Sedimentary characterisation and correlation of the Wilton package, greater McArthur Basin

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The informally named greater McArthur Basin is a vast predominantly sedimentary terrane stretching across the northern half of the Northern Territory from northeastern Western Australia to northwestern Queensland. It includes Palaeo- to Mesoproterozoic successions of the McArthur and Birrindudu basins, and large parts of the Tennant Region (**Figure 1**). These basins are interpreted to have been interconnected at time of deposition. A widely distributed cyclic succession of Mesoproterozoic siliciclastic sedimentary and minor igneous rocks at the top of the greater McArthur Basin is included within the Wilton package of Rawlings (1999). The rarity of limestone distinguishes this package lithologically from underlying sedimentary successions of the greater McArthur Basin. The Wilton package is correlated with the South Nicholson Group (South Nicholson Basin), which outcrops in the eastern NT and western Queensland. During 2015, the Northern Territory Geological Survey (NTGS) completed a systematic study (Munson in press) of all sedimentary units of three groups of the Wilton package: the Roper Group (McArthur Basin), Tijunna Group (Birrindudu Basin) and Renner Group (Tomkinson Province, Tennant Region). The main aims of this study were: (1) to collate and combine historical and new field-based data in order to produce baseline datasets of all stratigraphic units; (2) to integrate and interpret geochronological data to assist in the determination of sedimentary provenances and maximum depositional ages, and to test proposed correlations of the successions; and (3) to test and refine existing palaeoenvironmental and palaeogeographic interpretations. An unnamed group, comprising the Jamison sandstone and Hayfield mudstone, that overlies the Roper Group in the Beetaloo Sub-basin was also described and reinterpreted.

The Roper Group is a siliciclastic succession characterised by alternating mudrock-rich and cross-bedded sandstone formations. The group is subdivided into the lower sandstone-rich Collara Subgroup and upper mudrock-rich Maiwok Subgroup. Sandstone-dominated units consist of cross-bedded, fine- to medium-grained, supermature quartz sandstone, deposited in a shoreline to shallow-marine inner

