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Evidence of ENSO mega-drought triggered collapse of prehistory Aboriginal society in northwest Australia

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Abstract

The Kimberley region of northwest Australia contains one of the World's largest collections of rock art characterised by two distinct art forms; the fine featured anthropomorphic figures of the Gwion Gwion or Bradshaw paintings, and broad stroke Wandjina figures. Luminescence dating of mud wasp nests overlying Gwion Gwion paintings has confirmed an age of at least 17,000 yrs B.P. with the most recent dates for these paintings from around the mid-Holocene (5000 to 7000 yrs B.P.). Radiocarbon dating indicates that the Wandjina rock art then emerged around 3800 to 4000 yrs B.P. following a hiatus of at least 1200 yrs. Here we show that a mid-Holocene ENSO forced collapse of the Australian summer monsoon and ensuing mega-drought spanning approximately 1500 yrs was the likely catalyst of this change in rock art. The severity of the drought we believe was enhanced through positive feedbacks triggered by change in land surface condition and increased aerosol loading of the atmosphere leading to a weakening or failure of monsoon rains. This confirms that pre-historic aboriginal cultures experienced catastrophic upheaval due to rapid natural climate variability and that current abundant seasonal water supplies may fail again if significant change in ENSO occurs. 2012. American Geophysical Union. All Rights Reserved.

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Evidence of ENSO mega-drought triggered collapse of prehistory Aboriginal society in northwest Australia

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[1] The Kimberley region of northwest Australia contains one of the World's largest collections of rock art characterised by two distinct art forms; the fine featured anthropomorphic figures of the Gwion Gwion or Bradshaw paintings, and broad stroke Wandjina figures. Luminescence dating of mud wasp nests overlying Gwion Gwion paintings has confirmed an age of at least 17,000 yrs B.P. with the most recent dates for these paintings from around the mid-Holocene (5000 to 7000 yrs B.P.). Radiocarbon dating indicates that the Wandjina rock art then emerged around 3800 to 4000 yrs B.P. following a hiatus of at least 1200 yrs. Here we show that a mid-Holocene ENSO forced collapse of the Australian summer monsoon and ensuing mega-drought spanning approximately 1500 yrs was the likely catalyst of this change in rock art. The severity of the drought we believe was enhanced through positive feedbacks triggered by change in land surface condition and increased aerosol loading of the atmosphere leading to a weakening or failure of monsoon rains. This confirms that pre-historic aboriginal cultures experienced catastrophic upheaval due to rapid natural climate variability and that current abundant seasonal water supplies may fail again if significant change in ENSO occurs. **Citation:** McGowan, H., S. Marx, P. Moss, and A. Hammond (2012), Evidence of ENSO mega-drought triggered collapse of prehistory Aboriginal society in northwest Australia, *Geophys. Res. Lett.*, *39*, L22702, doi:10.1029/2012GL053916.

1. Introduction

[2] Rapid climate change and potential catastrophic impacts are of major concern as they may severely challenge the ability of societies to respond and adapt due to environmental, economic, cultural and geopolitical constrains. Yet the historical and geologic records contain numerous examples of rapid climate change and impacts that have, at times, led to collapse of civilizations including the Maya (Central America [*Medina-Elizalde and Rohling*, 2012]), Norse (Greenland [*D'Andrea et al.*, 2011]) and Anasazi (North America [*Benson et al.*, 2007]).

