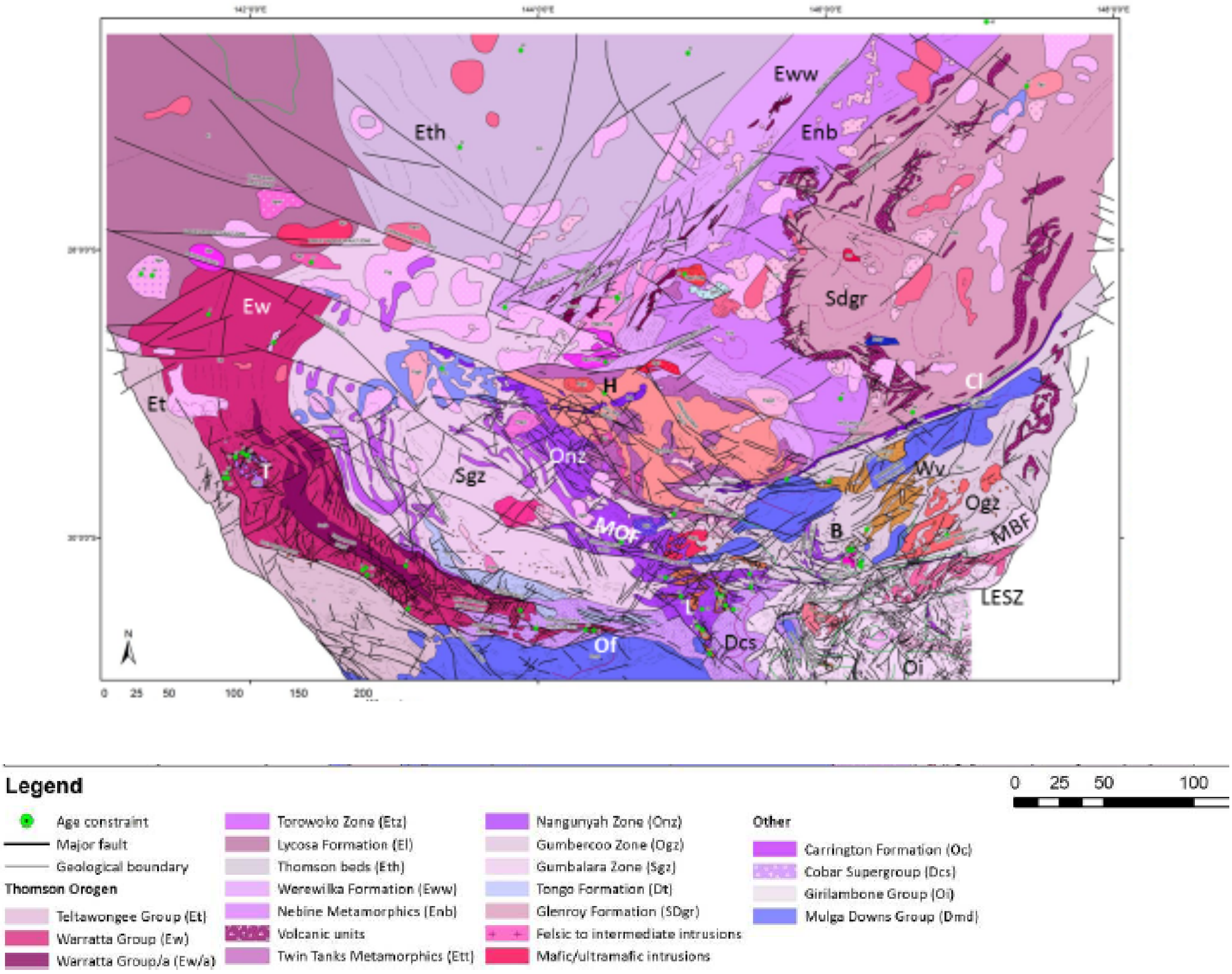

Figure 2. Basement geology of the Southern Thomson Orogen (from Purdy et al., 2017). B - Bourke, H - Hungerford, L - Louth, T - Tibooburra. Cl = Culgoa lineament, Of = Olepoloko Fault, LESZ = Louth-Eumarra shear zone, MBF = Mount Bendemeer Fault, MOF = Mount Oxley Fault, Wv = Warraweena volcanics. Other labels in legend.

