Revision of the Neoproterozoic stratigraphic nomenclature of the Beetaloo Sub-basin, Northern Territory

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Lanigan *et al* (1994) first recognised the presence of a thick siliciclastic succession unconformably overlying Mesoproterozoic Roper Group rocks in petroleum exploration drillholes penetrating the Beetaloo Sub-basin in the central-northern Northern Territory (**Figure 1**). They subdivided this post-Roper group succession into two ungrouped formations that they informally named the 'Jamison Sandstone' and overlying 'Hayfield Mudstone', and interpreted them as being probably Neoproterozoic in age. These formations have been referred to in numerous subsequent studies (eg Munson 2016 and references therein) as 'Jamison sandstone' and 'Hayfield mudstone'. The 'Jamison sandstone' comprises two sandstone-rich units separated by a possible unconformity (Gorter and Grey 2012), whereas the 'Hayfield mudstone' is a finer-grained mudrock-dominated unit containing minor thin sandstone bedsets, including a laterally persistent metre-scale sandstone layer that was informally named the 'Hayfield sandstone member' (Silverman *et al* 2007, Altmann *et al* 2020). Unconformably overlying this succession is another as-yet unnamed sandstone-rich formation that was considered to be probably Cambrian in age by Lanigan *et al* (1994) but was dated as probably Neoproterozoic by Munson *et al* (2020).

There has been considerable historical and ongoing confusion in regards to the nomenclature, age and distribution of this post-Roper group succession, which has created significant difficulties for government, academic and industry professionals when targeting the group for research and petroleum exploration. The units have been variously logged in well completion reports as: ungrouped and unnamed early Cambrian or Neoproterozoic units; the 'Jamison Sandstone/sandstone/sands' and overlying 'Hayfield Mudstone/mudstone' (eg Lanigan *et al* 1994); Mesoproterozoic upper Roper Group units of the McArthur Basin, including the Moroak Sandstone, Bukalorkmi Sandstone and Chambers River Formation (eg Pietsch *et al* 1991, Lanigan and Torkington 1991, Frances 1994, Gorter and Grey 2012); and the Bukalara Sandstone and overlying Cox Formation of the Neoproterozoic Kiana Group of the Georgina Basin (eg Altmann *et al* 2020).

In order to address these historical issues, Munson 2023 identified and documented the distinguishing characteristics of the post-Roper group units to better resolve their stratigraphic relationships in order to provide a consistent, formally defined nomenclatorial framework and improve inter-well and inter- and intrabasinal correlations. Munson (2023) reviewed the lithological and stratigraphic characteristics of the post-Roper group succession of the Beetaloo Sub-basin, as well as exposed stratigraphic units around the margins of the sub-basin that could represent equivalents of these formations, such as the Chambers River Formation and formations of the Kiana Group.

The Chambers River Formation is exposed to the north and northeast of the Beetaloo Sub-basin (**Figure 1**) and is currently included as the topmost unit of the Roper Group. In some previous reports (eg Lanigan and Torkington 1991, Frances 1994, Abbott *et al* 2001, Gorter and Grey 2012), this formation was either logged as, correlated with, or considered to be a senior synonym of the Hayfield mudstone. The Chambers River Formation probably disconformably overlies the Bukalorkmi Sandstone (Roper Group; Munson 2016) and is unconformably overlain by the early Cambrian Antrim Plateau Volcanics (Kalkarindji Suite), and by the Bukalara Sandstone (Kiana Group) in northeastern HODGSON DOWNS[3] (Dunn 1963, **Figure 1**). It is not intruded by the ca 1330–1295 Ma Derim Derim Dolerite (Abbott *et al* 2001, Munson 2016), which intrudes all other formations of the upper Roper Group.

