Detrital zircon analysis from the Galilee Basin, Queensland.

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SUMMARY

The effect of the Permian onset of the Hunter-Bowen Orogeny on sedimentation patterns in the eastern Galilee Basin of Queensland was investigated through a comparison of age populations of detrital zircon grains in sandstones in the Cisuralian (early Permian) Joe Joe Group and the Lopingian (late Permian) Betts Creek beds and a potential shift in sediment provenance has been recognised. One key well (OEC Glue Pot Creek 1) was selected from the eastern Galilee Basin for detrital zircon analysis. The well intersected both Cisuralian and Lopingian strata. Nine sandstone samples were collected (three from the Cisuralian and six from Lopingian) and zircon grains were extracted. U-Pb isotopic data was gathered using the Laser Ablation – Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) technique.

A total of 286 concordant ages were obtained from the nine samples. The Cisuralian samples have a varied age population range, with multiple peaks between 300 and 1200 Ma, suggesting numerous sources and orogenic recycling. In contrast, the Lopingian samples have a dominant peak of 250 to 300 Ma zircons, with a singular minor peak of 1500 Ma zircons, suggesting a transition in provenance between the Cisuralian and Lopingian.

Key words: Galilee Basin, Detrital Zircons, Cisuralian, Lopingian, Hunter-Bowen Orogeny

INTRODUCTION

In sedimentary basins, where outcrops and geophysical data are sparse, detrital zircons from drill core samples can provide insights into the provenance and timing of sediment deposition (e.g. Cawood et al., 2012 and Shaanan et al., 2015). When the detrital zircons' geochronological ages are identified, and combined with known magmatic ages of surrounding provenances and sedimentary palaeocurrents, a picture of possible sedimentation patterns can be drawn. During periods of high tectonism, exhumation of the surrounding geology may alter sedimentation patterns within a basin (e.g. Dickinson et al., 2012 and Valloni and Zuffa, 1984). Such changes may be trackable in the age distributions of the detrital zircons deposited within the basin.

The Carboniferous – Triassic sedimentary Galilee Basin (Figure 1), located in central Queensland, is largely a subsurface basin, mostly sub-cropping under a thin Tertiary cover to its northern and eastern margin. A revival of exploration work in Galilee Basin has been underway for a couple of decades with focus on its vast thermal coal resources, however the basin remains relatively understudied in comparison to its coeval neighbours, the Cooper and Bowen basins (to its south west and east respectively, Figure 1). The Galilee Basin is situated within the Thomson Orogen (Glen, 2005), separated from the Bowen Basin to its east by exposed Thomson Orogen basement, the Anakie Inlier and the Devonian – Carboniferous Drummond Basin (Figure 1). The Bowen Basin is situated within the New England Orogen. During the Galilee Basin's development, the New England Orogen to the east of the Anakie Inlier underwent the Hunter-Bowen Orogeny, a conspicuous thrusting and folding event. Numerous tuffaceous horizons that are preserved within the coal seams of both the Galilee and Bowen basins are attributed to volcanism associated with the Hunter-Bowen Orogeny (e.g. Anderson, 1985, Matheson, 1990 Ayaz et al., 2015, and Phillips et al., in Review-a). This major event of tectonism to the east of the Galilee Basin is thought to have initiated a 15-30 My mid-Permian sedimentation hiatus (Korsch et al., 2009, Nicoll et al., 2015 and Phillips et al., in Review-a).

Through palynological and sedimentological interpretation of palaeoenvironments, the Cisuralian (early Permian) experienced fluctuating base levels as a result of glaciation periods (Jones and Truswell, 1992 and Jones and Fielding, 2008). Lopingian (late Permian) palaeoenvironments have also been interpreted to show base level fluctuations, however, it is unclear if these base level changes were as a result of glacial periods or tectonic movement (Hawkins, 1976, Allen and Fielding 2007a, 2007b and Phillips et al., 2017). Recent studies of Lopingian palaeoenvironments in the Galilee Basin have led to an interpretation that there was a significant base level drop, soon after the mid-Permian hiatus, which rose again towards the end of the Permian and into the Triassic, however, it is not known if this drop in base level exposed the terrane, shedding sediment into the Galilee Basin.