The most obvious structure of the STO is a major ENE- to NE-trending megafold associated with high-strain zones on southern limbs, which include the Culgoa lineament (Cl), the Louth-Eumarra shear zone (LESZ) and the Olepoloko Fault (Of). All these high-strain zones are N-dipping and offset Late Devonian strata of the Mulga Downs Group where juxtaposed Deep seismic profiles across the Olepoloko Fault show it has at least 5 km of S-directed thrust offset of the Late Devonian sediments (Glen et al., 2013).Thus the last major movement was at least Carboniferous in age and a component of fold development occurred at this stage. Details on the structural evolution are discussed below.

From west the east through the axis of the megafold, lithological components generally become younger. Thus:

1. The westernmost unit is the *Teltawongee Group (Et)*, which is part of the Early Cambrian Kayrunnera block of the Delamerian orogen (Johnson et al., 2016). It appears to extend eastward under Darling Basin (fluviatile mid-late Devonian Mulga Downs Group), toward the Cobar Basin (Csg).
2. Directly eastward, the tight to isoclinally folded *Warratta Group* is structurally conformable with Teltawongee Group (Wong et al., 2017), but separated by the Oleopoloko Fault. Warratta Group sediments are cut by the ~428 Ma Tibooburra Suite plutons, indicating that the major NW-trending fabrics are likely Benambran (~440 Ma) in age.
3. The *Gumbalara zone (Sgz),* located farther east, appears to extend northward, probably as the Thomson beds (Eth), but they swing eastward to the south and are a major component of the megafold. They appear to be overlain to the east by the Louth volcanics of the *Nangunyah zone*.
4. In the Hungerford (H) area, the core of the fold is largely occupied by granitic complexes which have intruded the *Werewilka Formation*. Within this formation, the 455 Ma Granite Springs pluton appears conformable with the NE-trending structural grain, which appears to be associated with micaceous schists. The schists occur as xenoliths within the granite, and are likely to be part of the high-temperature, low-pressure metamorphism associated with generation of this S-type granite. The granite places a minimum Middle Ordovician age on the Werewilka Formation.
5. Adjacent to the Werewilka Formation, the *Nebine metamorphics* (Enb) are quartz-mica schists metamorphosed from greenschist to amphibolite facies. They have a maximum depositional age (MDA) of ~520 Ma (Purdy et al., 2016), and thus are probably Cambrian.
6. The eastern unit in the core of the megafold is called the *Glenroy Formation* (Sdgr), and assigned a Silurian or Devonian age by Purdy et al. (2017). Note the southern boundary is the Culgoa lineament.

Given the general youngling to the NE along the megafold axis, it is likely to be a synclinorial structure.

Detrital Zircon Study

Work at the University of Newcastle focussed on a geochemical and an age-dating program of igneous and metasedimentary rocks from the NSW section of the STO, for use as correlation tools between the northern Lachlan Orogen (LO) and the STO. The detrital zircon population of the Cobar basin was studied initially, to obtain an “age spectra” template for the Early Devonian sedimentation event in the northern LO, against which other age spectra could be compared. Previously published detrital zircon datasets provided suitable templates for the Cambro-Ordovician Delamerian orogen (Johnson et al 2016), Early Ordovician Thomson beds of the northern Thomson Orogen (Purdy et al., 2016), and Early to Late Girilambone Group of the northern LO (Fergusson et al., 2009). Other areas that were studied include the Bourke region, in particular the Warraweena volcanics, the Louth region NNW of Cobar, and the Yancannia region, approximately 100 km SSE of Tibooburra (Fig. 2)

Cobar Basin

The Cobar Basin is an asymmetric, turbidite filled depocentre that formed in a back-arc tectonic setting during the Early Devonian, though deposition and extension-related silicic magmatism may have begun slightly earlier, in the latest Silurian. U-Pb age data for six samples were combined with published data to show the basin has a unique age spectra characterised by a subordinate Late Ordovician peak superimposed on a dominant ~500 Ma peak. Maximum depositional ages (MDA) for most of the samples were ~425 Ma, close to the Early Devonian (419-401Ma) biostratigraphic age, though importantly, some samples yielded MDAs of ~500 Ma. Very few ~1000 Ma zircons old were analysed.