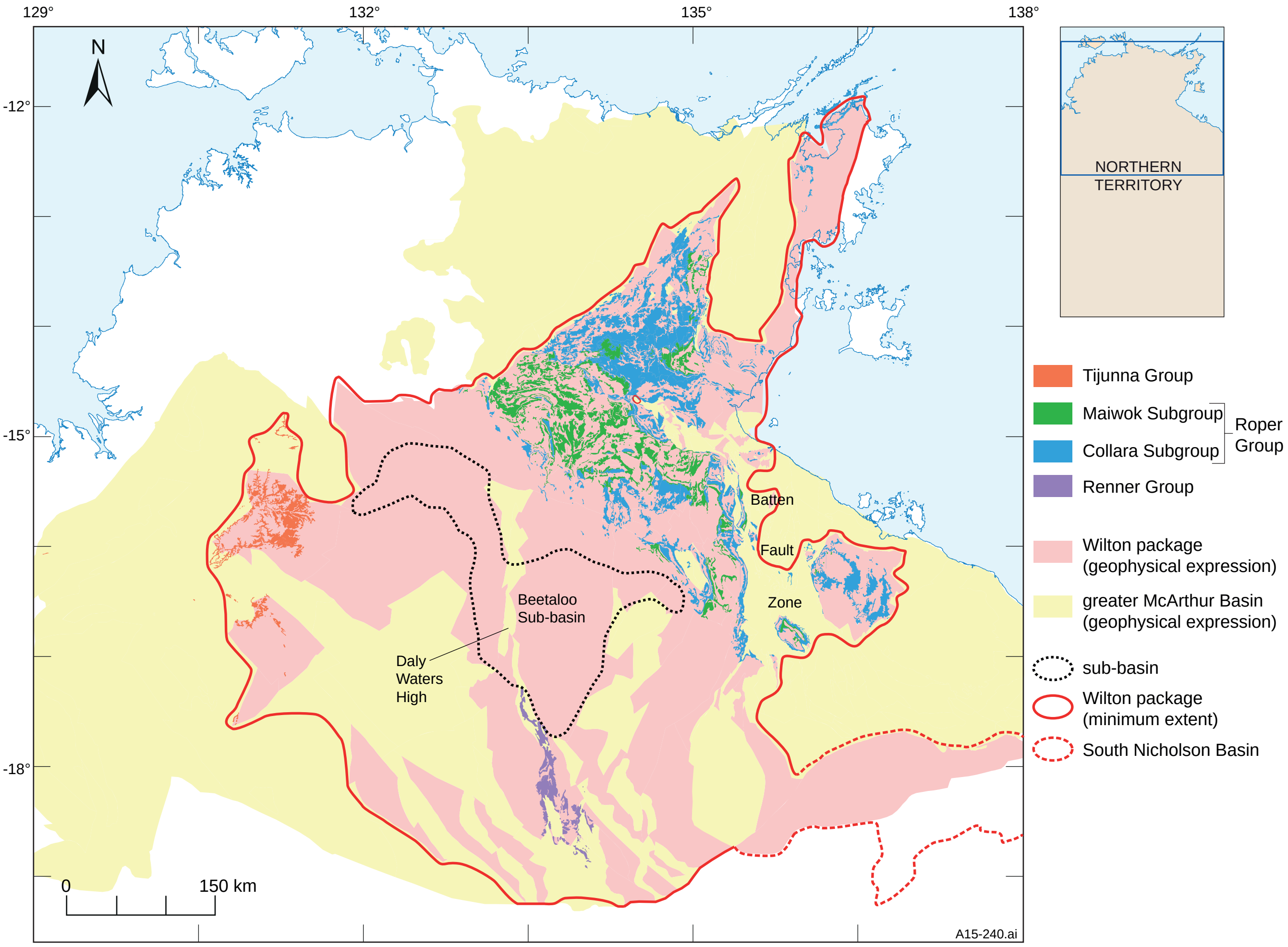

Figure 1. Minimum extent of Wilton package sedimentation, showing mapped outcrops of Tijunna, Roper and Renner groups, and correlative South Nicholson Group. Subsurface extent of package and of greater McArthur Basin, defined by potential-field interpretation mapping, redrafted after Betts *et al* (2015).

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shelf setting. They are commonly capped by thin intertidal to emergent facies. Mudrock-rich units are dominated by commonly interlaminated and interbedded claystone, siltstone and minor fine-grained sandstone. Abundant evidence for periodic and regular current activity indicates deposition mostly from wave-induced density flows or turbidity currents and from suspension in a shallow-marine mud-dominated shelf setting.

The sandstone-rich Jamison sandstone and mudrock-rich Hayfield mudstone form a subsurface sedimentary package that unconformably overlies the Roper Group. They consist of alternating fine- and coarser-grained siliciclastic rocks that were deposited in environments similar to those of the Roper Group. However the quartz-lithic sandstones are distinctly less mature than typical Roper Group sandstones.

Alternating cross-bedded quartz sandstone- and mudrock-dominated units of the relatively thin Tijunna Group are similar to those that characterise the Roper Group; they were deposited in similar shoreface to shallow-marine shelf settings.

Sandstone- and subordinate mudrock-rich units of the Renner Group are characterised by having a relatively high proportion of interpreted intertidal, supratidal and fluvial facies compared to the Roper and Tijunna groups, in addition to shallow-marine shelf and shoreline facies. Interpreted shallow to emergent palaeoenvironments for this group might indicate either a general proximity to a basin margin or that the underlying Daly Waters High may have been a significant topographic feature at the time of deposition.