Sensitive high resolution ion microprobe (SHRIMP) U–Pb detrital zircon geochronology yielded a YPP[4] maximum deposition age (MDA) of 1320 ± 15 Ma (n = 17) for the Chambers River Formation (Kositcin *et al* 2017; **Figure 2**); the most likely source for these young zircons is igneous activity associated with intrusion of the Derim Derim Dolerite. This supports the observation that the Chambers River Formation is not intruded by this intrusion, and provides a maximum depositional age constraint. A middle to late Mesoproterozoic minimum age constraint for the formation is given by the ca 1300–1050 Ma post-Wilton package deformation event of Betts *et al* (2015), which folded the Chambers River Formation but not the overlying Bukalara Sandstone and the post-Roper group succession of the Beetaloo Sub-basin. A Mesoproterozoic age for the formation is further supported by palynological investigations (Hawkes 2017). Collectively, these data indicate that the Chambers River Formation is older than both the post-Roper group succession of the Beetaloo Sub-basin and the Kiana Group of the Georgina Basin, and therefore cannot be a correlative unit.

Munson (2023) reviewed the lithological characteristics and age relationships of the Neoproterozoic units of the Beetaloo Sub-basin and of the Kiana Group (basal Georgina Basin), which outcrops extensively to the east and southeast of the Beetaloo Sub-basin (**Figure 1**). The Kiana Group is the only exposed stratigraphic succession in the vicinity of the sub-basin that could potentially be a correlative of the subsurface formations. Both of these successions postdate the ca 1330–1295 Ma Derim Derim Dolerite and the ca 1300–1050 Ma post-Wilton package deformation event; and both are older than the unconformably overlying early Cambrian Kalkarindji Suite. The two successions therefore

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[3] Names of 1:250 000 mapsheets are shown in large capital letters, eg HODGSON DOWNS.
[4] YPP method = mode of the youngest graphical peak on a probability density plot.