The major source of the 500 Ma zircons was probably the Ordovician basement, which had be deformed, thickened, and exposed in the early Silurian Benambran Orogeny. Lesser amounts of zircon were derived from the Macquarie arc to the east, and minor amounts from Late Silurian volcanics, probably from the adjacent Mineral Hill zone. The age spectra provides a robust template for comparison with metasedimentary rocks in the Southern Thomson Orogen further north.

Louth region

Two temporally and compositionally distinct igneous groups exist in the Louth region north of Cobar (Dwyer et al., 2017) in what is called the Nangunyah zone (Purdy et al., 2017). The older Early Devonian, calc-alkaline group corresponds to complexly folded, high-intensity curvilinear magnetic anomalies called the Louth volcanics, which appear to extend northward to the Queensland border east of Hungerford (Fig. 2). The volcanic assemblage has a distinct calc-alkaline composition, suggesting a subduction-related origin. Although previous age constraints had suggested that the Louth volcanics may have been Silurian (Glen et al. 2013), the results of this study suggest they are Early Devonian, between 400-415 Ma. They are probable correlatives with volcanics of the Mineral Hill zone on the eastern side of the Cobar Basin.

Metasedimentary rocks are interlayered with the calc-alkaline rocks within drillcore, and are poorly exposed in the Louth region. Previous zircon and graptolite fossil age constraints from these drillcore (references in Glen et al. 2013) suggest that some of these sedimentary rocks were deposited in the Ordovician, though others appear to be Late Devonian. A tuffaceous sandstone has an MDA of 402 ± 5.2 Ma (late Early Devonian), though the peak of the younger cluster is ~430 Ma. A subordinate older cluster of inherited zircons has significant peaks at ~500 Ma and 590 Ma. Another volcanogenic sandstone has an MDA of 482.5 ± 5.4 (Early Ordovician), consistent with its biostratigraphic age. Both sediments have broad age clusters between 490-630 Ma with a minor Grenvillean-aged (1100-1000 Ma) component. Their age spectra are most similar to sediments from the northern Lachlan Orogen.

A distinctive group of alkaline mafic rocks, ranging in texture from basalts to gabbros, exist in many drillcores from the region. They include the Getty Gabbro, interpreted to be of Neoproterozoic age (Glen et al., 2013). However, detailed work on a range of these alkaline rocks, including the gabbro, shows they contain an unusual number of inherited zircon, with age spectra that resembles the surrounding Ordovician or Silurian sedimentary detrital age spectra. A few zircons yield discrete Devonian or Carboniferous ages and it is not clear if they represent New England Orogen magmatic events or have been partially reset. Nonetheless, a concordant age cluster exists between 260-240 Ma, indicating the alkaline rocks are of Permo-Triassic age (Dwyer et al., 2017).

The alkaline rocks are commonly interbedded with fine-grained sedimentary and tuffaceous horizons, implying a deep-water origin. However, a Permian age precludes this possibility, as the Tasmanides were stable continental crust at this stage. Rather, the volcano-sedimentary associated must be associated with diatreme formation. The apparent abundance of these alkaline rocks in drillcore reflects the early exploration strategy of targeting small, circular magnetic anomalies. Regionally, the diatremes form part of an E-W corridor that appears to relate to focussed lithospheric extension associated with the later stages of the Hunter-Bowen Orogeny in the New England Orogen. The age spectra of the inherited zircons mimic detrital zircons from the Cobar Basin sediments and/or underlying Ordovician turbidites, indicating entrainment at upper crustal levels. Combined with the age spectra from sedimentary rocks, the Louth region (Nangunyah zone) appears to be part of the northern Lachlan orogen.