Detrital-zircon geochronology

LA-ICPMS U-Pb detrital zircon analyses were conducted on samples from representative sandstone units of the Roper, Renner and Tijunna groups (**Figure 2**) with the aim of determining maximum depositional ages and more usefully, gaining information on possible provenance. Analytical procedures and basic results are documented in Munson *et al* (in prep). Additional SHRIMP detrital zircon analytical data for the Stubb Formation (Carson 2013) and upper Velkerri Formation (Fanning 2012) were included and reinterpreted in the context of the entire dataset. A comparative relative probability diagram of detrital zircon data from all samples (**Figure 3**) enables the following conclusions to be drawn:

- Relative probability curves for the five Collara Subgroup (Roper Group) samples form a distinctive signature. Maximum depositional ages (MDA) are generally ca 1600 Ma or greater. More than 90% of analysed zircons are older than 1700 Ma; the majority form prominent peaks with maxima in the range 1950–1700 Ma. Transgressive sediments of the basal Phelp Sandstone sampled a wide range of basement terranes as shown by presence of numerous scattered individual and clustered analyses ranging through the Palaeoproterozoic to the Archaean.
- Relative probability curves for the four Maiwok Subgroup samples also have a distinctive signature. MDAs are generally in the range ca 1590–1530 Ma. The curves form very broad, complex irregular peaks with a number of maxima in the range ca 1900–1550 Ma. The percentage of analysed zircons older than 1700 Ma is generally in the range ca 70–80%, markedly less than that of the Collara Subgroup.
- Relative probability curves for the two units of the Tijunna Group (Wondoan Hill Formation, Stubb Formation) are dominated by broad irregular peaks with maxima in the range ca 1950–1550 Ma and closely resemble those of the Maiwok Subgroup.
- Relative probability curves for Renner Group formations support their tentative correlation by Hussey *et al* (2001) with Roper Group units. The curves for two older Renner Group units (Gleeson Formation, upper Grayling member of Baralandji Formation) are very similar to those of the Collara Subgroup; they are dominated by broad irregular peaks with maxima in the range 1950–1700 Ma and more than 90% of zircon analyses older than 1700 Ma. The curve for the younger Jangirulu Formation more closely resembles those of the Maiwok Subgroup than the Collara Subgroup; it is most similar to that of the Bessie Creek Sandstone with which it has been correlated (Hussey *et al* 2001).
- Relative probability curves for the unnamed group (Jamison sandstone, Hayfield mudstone) in the Beetaloo Sub-basin indicate that this is a distinct sedimentary package, significantly younger than the Maiwok Subgroup. Conservative MDAs and youngest zircons are late Mesoproterozoic (Stenian); this supports a latest Mesoproterozoic to Neoproterozoic age for this group. An older prominent peak at ca 1595 Ma is very distinctive and common to all three samples. Two samples have relatively young prominent peaks at ca 1186 Ma and 1162 Ma respectively. Fewer than 12% of analysed zircons are older than 1700 Ma.
- The lower Jamison sandstone was identified by Gorter and Grey (2012) as probable Bukalorkmi Sandstone, a unit near the top of the Roper Group that is exposed to the north of the Beetaloo Sub-basin. However the detrital zircon spectrum differs significantly from that of the Bukalorkmi Sandstone (sampled from the type section) and from the typical signature of the Maiwok Subgroup in general. In particular, it lacks broad complex peaks with maxima between 1900 and 1700 Ma.
- Overall, detrital zircon geochronology conducted systematically through the sedimentary succession offers good potential for intrabasinal correlation with resolution at subgroup scale.

Provenance

The presence of older palaeoproterozoic and Archaean zircons throughout the Wilton package supports previous interpretations (Cawood and Korsch 2008, Kositcin *et al* 2013, Carson 2013, Whelan *et al* 2014, Kraus *et al* 2015) that rocks of these ages formed a widespread contiguous basement of the North Australian Craton (NAC). Older zircons tend to be more abundant towards the base of successions above significant unconformities; they were presumably derived from Archaean terranes or older sedimentary rocks that were uplifted and exposed during deformation events. The small cluster of older zircons at ca 3100 Ma in the Stubb Formation (Tijunna Group) indicates a source older than any rocks yet recognised in the NT, possibly the Pilbara region of Western Australia. The relative abundance of these Archaean zircons in the Tijunna Group is consistent with its geographical proximity to potential sources areas in Western Australia.