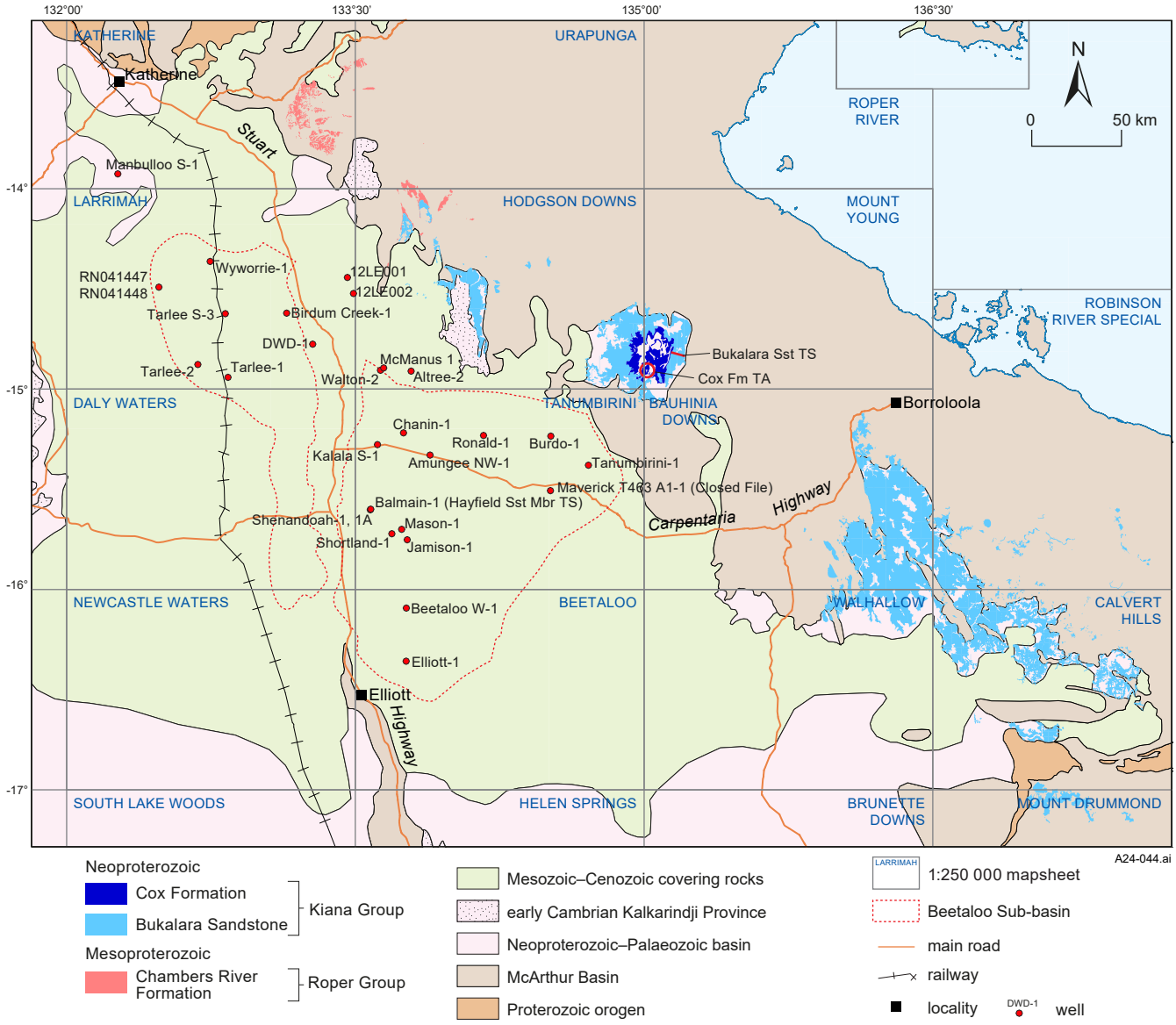

Figure 1. Map of Kiana Group in northeastern NT showing distribution of exposures and known drillhole intersections in and adjacent to Beetaloo Sub-basin (after Munson 2023: figure 2). Closest distance between exposures of group and subsurface intersection (in POG Burdo-1) is about 35 km. Mapped exposures of Mesoproterozoic Chambers River Formation in southern McArthur Basin are also shown. Background map is NT geological regions from NTGS 1:2.5M geological regions GIS dataset. TA = type area; TS = type section.

occupy the same relative stratigraphic position. The Bukalara Sandstone and 'Jamison sandstone' are lithologically similar and are of comparable thickness (Munson 2023). The overlying Cox Formation and 'Hayfield mudstone' are also lithologically similar, although insufficient Cox Formation outcrop is preserved for more detailed comparisons.

Detrital zircon age spectra for the Bukalara Sandstone, 'upper Jamison sandstone', and Hayfield Sandstone Member are markedly similar to one another in that they all have a characteristic bimodal spectral signature with zircon populations at ca 1680–1550 Ma and ca 1220–1130 Ma, and no or very sparse zircons with dates > ca 1800 Ma (**Figure 2**). Age spectra for the 'lower Jamison sandstone' differ from those of overlying units in that the younger < ca 1220 Ma population is represented by only a few zircons; this can possibly be attributed to zircon source areas not being completely exhumed and eroded at the time of deposition of this unit, or to changes in sediment pathways up-section through the 'Jamison sandstone'. Interpreted MDA estimates for all units are < ca 1150 Ma, which serves to distinguish them from the much older Roper Group, the MDA estimates for which are all generally > ca 1300 Ma.

Collectively, the available geological, stratigraphic and geochronological evidence strongly indicates that the 'Jamison sandstone' and 'Hayfield mudstone' are the subsurface equivalents of the exposed Bukalara Sandstone and Cox Formation respectively (Munson 2023). The formally defined Kiana Group names predate the informal Beetaloo Sub-basin unit names and take nomenclatorial priority (Munson 2023); therefore, the names Bukalara Sandstone and Cox Formation replace the informal names 'Jamison sandstone' and 'Hayfield mudstone' respectively. However, the name Hayfield Sandstone Member (previously 'Hayfield sandstone member' of 'Hayfield mudstone') is retained as a member of the Cox Formation. The Kiana Group, Bukalara Sandstone, Cox Formation and Hayfield Sandstone Member were all formally defined/redefined by Munson (2023). A summary of the nomenclatorial changes is provided in **Table 1**.