[3] In the remote Kimberley region of northwest Australia evidence of human settlement since at least the late Pleistocene has been found [*Roberts et al.*, 1997]. The most dramatic legacy left by these early inhabitants are thousands of rock art figures known as Gwion Gwion or Bradshaw paintings (Figure 1). Luminescence dating of mud wasp nests overlying Gwion Gwion paintings indicate an age of at least 17,000 yrs B.P. [*Roberts et al.*, 1997], which is supported by their depictions of the marsupial lion (*Thylacoleo carnifex*) [*Akerman and Willing*, 2009] which is known to have become extinct in the late Pleistocene [*Prideaux et al.*, 2010]. The most recent dates are from the mid-Holocene (5000 to 7000 yrs B.P.) [*Watchman et al.*, 1997]. The emergence of the broad stroke Wandjina rock art (Figure 1) is then recorded occurring around 3800 yrs B.P. [*Watchman et al.*, 1997; *Morwood et al.*, 2010] following a hiatus in painting of rock art of at least 1200 yrs. These two vastly different forms of rock art have led to conjecture and controversy that Gwion Gwion paintings are a legacy of a culture predating present day Aboriginal inhabitants, and that their demise is recorded in their rock art as images of conflict, possibly over dwindling resources [*Walsh*, 2000]. However, the cause of their disappearance and the emergence of Wandjina rock art more than 1200 yrs latter had remained unknown until now.

[4] The late Pleistocene was characterised by active summer monsoons during interglacials over northern Australia [*Bowler et al.*, 2001], and a climate more arid than present during the last glacial maximum (18,000 to 24,000 yrs B.P.) [*Wende et al.*, 1997], that transitioned to humid conditions around 14,000 yrs B.P. [*Wyrwoll and Miller*, 2001]. Intense monsoon seasons followed through the early to mid-Holocene which resulted in the establishment of a perennial Lake Mulan in the southern Kimberley at levels thought to be higher than under the modern climate regime [*Wende et al.*, 1997; *Nanson et al.*, 1995; *Fitzsimmons et al.*, 2012]. Northeast Australia then appears to have become drier during the mid to late Holocene with studies drawing a possible link to the emergence of enhanced ENSO conditions around 5000 yrs B.P. [*Moy et al.*, 2002; *Barron and Anderson*, 2011]. However, the climate of the remote Kimberley region of northwest Australia during this period has remained unknown.

2. Methods

[5] In July 2005 a 1.2 m sediment core was collected from Black Springs (lat. 15.633°S, long. 126.389°E; auxiliary material), a mound spring in the northwest Kimberley.[1] It was cut into segments of length between 3 and 10 mm which were oven dried at 60°C for 36 hrs to remove moisture. A sub-sample of known weight of each segment was

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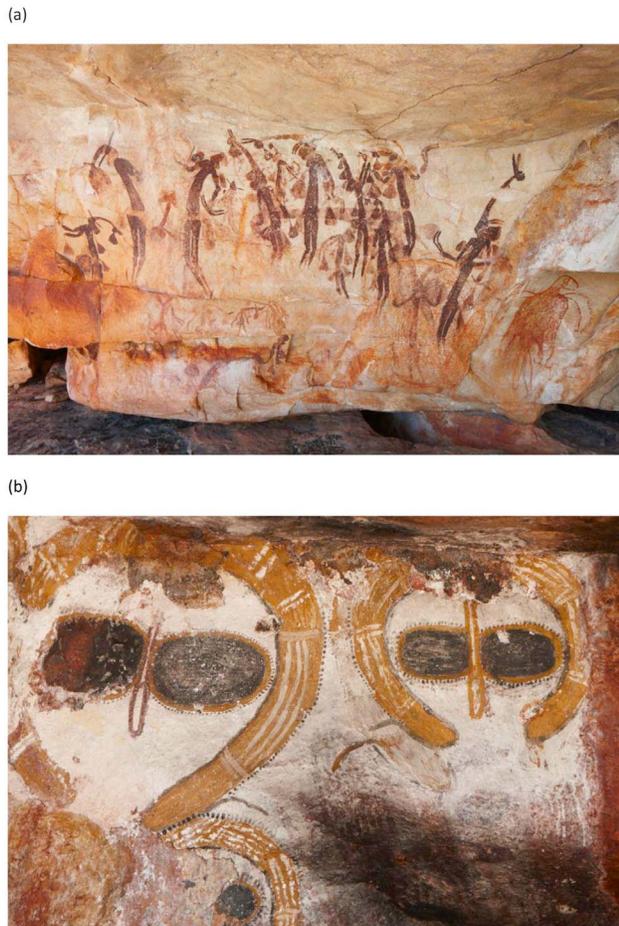
(a)