Major peaks for the Collara Subgroup and Renner Group are present in the range 1950–1700 Ma; major peaks for the Maiwok Subgroup and Tijunna Group are in the range 1950–1550 Ma. These all form a typical NAC basement signature that cannot be easily refined on these data. There are a number of source terranes in the NAC that produced

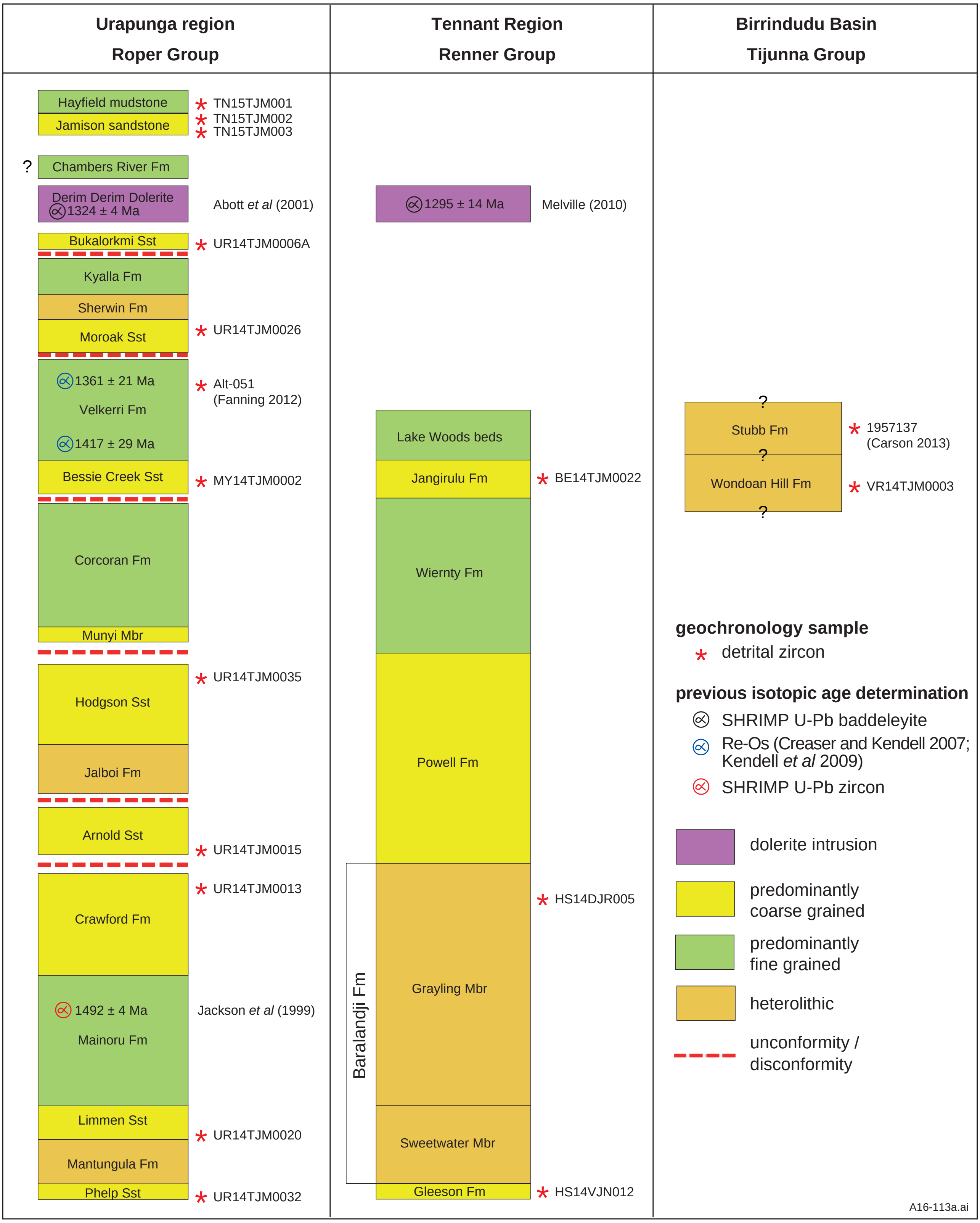

Figure 2. Simplified stratigraphic columns for Tijunna, Renner and Roper groups, showing intervals sampled for detrital zircon geochronology. Previously determined absolute dates are included at approximate levels sampled.