Bourke region

The Warraweena volcanics (WV) and associated volcanic-sedimentary sequences in the southern Thomson Orogen (STO) are part of the *Gumbercoo Zone* (Purdy et al., 2017). The southern boundary of the unit is marked by the Mount Oxley Fault (MOF) and Mount Bendemeer Faults (MBF), which are taken as the approximate boundary of the STO in this area (Fig. 2). Within the Gumbercoo zone, the major rock assemblages include the Warraweena volcanics, the Booda Formation and the Late Devonian Paka Tank Trough sediments.

The Warraweena Volcanics (Gilmore et al, 2017) have been mostly identified in drillcore, and form NE-trending magnetic anomalies within a generally magnetically quiet zone. Mineral exploration drill holes show they comprise massive, porphyritic and amygdaloidal andesite to basaltic andesite lavas with calc-alkaline to shoshonitic geochemical characteristics (Burton et al., 2008). No evidence exists that the Warraweena Volcanics were Neoproterozoic in age, as previously suggested based on zircon populations (Glen et al., 2013). We suggest the confusion relates to depositional environment. Sharp transitions between the volcanic horizons and interbedded volcanogenic sandstones suggest volcanism and sedimentation were synchronous, and most lavas were erupted subaqueously. Thus, we consider the zircons in the Warraweena volcanics identified by Glen et al (2013) are "detrital" xenocrysts, incorporated into lavas during emplacement into and over poorly consolidated sediments.

Drillcore observations indicate that the Warraweena volcanics are overlain by a cover sequence of mature, quartz-rich sandstones and pebble conglomerates, with quartz pebbles up to cm-size (Hack et al., 2017). Some sandstone units contain fragments of chert and micaceous lithic grains, whereas other units contain mafic volcanogenic fragments with phenocrystic clinopyroxene and are best described as greywackes. These metasediments are all part of the Booda Formation. Rare outcrops of the Formation at Mount Oxley (near Bourke) reveal steeply dipping, cleaved, siliciclastic siltstone and sandstone, possibly of turbiditic origin. Although contact relations between the Warraweena volcanics and sandstones are evident, contacts with the greywackes have not been observed. Nonetheless, geochemical and isotopic similarity of greywacke within the Warraweena Volcanics, and with the Macquarie Arc, confirms that the volcanics are Phase 4 of that arc system (Hack et al., 2017).

A maximum depositional age for the greywacke, from a set of euhedral zircons, yield a mean age of 441.8 ± 4.9 Ma. The dominant population 470-460 Ma is considered to be derived from the Macquarie arc. A smaller population also occurs at ~580 Ma. The greywacke yielded a maximum depositional age of 437.6 ± 4.1 Ma, confirming the Booda Formation as Early Silurian or younger. A well-sorted, fine-grained sandstone has a broad zircon age peak between 600-500 Ma, with a distinctive subsidiary peak at 1100 Ma. A population of seven grains define a maximum depositional age of 491.3 ± 2.9 Ma, similar to the MDA of samples analysed by Fraser et al (2014).

Sparsely quartz-phyric coherent rhyolite units associated with Booda Formation in drillcore contain distinctive embayed β-quartz phenocrysts, up to 2 mm in size, set within an originally glassy groundmass. One rhyolite unit has a sharp lower contact with the underlying sedimentary rock, and has increasing alteration at the top, which suggest it was eruptive. The U/Pb zircon crystallisation age of 415 ± 6.4 Ma for the rhyolite provides a well-defined depositional age for the Booda Formation. This Early Devonian age is similar to the Louth volcanics in the STO and to the Mineral Hill volcanics east of Cobar, which suggests that the Booda Formation is probably a lateral equivalent of the Cobar Basin.

Contrasting provenance in the Booda Formation is similar to that observed in the Cobar Basin, where some units yield an MDA of ~425 Ma and others an MDA of ~500 Ma (see also Fraser et al., 2014). The difference suggests local sources, a likely situation in localised backarc basins adjacent to sporadically developed volcanoes. Fergusson et al. (2005) observed metamorphic clasts derived from the underlying Girilambone Group in basal conglomerates of overlying Upper Silurian to Lower Devonian basins in the northern Lachlan Orogen, which appears to be a similar situation with the Booda Formation. Moreover, the Cobar Basin also has a bimodal distribution of MDAs and it was deposited on deformed, thickened and exposed Ordovician metasediments adjacent to the Macquarie arc. Therefore, it is likely that this bimodal population of metasedimentary and igneous zircons became available for deposition in nearby late Silurian early Devonian rift basins throughout the northern Lachlan and STO.