(b)

Figure 1. Examples of (a) Gwion Gwion rock art and (b) Wandjina rock art (photographs courtesy of Kimberley Foundation Australia).

then combusted at 450°C for 12 hrs to destroy the organic component, with the mineral sediment retained for trace element analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Accelerator Mass Spectrometry (AMS) radiocarbon dating of pollen (n = 9) exacted from the sediment core indicated that the lower section of the core contained apparent age reversals and no further analysis was conducted on this section. Ages from the top 0.80 m of the core (Table 1) returned a coherent age/depth relationship represented by a 2nd order polynomial giving an r^2 value of 0.95. These dates were calibrated using the ShCal04 calibration curve in the OxCal program [*Bronk Ramsey*, 1995] which confirmed that this section of core overlapped with the disappearance of Gwion Gwion rock art and the emergence of Wandjina rock art.

[6] Trace elements analyses were undertaken on 14 selected samples spaced through the top 0.80 m of the core on a Thermo X-Series11 instrument according to the protocol described in *Kamber* [2009] and *Marx et al.* [2010]. Rates of dust and fluvial sediment deposition to the mound spring were determined using a trace element provenance model. This approach uses the concentration of trace elements found to behave conservatively in the mound spring and during transport and deposition [*McGowan et al.*, 2005; *Marx et al.*, 2011]. In the Black Springs core 18 elements (Cs, Rb, Th, La,

Ce, Pr, Nb, Li, Nd, Sm, Eu, Gd, Tb, Sc, Dy, Y, Ti and Ga) were found to demonstrate conservative behaviour and were therefore used to provenance the sediment. In this study sediment deposited in the mound spring was assumed to be sourced from one of two end-members groups; either aeolian dusts or local fluvial sediments, or an admixture of the two.

[7] The trace element chemistry of potential aeolian dusts deposited in the spring was represented by a database of >200 source sediment samples collected from the main dust source regions in Australia, while local soil and river samples were collected to represent the trace element chemistry of local fluvial sediments. The chemistry of each mound spring sediment sample was then compared with the chemistry of all the potential dust sources and local fluvial samples. The closest matching samples from each end-member group were deemed the likely source(s) of sediment deposited in the mound spring. The relative contribution of the two closest matching samples from each end-member group was determined using a binary mixing model [*McGowan et al.*, 2005]. The outputs of this were used to calculate the deposition rates of dust and fluvial sediment in the core through time (Figure 2).

[8] Pollen samples collected from the core were mounted in glycerol and counted using a 400× compound microscope and the pollen sum consisted of 200 dryland taxa or two completely counted slides. Charcoal analysis involved counting all black angular particles above 5 μm in diameter across three evenly spaced slides at all depths. An exotic pollen marker (*Lycopodium*) was used to calculate pollen and charcoal concentrations [*Wang et al.*, 1999]. A pollen diagram was then produced using TG View and was divided into zones based on the results of a stratigraphically constrained classification undertaken by CONISS (Constrained Incremental Sums of Squares cluster analysis) [*Grimm*, 2004].

3. Results

[9] Our analysis of pollen from the core at a temporal resolution of approximately 250 yrs shows the vegetation transitioned to a dry swamp environment around 5750 yrs B.P. as indicated by an increase in *Pandaus* pollen and decrease in ferns and aquatics including the aquatic perennial *Triglochin dubia* (Figure 2). The vegetation record then shows evidence of a slightly wetter environment around 4600 yrs B.P. before becoming progressively drier until around 3200 to 2800 yrs B.P. Very dry conditions followed from about 2750 yrs B.P. to around 1300 yrs B.P. when an increase in aquatics including *Triglochin dubia* indicates a return to wetter conditions. This is coeval with a dramatic increase in charcoal concentrations to a level not seen in the previous 4,500 yrs which is likely to reflect the introduction of

