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# A review of rock art dating in the Kimberley, Western Australia

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ABSTRACT

This paper critically reviews the various approaches used to estimate the age of the rock art in the Kimberley region of Western Australia. They include: (i) the relative superimposition of styles; (ii) the use of diagnostic subject matter (depictions of extinct animals, stone tool technology, introduced European and Asian objects and animals); (iii) the recovery of a 'painted' slab from a dated archaeological unit; (iv) radiocarbon dating of beeswax figures, charcoal pigments, organic matter in overlying mineral deposits and 'accreted paint layers' (oxalate rich crusts and amorphous silica skin), pollen grains from an overlaying mud-wasp nest; and (v) optically stimulated luminescence (OSL) dating of quartz grains from overlying mud-wasp nests. Future directions for rock art dating in the Kimberley include uranium-series dating of overlying and underlying mineral deposits.



## 1. Introduction

Rock art is of unique heritage value and the Kimberley region of Western Australia has one of the greatest concentrations in the world. This archive is of international importance and of particular concern to local Aboriginal people. Given the number and variety of Kimberley rock art styles, the possible time-depth they represent, their potential association with occupation deposits and the amount of ethnographic information available, the region is an ideal place to apply new methods for studying rock art and to develop new techniques for determining its age.

The rock art of this region shows a sequence of distinctive figurative styles depicting changes and continuity in the natural and cultural environment. These include the Wanjina and Gwion Gwion (Bradshaw in earlier publications and known by other Aboriginal names depending on the area and the language spoken) as well as many other art styles. The antiquity of the Gwion Gwion has been the subject of controversy with the notions of Pleistocene aged rock art and non-Aboriginal authorship popularised through the work of Grahame Walsh (e.g. Walsh, 1994, 2000; AAA, 1995; Wilson, 1995; Sunday Program, 1996; Australian Story, 2002). For the Traditional Owners of this region the rock art is a fundamental part of a cultural landscape that was created by the ancestors who remain within Country (e.g. Doring, 2000; Chalarimeri, 2001).

The major problem with use of the Kimberley rock art as a source of scientific information about the past is the lack of a robust chronology (cf. Langley and Taçon, 2010). At present, there are very few numerical dates available to anchor the rock art sequence (Watchman, 1996, 1997; Watchman et al., 1997; A. Watchman, 2000; Roberts et al., 1997; Roberts, 1997, 2000; Morwood et al., 2010). Claims of Pleistocene aged rock art in the Kimberley come from optically stimulated luminescence (OSL) dating of quartz grains from a mud-wasp nest said to be overlying a rock painting (Roberts et al., 1997; Roberts, 1997, 2000), description of 'megafauna' (Akerman, 1998; Akerman and Willing, 2009), and the recovery of a 'painted' slab from a dated archaeological unit (O'Connor and Fankhauser, 2001). This paper is a critical review of rock art dating in the Kimberley region of Western Australia. It is also a review of rock art dating techniques and the issues it raises have relevance for rock art dating worldwide.

## 2. Dating approaches

### 2.1. Style sequence

Relative dating based on the combined evidence of differential weathering and superimposition of distinctive figurative styles is the most widely applied method of estimating the age of Kimberley rock art (e.g. Crawford, 1968, 1977; Welch, 1993a, 1993b, 1993c, 1999; Walsh, 1988, 1994, 2000; Walsh and Morwood, 1999). Stylistic rock art dating is based upon the idea that style is specific to certain times, places, and groups of people (Rosenfeld and Smith, 1997). However, social context may also result in non-temporal stylistic differences and therefore aspects of variation that appear due to temporal factors must be identified and isolated from those

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influenced by social factors (Rosenfeld and Smith, 1997). It is important to stress that relative chronology as such does not provide numerical data but the combination of the two groups of dating approaches (stylistic and numerical) can be used to ask and answer key archaeological questions.

Pleistocene date for Kimberley rock art has been suggested based on interpretations of styles and ethnographic comparisons. The Gwion Gwion art in particular has caught the imagination of people and is often referred to as Pleistocene. While it is true that the usual date cited is the OSL date (see below), this view initially derived from Grahame Walsh's interpretation of the Gwion Gwion figures. His claim was based on his interpretation of the relative age of an identified stylistic group (the Gwion Gwion figures). Because he interpreted these figures as representing a non-Aboriginal group that must have disappeared, and there are hiatuses in occupation in some west Kimberley sites at the end of the Pleistocene, he suggested (Walsh, 1994, 57) that the Gwion Gwion painters must have disappeared at that time. While his interpretation about a non-Aboriginal origin is generally not a view held by archaeologists (e.g. AAA, 1995), it is a view still widely embraced by the public.