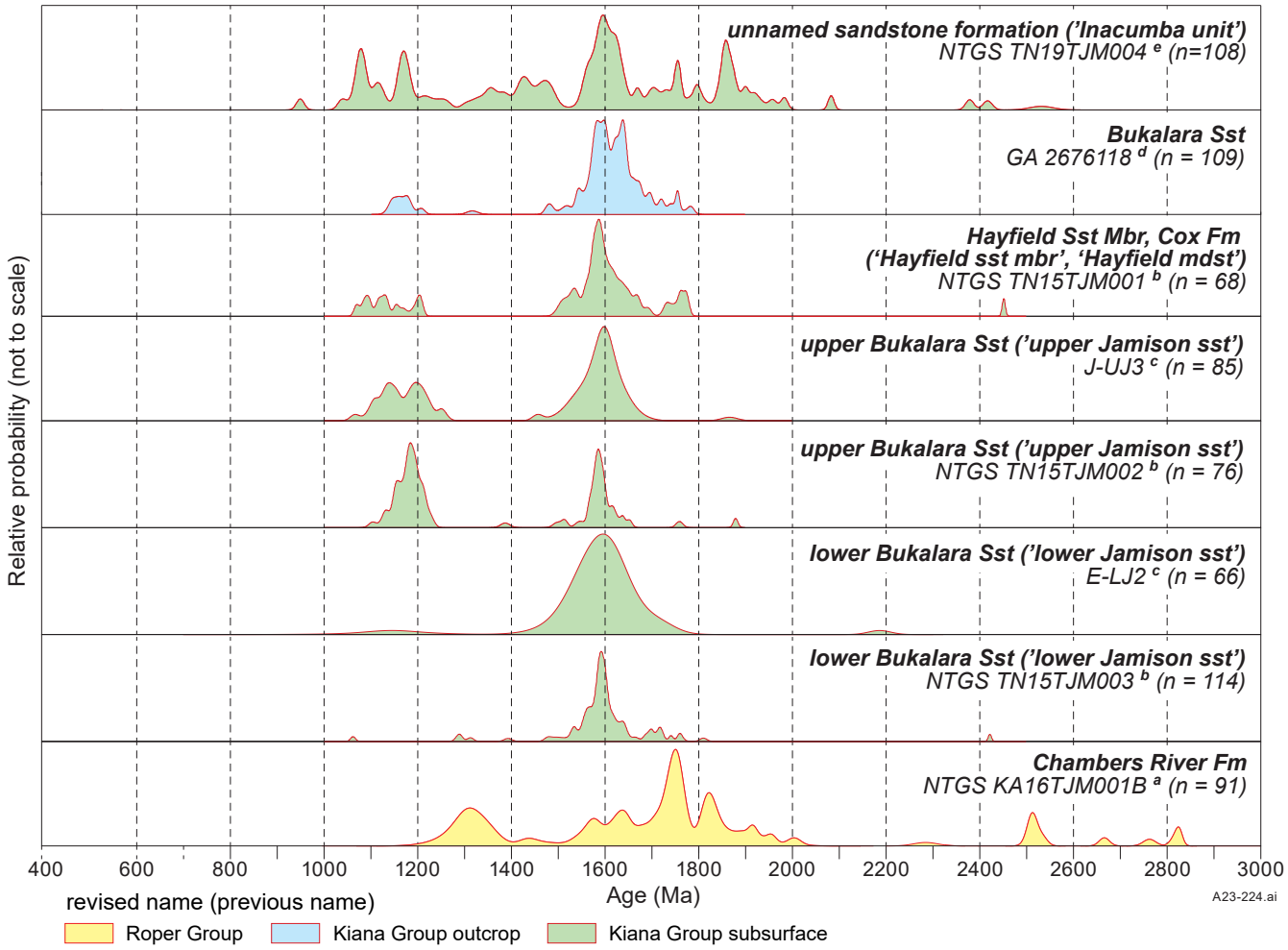

Figure 2. Comparative relative probability diagram of SHRIMP and LA–ICP–MS U–Pb detrital zircon age data (slightly modified from Munson 2023: figure 3). Stratigraphic units as defined herein are arranged in ascending stratigraphic order: Chambers River Formation (Roper Group); Bukalara Sandstone (including former 'lower Jamison sandstone' and 'upper Jamison sandstone'; Kiana Group); Hayfield Sandstone Member of Cox Formation (former 'Hayfield mudstone'; Kiana Group); and unnamed sandstone formation (Kiana Group). Relative probability age spectra are not to scale vertically; associated histograms used to construct the spectra are not shown for clarity; number of concordant and near-concordant (<10%) analyses (n) is shown on right. [a] = Kositcin *et al* (2017); [b] = Munson *et al* (2018); [c] = (Yang *et al* (2018); [d] = Anderson *et al* (2019); [e] = Munson *et al* (2020).

Unconformably overlying the Cox Formation (former 'Hayfield mudstone') at the top of the post-Roper group succession in the Beetaloo Sub-basin is an unnamed sandstone-dominated formation that was considered to be Cambrian by Lanigan *et al* (1994) and probably Neoproterozoic by Munson *et al* (2020). This unit consists of thinly to thickly bedded bedsets of mostly medium- to coarse-grained sandstone (Lanigan *et al* 1994, Munson *et al* 2020). It is probably equivalent to sandstone intervals above the Cox Formation that were logged as 'Bukalara Sandstone' or as the informally named 'Inacumba unit' in some drillholes (eg Santos Tanumbirini-1; Adderley 2015, Mills 2021). The sandstone formation is variable in thickness (from a few tens of metres up to 380 m in Tanumbirini-1) and has a variable distribution in Beetaloo Sub-basin wells (Lanigan *et al* 1994, Gorter