This study uses detrital zircon geochronological populations between 1) Cisuralian and Lopingian samples from OEC Glue Pot Creek 1 and 2) existing age populations from surrounding provinces in both the Thomson and New England orogens, to investigate the effect of the Hunter-Bowen Orogeny on provenance in the eastern Galilee Basin during the Permian.

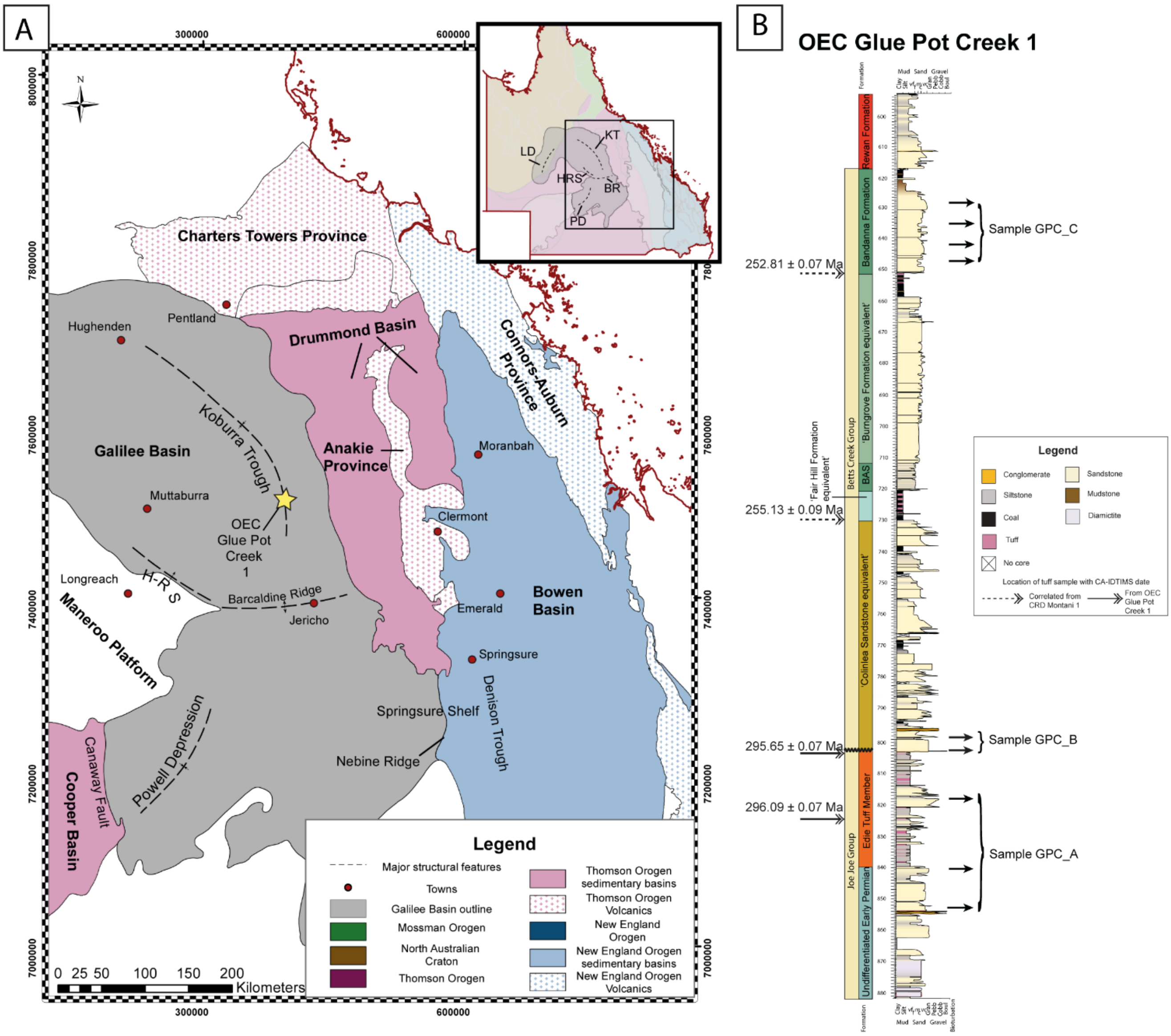


Figure 1: A) Map of the Galilee Basin showing the location of OEC Glue Pot Creek 1. Highlighted are the orogens in Queensland (main map and inset). Abbreviations: LD – Lovelle Depression, KT – Koburra Trough, BR – Barcaldine Ridge, PD – Powell Depression, H-RS – Hulton Rand Structure (From Phillips et al., in Review-b). B) Sedimentary log of OEC Glue Pot Creek (Phillips et al., 2017) showing sampling location on the right hand side. Left hand side shows CA-IDTIMS dates (from Phillips et al., in Review-a.)

Previous sandstone petrology studies

Previous studies along the eastern margin and southern areas of the Galilee Basin looked at the petrographic composition of the sandstones within the Galilee Basin as a tool for determining extrabasinal sediment sources (e.g. Bastian, 1965, Mollan et al., 1969, Hawkins, 1976, Hawkins and Carmichael, 1987, Van Heeswijck, 2006, Grigorescu, 2012). Both the Cisuralian Joe Joe Group and Lopingian Betts Creek Group are quartz rich. Feldspathic and metasedimentary content increases towards the south in the Joe Joe Group, whereas the Betts Creek beds contain a greater amount of volcanolithics (Kirkgaard, 1969, Hawkins and Carmichael, 1987, Van Heeswijck, 2006, Grigorescu 2012). The lithic component of the sandstone composition has been attributed to a number of sources for both the Cisuralian and Lopingian strata with no discernible difference between the two.

A wide variety of potential sources are located surrounding the Galilee Basin; in the east, the Neoproterozic – early Paleozoic Anakie Metamorphics of the Anakie Inlier, Devonian – Carboniferous Drummond Basin, the Devonian Dunstable Volcanics and the Carboniferous – Permian Kennedy Igneous Province, to the north the Ordovician-Silurian Ravenswood Granodiorite within the

