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Supercontinents and Glaciation: a perspective from western Gondwana

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Thesis Author Statement

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Thesis Abstract

Precise timing for the formation of the Palaeozoic supercontinent Gondwana has long eluded the geological community. Early hypotheses postulated that amalgamation occurred in the mid-late Neoproterozoic via a collision between East and West Gondwana. This idea developed with the identification of discrete collisional events between diverse, relatively small Neoproterozoic continents that amalgamated Gondwana in a piecemeal fashion over 150 million years, with a series of late Ediacaran–Cambrian orogens that represent the final phase of Gondwana amalgamation. A salient feature of the rocks preserving these events in the Neoproterozoic sedimentary record is the preservation of glacial sediments. Significant debate has centred around firstly whether these deposits are in fact glacial and secondly the spatial extent of these glaciations. This thesis addresses these deficits in our knowledge by presenting detailed sedimentology, geochronology, palaeomagnetic results from western Gondwana.

The Cryogenian-aged Toekems Sub-basin in the Damara Belt, Namibia comprises a wedge dominantly clastic, glacially influenced sediments. Our field observations and results imply a significant disconformity beneath the Naauwpoort Volcanics and suggest multi-phase rifting during the breakup of southwestern Congo Craton from Rodinia.

The northern Paraguay Belt in South America developed in response to the collision between the Amazonian Craton, the Rio Apa Block, the São Francisco Craton and the Paranapanema Block. The alleged 'Brasiliano' age (~620 Ma) of orogenesis was recently questioned by palaeomagnetic and radioisotopic ages that indicate the closing stages of orogenesis occurred well into the Cambrian that are believed to mark the suture zone of the Clymene Ocean—interpreted amongst the youngest of the Gondwana amalgamation orogens. The post-orogenic São Vicente Granite provides a long sort after minimum age of 518 ± 4 Ma for orogenesis within the belt, constraining the termination of deformation within the northern Paraguay Belt.

The Alto Paraguay Group, the youngest stratigraphic unit in the northern Paraguay Belt, contains unequivocal evidence for a glacial influence on sedimentation. $^{40}Ar/^{39}Ar$ detrital muscovite cooling ages from the upper part of the Alto Paraguay Group are as young as 544 ± 7 Ma. When considered with other data presented here, these ages suggest that this package of rocks developed in a mid-Ediacaran glaciation consistent with that expressed in the Gaskiers Formation of Newfoundland, Canada. U/Pb zircon maximum depositional ages from the top of the Alto Paraguay Group indicate that final sedimentation began no earlier than 527 Ma. The ε_{Hf} signature is consistent with a predominantly Amazonian source until the early-Neoproterozoic at which point the signal becomes significantly more evolved.

new palaeomagnetic data from Alto Paraguay Group represent a secondary magnetisation, likely acquired during regional emplacement of Jurassic basalt. This finding is at odds with recent results that have been used to suggest Amazonia was at low latitudes during the Ediacaran, which has implications for the snowball earth hypothesis and the tectonic evolution of the Paraguay Belt.

These data, when combined with other evidence discussed here, are consistent with an ocean to the east of the present-day Amazonian Craton that didn't close until the Cambrian.

Publications Arising From This Thesis

McGee, B., Collins, A.S. and Trindade, R.I.F., 2012. G'day Gondwana - the final accretion of a supercontinent: U-Pb ages from the post-orogenic Sao Vicente Granite, northern Paraguay Belt, Brazil. Gondwana Research 21, 316-322.

Bandeira, J., **McGee, B.**, Nogueira, A.C.R., Collins, A.S. and Trindade, R.I.F., 2012. Closure of the Neoproterozoic Clymene Ocean: sedimentary and detrital zircon geochronology evidence from the siliciclastic upper Alto Paraguai Group, northern Paraguay Belt, Brazil. Gondwana Research.

McGee, B., Halverson, G.P. and Collins, A.S., 2012. Cryogenian rift-related magmatism and sedimentation: South-western Congo Craton, Namibia. Journal of African Earth Sciences 76, 34-49.

McGee, B., Collins, A.S. and Trindade, R.I.F., Accepted. A glacially incised canyon in Brazil: Further evidence for mid-Ediacaran glaciation? The Journal of Geology.

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McGee, B., Trindade, R.I.F., Rosaffa, M., Collins, A.S. and Tohver, E., Under review. An inconvenient truth: Multiple geomagnetic reversals in the Neoproterozoic–Cambrian Alto Paraguay Group, Amazonian Craton, Brazil. Precambrian Research.