Table 1. Radiocarbon Dates and Calibrated Ages From the Black Springs Core

Laboratory Code	Depth (m)	Radiocarbon Age (yrs)	Calibrated Age[a] (yrs B.P.)
Wk-29127	0.225	516 ± 35	530 ± 20
Wk-28374	0.45	3455 ± 50	3740 ± 100
Wk-19128	0.55	4671 ± 32	5395 ± 75
Wk-29129	0.79	6938 ± 37	7750 ± 50

[a]Errors for ^{14}C calibrated dates represent 68.2% probabilities estimated using OxCal.
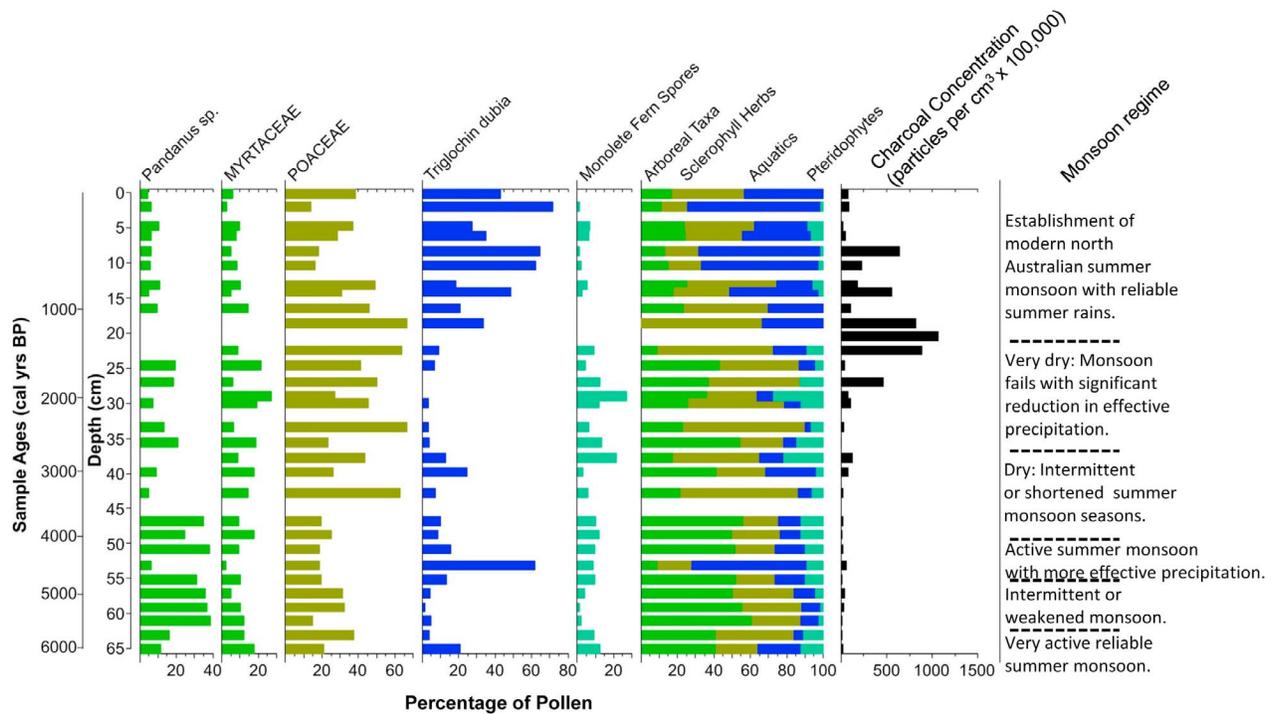
Figure 2. Pollen and charcoal record developed from analysis of the Black Spring core.

Aboriginal fire stick farming [*Jones*, 1969] and a corresponding increase in population.

[10] Trace element geochemical fingerprinting of sediments from the core show between 6300 to 3000 yrs B.P. and 2600 to 1500 yrs B.P long travelled aeolian dusts from the eastern Simpson Desert and Lake Eyre Basin of central Australia dominated sedimentation (Figure 3). Dust transport to the mound spring can only occur from these locations in strong south-easterly Trade winds associated with anticyclonic circulation. These winds strengthen as the sub-tropical ridge re-establishes over central Australia following the passage of cold fronts. This weather pattern must have been much more dominant during these periods with the monsoon further north than present day, only affecting northern Australian intermittently or, possibly, not at all for extended periods.