Nonetheless, the age spectra for the more mature sandstones of the Booda Formation more closely resemble the Thomson beds of the northern Thomson Orogen than the Girilambone Group in the Lachlan Orogen (Fraser et al., 2014). This suggests that the Gumbercoo zone might be a lateral equivalent to the Gumbalara zone farther west, and all are lateral equivalents folded around the STO megafold. Alternatively, the micaceous schist clasts in the sandstone could be local fragments from the Nebine metamorphics or Werewilka Formation, the former yielding a strong Grenvillean and a ~590-570 Ma peak (Purdy et al., 2016). Either way, the *Gumbercoo zone* appears to be the southern continuation of the Thomson Orogen rather than a northern extension of the Lachlan Orogen, even though it appears to contain Early Devonian sedimentary rocks potentially correlative with the Cobar Basin.

Yancannia region

The Yancannia Formation, part of the Warratta Group along the western margin of the STO (Fig. 2), is situated directly adjacent to the Kayrunnera zone of the Delamerian orogen, separated from it by the Olepoloko Fault. The Formation consists of deformed fine-grained, lithic-rich, turbiditic metasediments, suggesting deposition in a proximal, low-energy deep-marine environment. Muscovite and feldspar are common lithic components, similar to those observed in the Teltawongee Group of the Delamerian Orogen.

U-Pb detrital zircon geochronology identifies a major population of ~570 Ma from all samples, with one grain dated at 497 ± 13 Ma providing a maximum depositional age of the Yancannia Formation, similar to that to a published U-Pb age of 497 ± 2.6 Ma in a correlative tuff horizon. The dominant ~570 Ma peak in the Yancannia Formation, and Warratta Group in general, is most similar to the Teltawongee Group of the Kayrunnera zone, part of the Koonenberry Belt in the Delamerian Orogen, not the Girilambone Group of the Lachlan Orogen which has a dominant 500 Ma peak. Moreover, the Jeffreys Flat Formation, also part of the Warratta Group, has a distinctive age spectra characterised by a major 1100-1100 Ma population, most similar to peaks in Betoota and Machattie drillcores from the NW corner of the Thomson Orogen. As postulated by Purdy et al. (2016), these populations indicate a direct source from the Musgraves orogen of central Australia.

Structural analysis from a ~10 km, semi-continuous, across-strike section across the Warratta Group (Wong et al., 2017) shows a major, km-scale, upright, shallow NW-trending, doubly plunging anticline. This D_1 structure was associated with tight-to-isoclinal folding, penetrative cleavage, and abundant quartz veining of probable Benambran (~440 Ma) age. The structure is easily recognisable on first vertical derivative magmatic images of the region (Purdy et al., 2017). Later dextral transpressional deformation (D_2) produced a sporadic, weak cleavage and dextral faulting. A later, minor deformation event (D_3) was associated with kink folds, which may have pre-dated S-directed thrusting on the adjacent Olepoloko Fault during the Carboniferous. We relate these D_3 kinks to the STO megafold described above. The Warratta D_1 structures are concordant with major cleavage orientation in the Teltawongee Formation of the adjacent Kayrunnera zone of the Koonenberry Belt, and are probably the same age.

Structural Evolution

Our interpretation of the STO structural evolution has some similarities and differences with previous workers in the region.