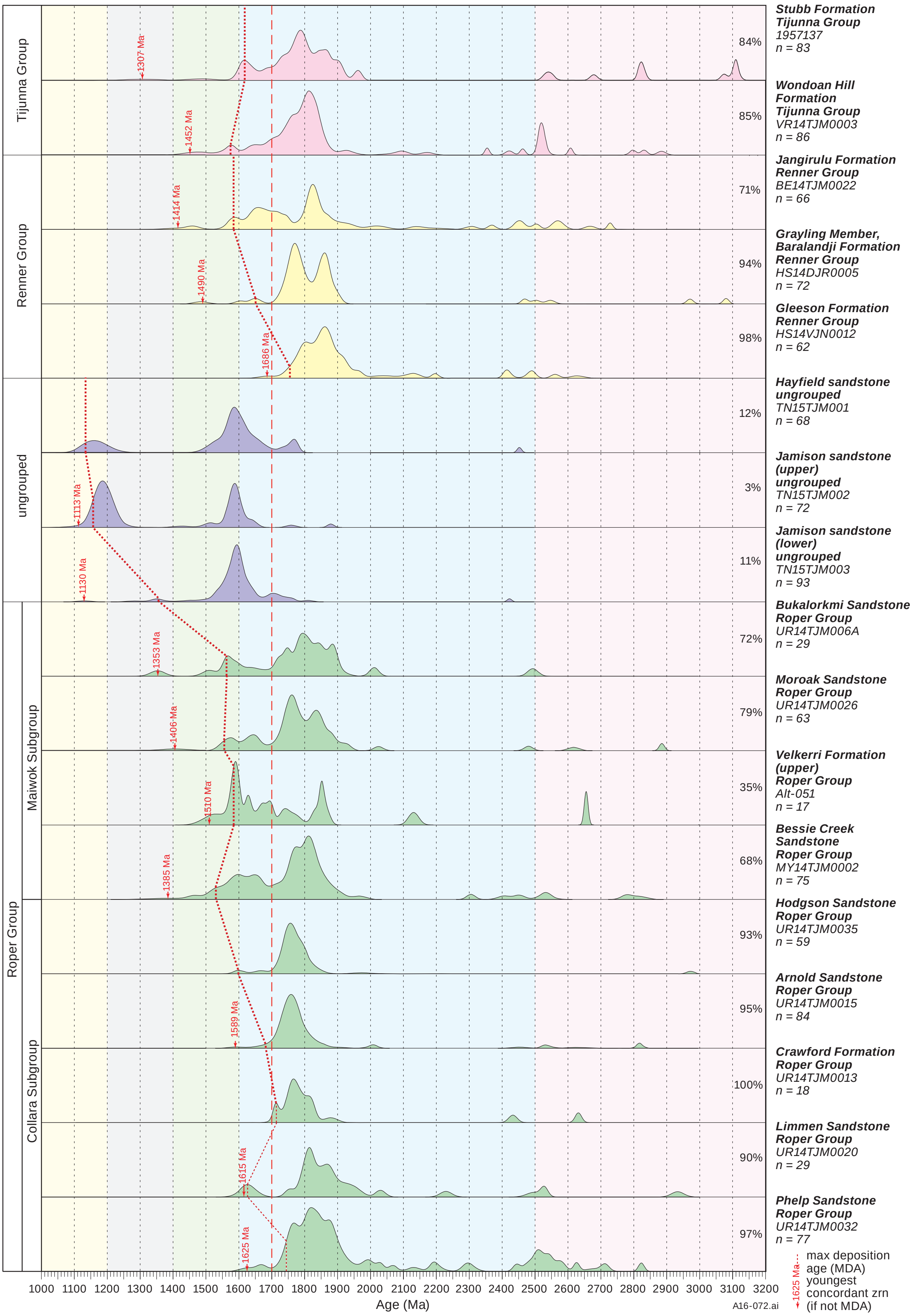

Figure 3. Comparative relative probability diagram of detrital zircon data arranged in stratigraphic order for Roper Group (green polygons), overlying ungrouped sedimentary rocks (mauve), Renner Group (yellow) and Tijunna Group (pink). Not to scale vertically. Stubb Formation plot derived from tabulated data in Carson (2013: supplementary papers); upper Velkerri Formation plot derived from tabulated data in Fanning (2012); NTGS analyses after Munson *et al* (in prep). Percentage of concordant analyses (n) on right. Irregular dotted line (left) indicates assigned MDA for each sample; isolated younger analysed zircons also indicated where not coincident with the MDA. Vertical red dashed line is 1700 Ma; percentages (right) indicate proportion of analysed zircons >1700 Ma for each sample.

magmatic zircons at these times including the Tanami Region, Mount Isa Province, Pine Creek Orogen, Arnhem Province, Aileron Province, Warumpi Province, Tennant Region and Musgrave Province. Sedimentological and palaeogeographic interpretations indicate a general, non-specific southerly to southeasterly source, at least for the Roper and Renner group successions.

There is a conspicuous lack of older Palaeoproterozoic and Archaean zircons in the ungrouped units in the Beetaloo Sub-basin; this indicates a significant shift in provenance for this younger sedimentary package through a change in sediment pathways and/or burial of older source areas. Major peaks for the ungrouped units overlying the Roper Group in the Beetaloo Sub-basin occur at ca 1590 Ma and ca 1090–1160 Ma. The most likely provenances for zircons of these ages are the Musgrave Province (see Pell *et al* 1997) and possibly the central-southern Arunta Region (see Wong *et al* 2015).