[11] Deposition by fluvial processes of local sediments in the mould spring was minimal (0.2 – 2.2 g m^{-2}) from the start of the record to about 3000 yrs B.P. A small increase in fluvial sedimentation between approximately 4600 to 4200 yrs. B.P. is coeval with a pronounced increase in *Triglochin dubia* (Figure 2) indicating an enhanced hydrology and wetter climate. Fluvial sedimentation increased from around 3000 yrs. B.P. to approximately 7.8 g m^{-2} corresponding to increase in the presence of ferns and aquatics, followed by a decrease coeval with increased deposition of long travelled dusts. This indicates that anticyclonic weather patterns became more frequent over central and northern Australia again directing dry south-easterly winds over the Kimberley. Collectively, these results confirm that the climate of the Kimberley became much drier at this time (Figure 2) until around 1300 to 1100 yrs. B.P. when it transitioned abruptly to conditions similar to today. This is shown in our record with the establishment of the contemporary vegetation assemblage (Figure 2) and increased

fluvial sedimentation reflecting an enhanced hydrology of the mound spring (Figure 3) as a result of increased summer monsoon rainfall.

4. Discussion

[12] Our record shows the Kimberley region of northwest Australia underwent rapid environmental change in the mid-Holocene starting around 6300 yrs B.P. when it transitioned from a tropical humid climate with intense summer monsoon to a much drier climate. This new climate regime was associated with increased anticyclonic circulation over central and northern Australia allowing a significant increase in dust transport from central Australia to the Kimberley. For this to occur, the Australian summer monsoon must have been much less active or intermittent. This finding is consistent with
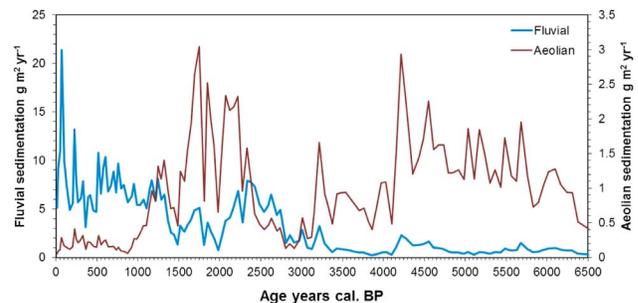

Figure 3. Sedimentation record developed for the Black Spring core. Separation of aeolian and fluvial sedimentation rates was achieved using geochemical fingerprinting to attribute provenance of sediments to either very distance sources (aeolian) or local source sediments (fluvial) (see Methods).

research showing an increasingly arid climate throughout tropical and sub-tropical northeast Australia from the mid-Holocene to approximately 3800 to 3400 yrs B.P. [*Donders et al.*, 2007]. For example, *Haberle* [2005] presented a pollen record from Lake Euramoo in the wet tropics of northeast Queensland, Australia and concluded that intensified El Niño activity after ~5000 cal yr B.P. was likely responsible for shifts from rainforest taxa towards taxa adapted to drought/fire in response to reduced rainfall. Coastal beach ridges south of the Kimberley on the Indian Ocean coast reveal a hiatus in severe tropical cyclones between 5400 to 3700 yrs B.P. Beach ridges deposited prior to this are overlain by aeolian sediments indicating a more arid climate [*Nott*, 2011]. Concurrent with the onset of this arid phase which we confirm affected the Kimberley are the most recent and possibly last Gwion Gwion paintings. The artists of these elegant anthropomorphic figures therefore appear to have abandoned the Kimberley concurrent with an increasingly arid climate as the monsoon became less reliable and possibly failed for long periods.