Charters Towers Province and to the west unspecified strata within the Thomson Orogen. These sources range both geo- and strati-graphically. Through U-Pb isotopic dating of detrital zircons within the sandstones, it may be possible to discern if a difference in sediment sources exists between the Cisuralian and Lopingian strata.

METHODS

Select sandstone samples from one key well, OEC Glue Pot Creek 1 (Figure 1) underwent detrital zircon U-Pb isotopic dating with Laser Ablation – Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS). The well was chosen as it interested Cisuralian and Lopingian strata. Nine sandstones samples from drill core were chosen based on their stratigraphic location, three from the Cisuralian Joe Joe Group and six from the Lopingian (two from the 'Colinlea sandstone equivalent' and four from the Bandanna Formation). All samples were crushed and underwent heavy mineral separation. Zircons were randomly picked as to not bias the sample towards one zircon morphology. Picked zircons were mounted in epoxy resin, which were then polished and carbon coated. Cathodoluminescence (CL) images were taken at Queensland University of Technology (QUT) of the mounts to determine zonation of the zircon grains. LA-ICPMS was conducted at QUT on an Agilent 8800 over two sessions. Standards used during the analysis were Temora 2 (TIMS $^{206}Pb/^{238}U$ age 416.78 ± 0.33 Ma, Black et al., 2004, n=24 and 11) and the Plešovice Zircon (TIMS 206Pb/238U age 337.13 ± 0.37 Ma, Sláma et al., 2008, n=24 and 9) for monitoring and correcting U-Pb fractionation. The National Institute of Standards and Technology (NIST) 610 glass standard was used for calculating trace element concentrations (n=25 and 13). Standards were measured at an interval between 10-12 unknowns. The central zonation ring was the target in all zircons.