Palaeogeography

The Wilton package was deposited in a vast anorogenic intracratonic basin (Figure 2) floored entirely by Archaean–Palaeoproterozoic rocks of the NAC. Evidence for a marine setting includes the presence of glauconite and marine microfossils at numerous stratigraphic levels, the high compositional maturity of the sandstones, and the lateral extensiveness of this facies. The various successions are characterised by: (1) a repetitive alternation of fine- and coarse-grained intervals; (2) deposition in a relatively narrow range of environments from marine shelf to shoreline to, rarely, continental or fluvial; and (3) lateral continuity of units over hundreds to thousands of square kilometres. There is no evidence for continental slope or deep basin deposits as are typical outboard of present-day open-marine continental shelves. In the Beetaloo Sub-basin, a greater rate of subsidence is indicated by greater thicknesses of strata, but the succession of facies is the same as in other areas of deposition indicating that rates of deposition were generally equivalent to rates of subsidence.

The depositional limits of the package are unclear. Marginal facies (eg shoreline, emergent) are recognised in the vertical succession, but do not generally form mappable areas that delineate palaeoshorelines from laterally more distal facies for any particular time period. Marginal facies are more abundant in the Renner Group than elsewhere in the basin suggesting that more of this succession was deposited at or closer to palaeoshorelines than other parts of the exposed Wilton package.