[13] Change in pollen assemblages and increase in fluvial sedimentation at the mound spring around 4600 to 4400 yrs. B.P. indicate increased rainfall due to the re-emergence of more active summer monsoons. The climate then appears to have transitioned back to a drier regime around 3200 yrs. B.P. which slightly predates the emergence of Wandjina rock art around 4000 to 3800 yrs B.P. [*Morwood et al.*, 2010]. In the language of the Wunambul, Wororra and Ngarinyin people of the Kimberley, "Wandjina" is the Rain Spirit, perhaps used by them to signify return of monsoonal rains sometime around 4000 yrs B.P. following 1500 yrs of drought and unreliable monsoon rains. A more arid period followed around 2400 to 1300 yrs. B.P. which is coeval with ENSO variability reaching or exceeding modern values [*Gagan et al.*, 2004]. Only after this arid phase is there unequivocal evidence of a transition to the modern summer Australian monsoon climate. This was associated with a pronounced increase in charcoal in the sediment core indicating increased presence of fire in the landscape, possibly as a result of a larger Aboriginal population and increase in woody vegetation. The pollen record shows that this was coeval with a pronounced increase in aquatics such as *Triglochin dubia* confirming a significant and reliable water supply (Figure 2).

4.1. Causes of Monsoon Variability

[14] Rapid transition of monsoon systems from intense too weak as evident in our record occur through amplifying feedback mechanisms, whereby small perturbations result in strong responses [*Levermann et al.*, 2009]. The trigger of such a strong response that resulted in a weakened or intermittent northwest Australian monsoon from around 6000 yrs and, again from 2400 to 1300 yrs. B.P., we believe was the onset of modern ENSO periodicities and increase in intensity and/or frequency of ENSO [*Sandweiss et al.*, 2001; *Gagan et al.*, 2004]. Palaeo-environmental evidence from across the tropical Pacific of ENSO forced changes in climate around these times are supported by coupled ocean–atmosphere climate modelling studies [*Liu et al.*, 2000]. ENSO triggers a complex chain of land-ocean–atmosphere interactions that may suppress monsoon activity through disruption of positive moisture-advection feedback. We believe that this occurred in the mid to late Holocene as a result of reduced latent heat flux transfer to the troposphere

over the cooler ENSO west Pacific Warm Pool northwest of Australia [*Webster et al.*, 1998; *Levermann et al.*, 2009].

[15] The breakdown of this primary dynamical forcing of monsoon may have been compounded by increased atmospheric dust loading over northern Australia as shown in our record. Absorption of solar radiation by dust increases atmospheric stability and would have strengthened the elevated subsidence inversion in the subtropical ridge [*Rotstayn et al.*, 2011]. Further positive feedback would come from reduced soil moisture and higher land surface albedo due to vegetation dieback. The associated suppression of convection would reduce onshore moisture advection, thereby increasing aridity. Our research shows that the rapid onset of these conditions in the Kimberley in the mid-Holocene most likely lead to the demise of the Gwion Gwion artists.

[16] Amelioration of the climate around 4600 to 3600 yrs B.P. appears to have attracted Wandjina painters to the Kimberley. Whether these people stayed through the following severe drought from around 2400 to 1300 yrs. B.P is unknown. The charcoal record clearly shows increased presence of fire in the landscape after 1100 yrs B.P. which we infer to reflect increase in Aboriginal population as the summer monsoon re-established. This supports research from elsewhere in Australia showing that change in the frequency and intensity of ENSO underpinned environmental stresses on prehistory Aboriginal populations [*Williams et al.*, 2010]. This is contrary to the conventional view that Australian Aboriginals lived a highly sustainable hunter-gather existence in which their knowledge of the landscape meant they adapted to climate variability with little impact.

5. Conclusions

[17] Here we have shown the first evidence of significant rapid change in the monsoon over northwest Australia during the mid- to late Holocene. This was linked to enhanced ENSO and associated breakdown of positive moisture-advection onto the Kimberley region, thereby allowing the Southern Hemisphere subtropical ridge to extend further north. Palynological and sedimentological evidence from the Black Springs site confirmed that the failure of the monsoon resulted in prolonged aridity coeval with major change in rock art. We conclude that ENSO forced change of the northwest Australian monsoon lead to change in artists of the Kimberley rock art.

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