RESULTS

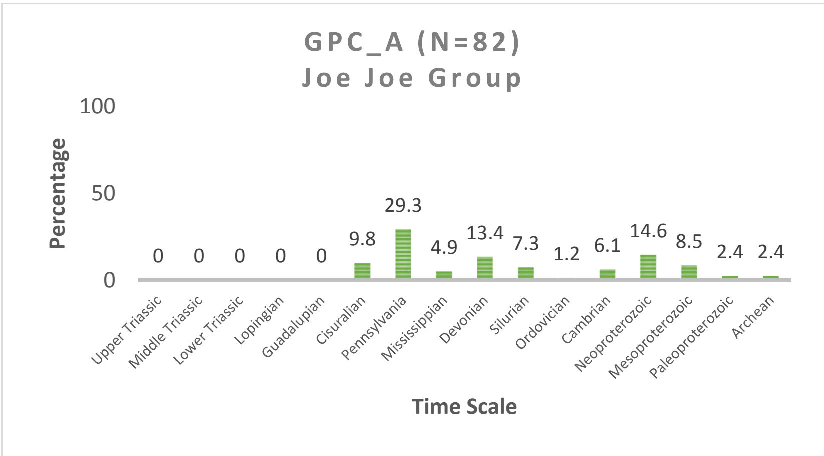
Results are summarised in Figure 2. Some of the samples yielded poor zircon content, therefore three composite samples (GPC_A, GPC_B and GPC_C) were created by combining individual samples taken from the stratigraphic horizon.

Cisuralian samples yielded a total of 82 concordant ages (n=41, 16 and 25 individually). The individual samples' results have been combined and named GPC_A. The predominant group of zircons were Pennsylvanian in age (29.3%), followed by Neoproterozoic (14.6%) and Devonian (13.4%). Minor populations of Cisuralian (9.8%), Mississippian (4.9%) Silurian (7.3%), Ordovician (1.2%), Cambrian (6.1%), Mesoproterozoic (8.5%), Paleoproterozoic and Archean (both 2.4%) -aged zircons were also recorded.

The Lopingian samples have been separated into two groups: early Lopingian and late Lopingian. The early Lopingian samples from the 'Colinlea Sandstone equivalent' yielded a total of 122 concordant ages (n=9 and 113 individually). The late Lopingian samples from the Bandanna Formation yielded a total of 82 concordant ages (n=11, 40, 15 and 16 individually). The individual samples' results have been combined and named GPC_B and GPC_C for the early Lopingian and late Lopingian respectively.

The predominant group of zircons from GPC_B were Cisuralian in age (66.4%), followed by Pennsylvanian (19.7%) and Guadalupian (7.4%). Minor populations of Lower Triassic (0.8%), Mississippian (1.6), Upper Devonian (1.6%), Neoproterozoic (1.6%) and Mesoproterozoic (0.8%) -aged zircons were also recorded.

The predominant group of zircons from GPC_C were Middle Triassic in age (26.8%), followed by Lower Triassic (17.1%) and Cisuralian and Pennsylvanian (both 12.2%). Minor populations of Upper Triassic (1.2%), Lopingian (6.1%), Guadalupian (4.9%), Mississippian (4.9%), Devonian (3.6%), Silurian (2.4%), and Mesoproterozoic (8.5%).