The key boundary conditions are:

i) that the NNW-trending deformation in the Warratta region in the west is most likely to be Benambran (~440 Ma) or younger,

ii) Benambran AND Tabberabberan (~390 Ma) structures also trend NNW, extending northward through the Cobar Basin and adjacent Girilambone zone (Fergusson et al., 2005; Downes et al., 2016), but are cut by E-W structures of the STO.

iii) the E-W trending Louth-Eumarra Shear Zone represents a broad zone of dextral shearing that extends at least 100 km northward to the Culgoa lineament (Dunstan et al., 2016). Deformation is younger than ~416 Ma, the age of displaced Early Devonian (~416 Ma) granites of the Tarcoon Plutonic Complex

(Dunstan et al., 2016).

iv) Steeply dipping Early Devonian (~415 Ma) sediments of the Booda formation in the Mount Oxley region indicate that (likely) Tabberabberan deformation was pervasive in the Gumbercoo zone, located to the NE of the Cobar Basin

v) alignment of ~400 Ma granite plutons (Tinchelooka and Conlea) along ENE-trending structures appear to be axial planar to the regional synclinorium, suggesting the fold-structure was evolving as Tabberabberan deformation proceeded to the south in the Lachlan orogen.

vi) the dominant E-W structures of the STO in the Louth region fold Tabberabberan structures associated with Cobar Basin deformation. If the STO megafold is synclinorial, this could be the anticlinorial equivalent, suggesting they are a 100 km-scale structural pair.

vii) The anti-and synclinorial paired structure is truncated by major faults (Culgoa, Mount Oxley, Mount Benemeer, Olepoloko) which also offset the Late Devonian fluviatile sedimentary basin strata in the region, where juxtaposed

viii) the major E-W shear zone/fault structure are therefore likely are Carboniferous

Tectonic Evolution

The Warratta Group is generally considered as post-Delamerian (Greenfield et al., 2010). However, its immature sedimentary character, deep water sedimentation characteristics, and similarity to the detrital zircon age spectra of the Teltawongee Group within the Delamerian Orogen, suggests this is unlikely. We have found no evidence of the syn-orogenic, molasse-style deposition that would be expected if the Warratta group formed adjacent to the rising Delamerian orogen. Given the relatively high proportion of Musgravian zircons in the Teltawongee sedimentary rocks and in some units of the Warratta Group, we consider that both units could have been translated southward as para-authochthonous (Kayrunnera and Warratta) terranes during dextral transpression, probably associated with Benambran deformation. However, the Kara Formation, inboard of both these “terranes” in the Wonnaminta zone, contains a much higher, almost exclusive Musgravian population, which casts doubt on this concept. If the outboard terranes have not migrated southward, then the effects of the Delamerian orogen die out northward. A final possibility is that the Kayrunnera zone is post-Delamerian.

Zircon age spectra of the Warratta Group, with the characteristic 590-570 Ma detrital zircon peak and trivial 500 Ma shoulder, is typical of the Cambrian sediments within the Koonenberry Belt. Furthermore, the widespread Cambrian(?) to Ordovician Thomson beds of the Northern Thomson Orogen, and correlatives in the Anakie and Charters Towers inliers farther east and north, have similar detrital zircon age spectra (Purdy et al., 2016). It appears that all these sedimentary units formed in close proximity, or at least in a similar tectonic environment. Like the sedimentas of the Warratta Zone, the Thomson beds also appear to lack a Delamerian overprint (Purdy et al., 2016).

Given this tectonic context, it appears that the Warratta Group was deposited in an east-facing, deep-water depocentre unaffected by Delamerian orogenesis. The basin is more likely to have been a Cambrian-Ordovician backarc (Johnson et al., 2016) rather than a Delamerian accretionary prism (Greenfield et al., 2011). The Anakie and Charters Towers inliers and associated metamorphic rocks of the northern Thomson Orogen, including the Argentine Metamorphics west of Townsville, underwent high degrees of extensional tectonism in the Early-Middle Ordovician. Extension was associated with widespread 470-455 Ma old S-type granites in a >1000 km long belt extending from Townsville (Argentine Metamorphics) in the north, through the Anakie Inlier, to the Granite Springs pluton in the STO. This vast magmatic system of S-type granites in the Thomson Orogen was coeval with development the Macquarie arc farther southward in the Lachlan Orogen.