Thesis Outline

The latest Proterozoic and earliest Paleozoic eras beautifully illustrate the complexity and interconnectedness of the interactions between Earth's systems. Mantle dynamics have long been considered to influence the topography and mechanics of the overlying lithosphere (Mitrovica et al., 1989; Pysklywec and Mitrovica, 1997). The impact of 'mantle avalanches' have been suggested to play a causal role in the supercontinent cycle (Condie, 1998; Li et al., 2008) – by initiating superplume development – cited as one potential cause for the break-up of Rodinia (Frimmel et al., 2001; Li et al., 2008; Li et al., 1999). The fragmentation of this supercontinent provided the building blocks for its successor Gondwana.

Undeniably, these deep processes began to effect surface processes, irrevocably changing the Earth to its current biologically rich/diverse state. Increased heat transfer, afforded by the superheated plume head (Campbell and Davies, 2006), enhanced hydrothermal activity in the oceans – indicated by Sr isotopes (Melezhiik et al., 2001) – resulting in increased leaching of metals, capturing large amounts of oxygen, stratifying the ocean and depositing vast banded iron formations (Kaufman et al., 1991) after a hiatus for some 1000 million years. Other important elements were also released initiating plankton hyperproductivity (Gaucher et al., 2003) and ^{13}C levels were enriched (Halverson et al., 2005). The changing oceans caused the atmosphere to evolve to its oxygenated state (Canfield et al., 2007; Canfield and Teske, 1996; Garrels et al., 1973) and the most intense periods of glaciation in Earth's history (Hoffman et al., 1998; Kirschvink, 1992; Roberts, 1971). These extreme glacial events are suggested to be partly responsible for the birth of diverse animal life (Bowring and Erwing, 1998; Knoll, 1992; Narbonne and Gehling, 2003) and us such understanding them is crucial to our knowledge of the Earth system.

The central aim of this thesis is to investigate some examples of Neoproterozoic sedimentary basins that record evidence for these glacial events and the tectonic history of their cratonic roots in their journey from Rodinia to Gondwana. This is achieved through detailed sedimentary, geochronological and palaeomagnetic studies with a focus on western Gondwana.

The specific aims of this thesis are:

1. Shed light on the relationship between Rodinian rifting and glaciation from the Damara Belt in Namibia and to show that there is a glacial influence on sedimentation.
2. Constrain the termination of deformation in the Paraguay Belt
3. Delineate a glacial incision surface along the Serra Azul in the northern Paraguay Belt and discuss other global evidence for similar aged glacial deposits.
4. Provide a detailed sedimentary and stratigraphic analysis of the Serra Azul Formation complemented by Argon cooling ages to provide the first age constraints on the Serra Azul Formation and information on low temperature events within the northern Paraguay Belt
5. Provide a long-awaited and comprehensive detrital zircon study from the northern Paraguay Belt and discuss the now significant body of evidence that exists for a Cambrian age of orogenesis.
6. To show that new palaeomagnetic data from the Alto Paraguay Group suggest a significant remagnetisation event occurred in the northern Paraguay Belt, most likely in the Jurassic.

The location for the first aim was selected in Namibia based on the excellent exposure of Neoproterozoic rift basins in the Damara Belt. The Toekems Sub-basin contains a unique exposure of rift-related sediments under a Sturtian aged cap-carbonate.

The remaining aims are addressed in the northern Paraguay Belt in central South America, which provides a place where the relationship between tectonics, oceans, atmosphere and the biosphere during the Neoproterozoic–Cambrian can be studied. The belt is comprised of a thick succession of passive margin sediments on the southwestern edge of the Amazonian Craton. Mounting evidence suggests that the Paraguay Belt marks the suture zone of the Clymene Ocean, which separated Amazonia, Rio Apa, Pampia and proto-Gondwana (Bandeira et al., 2011; Tohver et al., 2011; Tohver et al., 2010; Trindade et al., 2006).

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Author Contribution Statement

The research contained in this thesis has been published or submitted for publication in scientific journals. The bibliographic details of each journal article comprising a chapeter are listed at the beginning of the chapter, which includes the names of all authors involved in their production. The contribution of each author to the conceptualisation, realisation and documentation of these works is described below.

MCGEE, B. (Candidate)
Chapters 1–6: Project conceptualisation and planning; fieldwork, including mapping and stratigraphic logging; sample selection and preparation; LA-ICPMS data collection; all calculations and data processing; data interpretation; manuscript design, writing and creation of all figures; article submission to journals.

I certify that the above statement is accurate

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