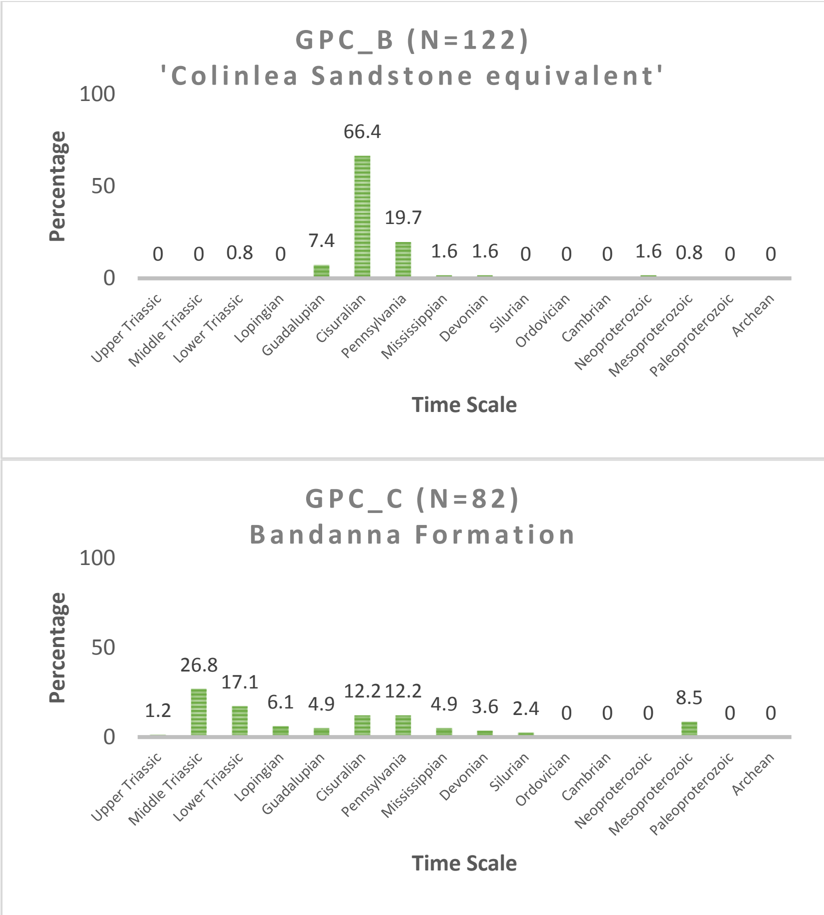


Figure 2: Bar graphs summarising the geochronology ages of the detrital zircons analysed in this study. Individual sample analysis can be found in Phillips et al., in Review-b.

DISCUSSION

Cisuralian

Recent CA-IDTIMS analysis by Phillips et al. (in Review-a) and Nicoll et al. (2015) on the ash layers in Edie Tuff member of the Joe Joe group (Cisuralian stratigraphic unit) give ages of 296.09 ± 0.07 and 295.65 ± 0.07 Ma from the middle and top of the member, respectively. These Cisuralian ages provide a constraint on the depositional age of sample GPC_A. These ages are not significantly different than the Cisuralian age detrital zircon population in sample GPC_A. This suggests a short time span between source eruption and sink. The identification of multiple ash layers (Phillips et al., in Review-a) near samples GPC_A suggests that the Cisuralian experienced multiple explosive volcanic episodes. The onset of deposition within the Galilee Basin is thought to be within the Mississippian(?)-Pennsylvanian (Van Heeswijck, 2010). The crustal extension event thought to have initiated this deposition is associated with eastwards magmatism recorded in the Thomson (e.g. Bullgonunna Volcanic Group and Kennedy Igneous Province) and New England orogens (e.g. Connors Subprovince) stratigraphic record (Allen et al., 1998, Black, 1994, Cross et al., 2009, Cross et al, 2012, Cross et al., 2016, Fanning et al., 2009). Therefore, it is reasonable to interpret the source for the Mississippian- to Cisuralian-aged detrital zircons to be either direct erosion of the volcanic provinces in both the Thomson and New England orogens (e.g. the Pyramid Rhyolite or the Urannah Batholith) and ash fall associated with these provinces that have been reworked and deposited within the sampled sandstone (Figure 3).

The Proterozoic-aged detrital zircon populations are similar to that of the Delamerian, Thomson and New England orogens (Shaanan et al., 2017). Geographic proximity to the eastern Galilee Basin suggests that erosion of the nearby Thomson Orogen basement exposed in the Anakie Province to the Galilee Basins east may be the source of the Proterozoic-aged detrital zircon populations (Figure 3). Another possible route for the detrital zircons to be carried would be from the Charters Towers Province to the north of the Galilee Basin (Figure 3). Both of these provinces contain metasedimentary rocks, which may be the origin of the metamorphic lithics within the Joe Joe group noted by Mollan et al., 1969.