Although described as the Larapinta event (Purdy et al., 2016), we consider the major Early Ordovician extension in the Thomson Orogen occurred as a continental ribbon was rafted off the Australian margin, beginning in the late Cambrian. The ribbon was possibly Musgravian crust or Neoproterozoic passive margin (Fergusson et al., 2007). Extension occurred during subduction retreat and formation of the Macquarie arc (Collins & Richards, 2008), with the Ordovician Thomson beds and Girilambone Group of the Lachlan orogen deposited in the vast, deep-water backarc basin behind the retreating continental ribbon/oceanic arc. Accordingly, these vast Ordovician-aged, deep-water turbidites, which also occupy most of the Lachlan and Thomson orogens, are probably lateral equivalents even though the proportion of their source components (provenance) gradually changes from north to south.

Contractional deformation of both orogens occurred in the Late Ordovician/Early Silurian (Benambran) and Middle Devonian Tabberabberan. Major NNW-trending structures in the northern Lachlan Orogen are D_3/D_4 upright folds, which have rotated bedding-parallel, peak metamorphic (S_2) Benambran fabrics (Fergusson et al., 2005). These post-Benambran structures are concordant with tight to isoclinal folds in Silurian-Devonian basins, which are considered as Tabberabberan (Downes et al., 2016). The apparent continuity of Silurian-Devonian basins from the northern Lachlan into the STO suggest they all formed part of a single tectonic entity that underwent repeated mid-Paleozoic (Benambran and Tabberabberan) deformation. A major difference between the orogens appears to be that, in the Early Ordovician, the Thomson orogen formed on thinned continental crust behind a continental ribbon, whereas the Lachlan underwent higher degrees of stretching to form an oceanic substrate behind the intraoceanic Macquarie arc.

Both the Thomson and northern Lachlan orogens thus underwent E-W shortening during the Benambran and Tabberabberan contraction events, followed by southerly translation of the Thomson orogen during the N-S shortening, continental-scale, Devonian-Carboniferous, Alice Springs Orogeny (Collins & Teyssier, 1989; Raimondo et al., 2014). This general N-S shortening produced a megascale, S-shaped fold pair with a generally NE-trending, axial surface trace. Ongoing deformation produced a series of distributed, but not connected, E-W trending, curvilinear thrust faults associated with SE-directed, dextral transpression and thrusting. Farther east in the Macquarie arc, these faults rotate into meridional shear zones concordant with the dominant structural grain of the Lachlan Orogen, where they are buried beneath Mesozoic sedimentary cover.

Implications for mineralization

The key elements for mineral exploration targeting in the STO are:

1) the Warraweena volcanics are equivalent to Phase 4 of Macquarie Arc, which is one of the more prospective phases of that magmatic system
2) Cobar Group age equivalents exist in the Louth region and northward, and most likely farther east in the Bourke region, as the Booda Formation
3) Pin-point magnetic anomalies, often the target for drilling, are generally Permo-

Triassic diatremes

REFERENCES

BURTON G. R. 2010. New structural model to explain geophysical features in northwestern New South Wales: implications for the tectonic framework of the Tasmanides, Australian Journal of Earth Sciences 57, 23-49.

BURTON G.R., DADD K.A. & VICKERY N.M. 2008. Volcanic arc-type rocks beneath cover 35km to the northeast of Bourke. Geol. Surv. New South Wales Quarterly Notes 127, 1–23.

CAYLEY R. A. 2012. Oroclinal folding in the Lachlan Fold Belt: consequence of southeast-directed subduction rollback superimposed on an accreted Ordovician arc assemblage in eastern Australia, In (ed. White, S.) Selwyn Symposium of the GSA Victoria Division, Geological Society of Australia Extended Abstract 103, 34–43.

COLLINS W.J. & RICHARDS S.W. 2008. Geodynamic significance of 'post-collisional' S-type granites in circum-Pacific orogens. Geology 36, 559-562.

COLLINS W.J. & TEYSSIER C. 1989. Crustal scale ductile fault systems in the Arunta Inlier, central Australia: Tectonophysics 158, 49-66.

DOWNES P. M., BLEVIN P., ARMSTRONG R., SIMPSON C.J., SHERWIN L., TILLEY D.B. & BURTON G.R. 2016. Outcomes of the Nymagee mineral system study - an improved understanding of the timing of events and prospectivity of the Central Lachlan Orogen. Quarterly Notes of the Geol. Surv. New South Wales 147.