In a large-scale regional sense, the Wilton package is broadly wedge-shaped, with the thickest sections in the southeast and south, thinning slightly into the Beetaloo Sub-basin in more central areas, then thinning further to west, north and east. The Renner Group in the central-south has a maximum (composite) thickness of greater than ca 3500 m (Hussey *et al* 2001). Thickness decreases northwards to ca 3000 m in the central areas of the Beetaloo Sub-basin (Silverman *et al* 2007), to nearly 1800 m in central areas of the McArthur Basin (Abbott *et al* 2001), and to ca 900 m further to the north (Rawlings *et al* 1997, Sweet *et al* 1999) where the top of the group is truncated from either erosion or non-deposition. To the west, the Wilton package thins to less than 300 m in the Birrindudu Basin (Tijunna Group). To the east of the Beetaloo Sub-basin, the thickness of the package decreases under cover to about 1000 m at the limits of seismic coverage in the eastern McArthur Basin (Rawlings *et al* 2004).

Depositional model

A restricted or partly restricted, or anoxic depositional environment with fluctuating salinities is indicated by geochemical studies (Donnelly and Crick 1988, Lambert and Donnelly 1992, Revie 2015a, b) and by the presence of synaeresis cracks at numerous stratigraphic levels. This is indicative of an enclosed marine basin, physically restricted to some extent by land or by chains of islands while retaining some connection with the open ocean (see Allen and Allen 2013). In this model, inflow and outflow of freshwater from rivers and seawater would have resulted in fluctuating salinities and would have largely determined whether the enclosed basin was oxic or anoxic at various times. If outflow of freshwater as a surface layer exceeded the inflow of deeper saline water, water stratification would have been likely, leading to anoxic conditions; present-day examples of anoxic enclosed basins include the Baltic and Black seas. If inflow of seawater exceeded the outflow of freshwater, water stratification is less likely to develop and oxic conditions would have resulted; present-day examples of oxic enclosed basins include the Red Sea, Mediterranean Sea and Persian Gulf. An analogous Australian example of an enclosed basin is the Neoproterozoic Centralian A Superbasin (Walter *et al* 1995, Munson *et al* 2013) that partially geographically overlaps the Wilton package; it had a similar vast areal extent, relatively shallow interpreted depths and a restricted connection to open ocean waters.

A shoreline–shelf depositional model similar to that characterising most modern shelfal systems (see Patruno *et al* 2015) can be applied to the Wilton package whereby overall aggradation of shelfal strata was generated by the vertical stacking of successive shoreline and subaqueous clinothem sets. Progradation of the successions resulted from the repeated, regressive–transgressive transit of deltas and shorelines across the shallow-marine shelf. **Figure 4** shows typical cross-sectional morphology and geometry of present-day subaerial and subaqueous delta clinothems, and summarises the oceanographic environmental features controlling their development.