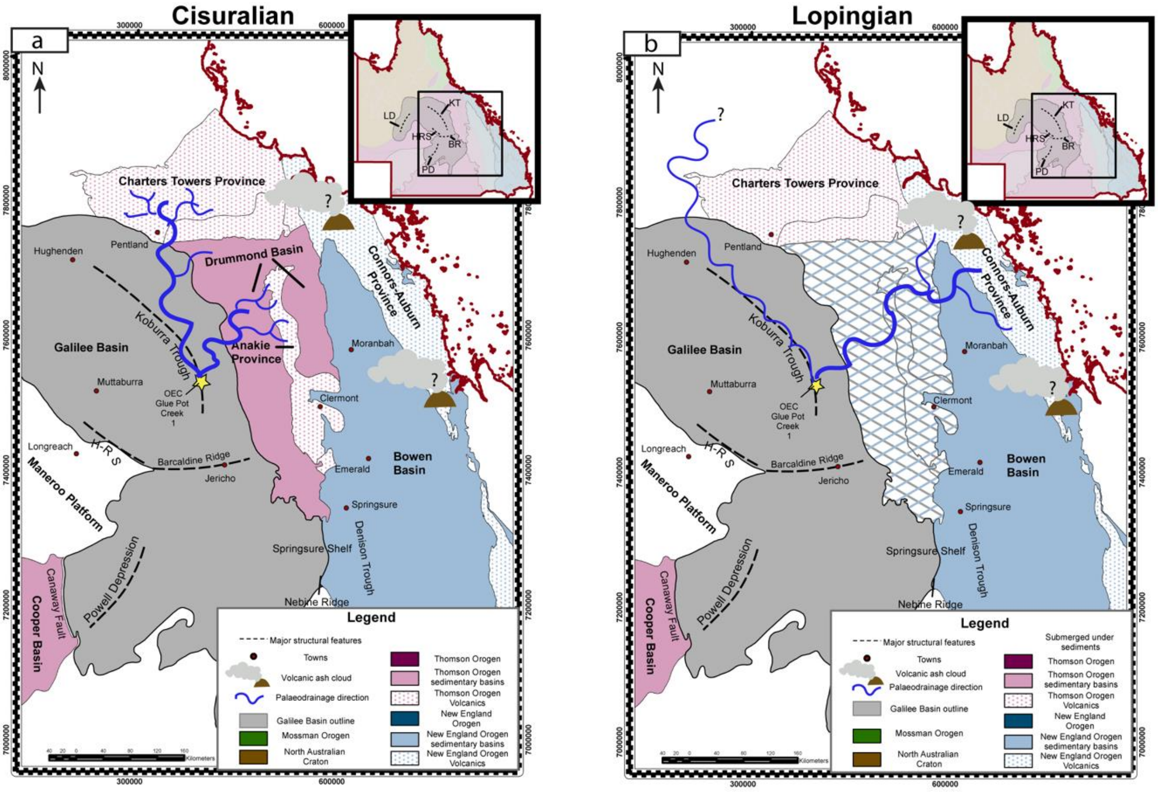


Figure 3: Maps showing possible palaeodrainage patterns into the eastern Galilee Basin during the Cisuralian and Lopingian as represented by detrital zircon ages in selected drill core from OEC Glue Pot Creek 1. Location of volcanoes are currently unknown. Modified from Phillips et al., in Review-b.

Lopingian

Both Lopingian samples show a marked difference in a reduction of the number of age populations compared to the older sample. This suggests that the drainage patterns changed from eroding the surrounding Thomson Orogen basement (Figure 3), as interpreted in the Cisuralian sample to being inundated by relatively young zircons (Figure 2). Depositional constraints of ~258 to ~251.9 Ma (spanning the Lopingian) can be placed on the Lopingian strata by 1) the correlation of CA-IDTIMS dates of ash layers in both the Galilee (Phillips et al., in review-a) and Bowen basins (Collins, 2009, Metcalfe et al., 2015, Michaelson et al., 2001, Smith and Mantle 2013) to strata in OEC Glue Pot Creek 1 by Phillips et al., (in Review-a), and 2) palynology of the OEC Glue Pot Creek 1 core (Purcell 2010). Triassic aged zircons (except one[1]) from GPC_C have a maximum age that surpasses the P-T boundary. Therefore, similar to sample GPC_A from the Cisuralian, a high proportion of the detrital zircons are 'young' and may represent a short source to sink route, potentially via volcanic ash clouds and/or the minor reworking of the sediments from the easterly Kennedy Igneous Province or Connors Subprovince (Figure 3).