and Grey 2012). Laser ablation inductively coupled plasma mass spectrometer (LA–ICP–MS) U–Pb detrital zircon geochronology was conducted on a sample of the sandstone by Munson *et al* (2020). The detrital zircon age spectrum (**Figure 2**) has major modes in common with underlying units but is otherwise very distinctive, with a much broader range of zircon sources, including

Table 1. Comparison of previous and new stratigraphic nomenclature for Kiana Group in Beetaloo Sub-basin (slightly modified from Munson 2023: table 1).

Previous studies		**Record 2023-012**	
ungrouped	unnamed sandstone formation / Inacumba unit	Kiana Group	unnamed sandstone formation
	Hayfield Mudstone/ mudstone (including Hayfield sandstone member)		Cox Formation (including Hayfield Sandstone Member)
	upper Jamison Sandstone/ sandstone/sands		upper Bukalara Sandstone
	lower Jamison sandstone/ sandstone/sands		lower Bukalara Sandstone

significant ca 1500–1350 Ma modes, which are generally rare in detrital zircon age spectra from the North Australian Craton; and with significant populations of > ca 1800 Ma zircons, which are not present in underlying formations of the Kiana Group. An MDA estimate of 952 ± 8 Ma (single grain) indicates a Neoproterozoic age for the unnamed

sandstone formation. There is no equivalent of this unit within the exposed Kiana Group, the top of which has been eroded so that only the basal Bukalara Sandstone and the lower part of the Cox Formation are preserved. Munson *et al* (2020) considered the detrital zircon age spectrum of this formation to be similar to that of the Spencer Sandstone (near top of Auvergne Group, Victoria Basin; Kositcin and Carson 2017) and suggested a possible correlation between these units.

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