DUNSTAN S., ROSENBAUM G. & BABAAHMADI A. 2016. Structure and kinematics of the Louth-Eumarra Shear Zone (north-central New South Wales, Australia) and implications for the Paleozoic plate tectonic evolution of eastern Australia. Australian Journal of Earth Sciences 63, 1–18.

DWYER R.C., COLLINS W.J., HACK A.C., HEGARTY R. & HUANG H. 2017. Age and Tectonic Significance of the Louth volcanics: implications for the evolution of the Tasmanides of eastern Australia. Australian Journal of Earth Sciences *(in review).*

FERGUSSON C.L., FANNING C.M., PHILLIPS D. & ACKERMAN B.R. 2005. Structure, detrital zircon U-Pb ages and 40Ar/39Ar geochronology of the Early Palaeozoic Girilambone Group, central New South Wales: subduction, contraction and extension associated with the Benambran Orogeny. Australian Journal of Earth Sciences 52,137 – 159.

FERGUSSON C.L., HENDERSON R.A., WITHNALL I.W., FANNING C.M., D. PHILLIPS D. & LEWTHWAITE K.J., 2007 Structural, metamorphic, and geochronological constraints on alternating compression and extension in the Early Paleozoic Gondwanan Pacific margin, northeastern Australia. TECTONICS 26, TC3008, doi:10.1029/2006TC001979

FRASER G.L., GILMORE P.J., FITZHERBERT J.A., TRIGG S.J., CAMPBELL L.M., DEYSSING L., THOMAS O.D., BURTON G.R., GREENFIELD J.E., BLEVIN P.L. & SIMPSON, C.J. 2014. New Shrimp U-Pb Zircon Ages from the Lachlan, Southern Thomson and New England Orogens, New South Wales: February 2011-June 2013..

Geoscience Australia Record 2014/53

GILMORE P.J., CAMPBELL L.M. & TRIGG S.J. 2017. Mount Oxley 1:100 000 geological sheet 8137. Geological Survey of New South Wales, Maitland (in press).

GLEN R. A., KORSCH R. J., HEGARTY R., SAEED A., POUDJOM DJOMANI Y., COSTELLOE R. D. & BELOUSOVA E. 2013. Geodynamic significance of the boundary between the Thomson Orogen and the Lachlan Orogen, northwestern New South Wales and implications for Tasmanide tectonics. Australian Journal of Earth Sciences 60, 371-412.

GREENFIELD J.E., GILMORE P.J. & MILLS K.J. 2010 Explanatory notes for the Koonenberry Belt geological maps. Geol. Survey New South Wales Bull. 35, 498pp

HACK A.C., PHILLIPS G., WHALAN S. & HUANG H. 2017. Warraweena Volcanics and related rocks: Evidence for a long-lived arc system in the Southern Thomson Orogen. Australian Journal of Earth Sciences *(in review).*

JOHNSON, E.L. PHILLIPS G. & ALLEN C.M. 2016. Ediacaran-Cambrian basin evolution in the Koonenberry Belt (eastern Australia): implications for the geodynamics of the Delamerian Orogen. Gondwana Research 37, 266-284

PURDY D.J., CROSS A.J., BROWN D.D., CARR P.A. & ARMSTRONG R.A. 2016. New constraints on the origin and evolution of the Thomson Orogen and links with central Australia from isotopic studies of detrital zircons. Gondwana Research 39, 41-56

PURDY D. J., HEGARTY R. & DOUBLIER M.P. 2017. Basement Geology of the Southern Thomson Orogen. Australian Journal of Earth Sciences (in review).

RAIMONDO. T., HAND, M. & COLLINS W.J. 2014. Compressional intracontinental orogens: Ancient and modern perspectives. Earth-Science Reviews 130, 128–153.

WONG S.C.T., COLLINS W.J., HACK A. & HUANG H. 2017. Provenance and Structural Evolution of the Yancannia Formation, Southern Thomson Orogen: Implications for the Tectono-stratigraphic Evolution of the Cambro- Ordovician Western Tasmanides. Australian Journal of Earth Sciences (in review).