The relatively great (8.5%) presence of Mesoproterozoic detrital zircons in sample GPC_C in comparison to the GPC_A and B samples suggests that towards the end of the Lopingian the drainage patterns into the eastern Galilee Basin changed. A potential source for these zircons is the Mossman Orogen (Shaanan et al. 2017, Figure 3) where a similar aged detrital zircon population has been observed.

The absence of Thomson Orogen-aged basement populations suggests that the Anakie Inlier and/or Charters Towers Province were no longer sources of sediment during the Lopingian (Figures 2 and 3). This may be due to a change in topography between the Cisuralian and the Lopingian as a result of the onset of the Hunter-Bowen Orogeny during the mid-Permian. The Anakie Inlier and Charters Towers Province may no longer be a palaeohigh and drainage patterns are no longer shedding material off these provinces into the eastern Galilee Basin.

CONCLUSIONS

This study used U-Pb isotopic dating techniques to determine if a shift in sedimentation patterns occurred during the Permian in the eastern Galilee Basin. The era of the mid-Permian Hunter-Bowen Orogeny marked a change in sedimentation patterns in the eastern

[1]One grain produced an age of 233±13 Ma. After ablation, examination of the grain in transmitted light, the laser spot is positioned at the edge of the grain and some epoxy was ablated. Therefore, it may have produced an unreliable age.

Galilee Basin. During the Cisuralian the drainage patterns into the basin were complex and originated from many sources, while drainage pattern during the Lopingian were predominantly from a single source. The main conclusions from this study are:

- Zircons of similar age to the encasing strata indicate that during both the Cisuralian and Lopingian syn-deposition of volcanic sediments occurred as ash fall. However, the palaeoenvironment at the time of deposition did not allow for the preservation of the ash layer and so minor sedimentary reworking of the physically robust zircons occurred.
- In addition to ash fall, the Cisuralian sediments contained a large proportion of Neoproterozoic – early Paleozoic-aged zircons. These zircons have been attributed to a basement source, potentially the Anakie Inlier and/or the Charters Towers Province (to the east and north of the Galilee Basin respectively) suggesting a westerly and southerly palaeodrainage pattern into the eastern Galilee Basin.
- A large proportion of the detrital zircons in the Lopingian samples have been interpreted to be from ash fall. Cisuralian-aged detrital zircons have been interpreted to originate from the volcanic provinces in the New England Orogen such as the Kennedy Igneous and Connors Arch provinces to the east of the Galilee Basin. This indicates a westerly drainage pattern into the eastern Galilee Basin during the Lopingian.
- A minor but consistent population of Mesoproterozoic-aged zircons in the latter Lopingian samples indicate a contribution from another source, potentially the Mossman Orogen to the north of the Galilee Basin, suggesting a change in drainage patterns towards the end of the Lopingian.

FUTURE WORK

It is acknowledged that results and subsequent discussions in this study were generated from one key well in the Galilee Basin. Future research can build on the conclusions found in this study in a number of ways. 1) analysing the geochronology of detrital zircon grains from other wells along the eastern margin of the Galilee Basin will provide a larger scale regional view of drainage patterns into the Galilee Basin, 2) the use of image logs as a tool for palaeocurrent interpretation may confirm or refute the sedimentation patterns drawn in this study and 3) the separates can be used for further isotopic geochronological or geochemical work, for example U-Pb dating on rutiles and Rb-Sr isotopic work on apatites.

ACKNOWLEDGMENTS

The authors of this study would like to acknowledge funding from the Vale-UQ Coal Geoscience Program and the Australian Coal Association Research Program (ACARP), grant number C22028. The 34th IGC travel grant awarded by the Australian Geoscience Council (AGC) and the Australian Academy of Science (AAS) provided funds for travel and associated costs to the 2018 Australian Exploration Geoscience Conference (AEGC), Sydney.

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