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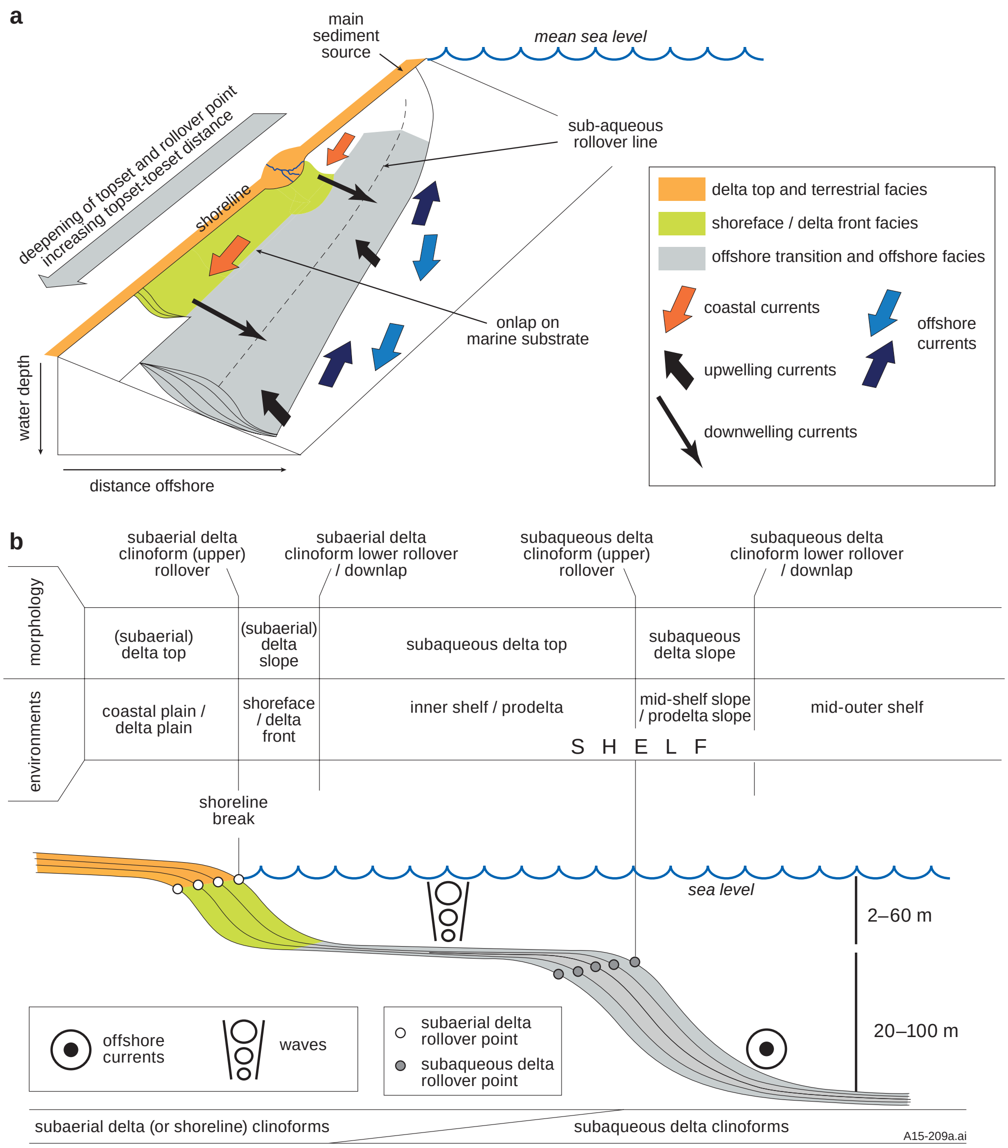

Figure 4. Architectural components of most present-day shoreline to shelf successions. Not to scale vertically. (**a**) 3D scheme portraying main architectural features and typical oceanographic environment of present-day, delta-scale compound clinothems (modified after Patruno *et al* 2015: figure 4). Both subaerial and subaqueous delta clinoforms are characterised by vertical relief of tens of metres and by laterally extensive, alongshore geometries, with little along-strike variability and only minor protuberances that correspond to the position(s) of feeder rivers. In subaerial deltas, the clinoform topset-to-foreset rollover point is the shoreline break; in subaqueous deltas, the rollover point is at water depths of up to 40–60 m. Shore-parallel coastal currents contribute to uniform growth of clinothems, by along-shelf redistribution of sediments fed by fluvial input points. Subaqueous clinothems can be mud-prone, or sand-prone, or heterolithic, and can extend over very large areas of sea floor; in modern shelves, mud-prone subaqueous clinothem successions can prograde up to 125 km from shorelines on wide, gently-sloping (0.01–0.38°) shelves. Downwelling currents and mass-flow mechanisms transport shoreface sediments offshore, thereby sustaining overall growth and progradation of subaqueous clinothems perpendicular to alongshore currents that feed it. Position of subaqueous clinoform bottomsets is controlled by seafloor-hugging offshore currents flowing parallel to clinoform strike and/or by upwelling processes, which force sediment transport along clinothem strike rather than offshore. (**b**) Cross-sectional profile parallel to depositional dip showing typical delta-scale compound clinoform system, comprising subaerial and subaqueous delta clinoforms (after Patruno *et al* 2015: figure 1B, modified from Helland-Hansen and Hampson 2009).

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