### *2.2. Diagnostic subject matter*

The presence and absence of diagnostic subject matter in Kimberley rock art have been used as a chronological tool. The success of this approach is dependent on the positive identification of the diagnostic subject matter and may be prone to issues related to differences in the conceptualisation of the universe on the part of the observer and the creator of rock art.

Depictions of locally extinct animals, notably the Tasmanian tiger (*Thylacinus cynocephalus*) (Akerman, 2009; Walsh, 1994) and the marsupial lion (*Thylacoleo carnifex*) (Akerman and Willing, 2009; Akerman, 1998) have been reported in Kimberley rock art. Given these are known to have become extinct on the Australian mainland at about 3000 years ago (cf. Gale, 2009) and in the late Pleistocene (e.g. Prideaux et al., 2010) respectively, their depiction may provide an estimation of age. Additionally, depictions of dingoes (*Canis lupus dingo*) (Welch, 1993b; Walsh, 1994), a species introduced to Australia about 3500 years ago (Gollan, 1984) are confined to 'recent' parts of the rock art sequence reflecting the relatively late introduction of this animal to Australia. Despite the use of these images for dating, such images can only be considered a potential indication of antiquity, particularly given the frequency with which non-literal art appears and because of the subjective nature of subject matter identification. Consequently, the presence of a marsupial lion image should be considered an interesting stimulus for further investigation rather than proof of Pleistocene aged rock art.

Another example of this dating approach is the suggestion that the 'Clawed Hand' painting style (relatively situated between the Gwion Gwion and the Wanjina in the rock art sequence) (Walsh, 1994) must be of Holocene age, for late panels of this style include depictions of stone spear points that were introduced to the Kimberley in the mid-Holocene (Dortch, 1977; O'Connor, 1996; Veitch, 1996; Walsh and Morwood, 1999). It was also argued that the absence of these stone spear points in some 'Bradshaw' paintings indicate that these paintings were older than the introduction of this technology in the region (Crawford, 1968).

Several European and possibly one Indonesian watercraft depictions have been reported in the Kimberley rock art (cf. O'Connor and Arrow, 2008). An example of these is what appears to be a rowboat with three 'Wanjina-style' figures smoking pipes (Crawford, 1968). These watercraft depictions are thought to be post mid 17th century when Indonesian fishing fleets started sailing to the northern coast of Australia (cf. O'Connor and Arrow, 2008).

### *2.3. Excavation*

Excavation at Carpenter's Gap in the Napier Range has unveiled a 'painted' slab bracketed in time by radiocarbon dates on charcoal from the strata above (33,600 $\pm$ 500 years BP) and below (42,800 $\pm$ 1850 years BP) (O'Connor and Fankhauser, 2001). It is presumed that a fragment of decorated limestone from the cave roof or walls must have fallen to the ground and was subsequently covered by sediments. Description of the slab reports a red substance on two sides and one edge but no mention of iconic representation. The authors have used energy dispersive X-ray analysis (EDXA) to determine the elemental composition of the red substance on the limestone slab and have concluded that it is consistent with that of an ochre. Despite this interesting find, the presence of ochre alone provides no evidence for the use of this substance for artistic expression. Ochre occurs naturally in the geological record and has been observed elsewhere seeping from limestone cave surfaces (e.g. Aubert et al., 2007; Taçon et al., 2012). While a non-local composition for the ochre (O'Connor and Fankhauser, 2001) may suggest anthropogenic transport, a robust interpretation of Pleistocene rock art would require a recognisable motif as ochre was not exclusively used to produce rock art.

### *2.4. Radiocarbon dating*

Accelerator mass spectrometry (AMS) radiocarbon dating was used to date beeswax figures and underlying and overlying paintings (Watchman, 1997; A. Watchman, 2000; Morwood et al., 2010), charcoal pigments (Watchman, 1997; Watchman et al., 1997; A. Watchman, 2000; Morwood et al., 2010), oxalate salts in mineral crust from the base of a pecked cupule (Watchman, 1997; A. Watchman, 2000; Morwood et al., 2010), 'oxalate accreted paint layers' (Watchman, 1997; Watchman et al., 1997; A. Watchman, 2000), carbon-bearing substances in amorphous silica skin overlying a painting and in the 'silicate accreted paint layer' (Watchman, 1996, 1997; Watchman et al., 1997; A. Watchman, 2000); and pollen grains from a mud-wasp nest overlying a painting (Roberts et al., 1997). Principles, assumptions and technical problems of radiocarbon dating are not discussed here but have been reviewed elsewhere (e.g. Elias, 2007). In this paper, radiocarbon years are reported before present (BP), meaning before A.D. 1950. These are not calibrated calendar years but statistical expressions of radiocarbon ratios.

'Beeswax' rock art figures are mainly composed of bees-collected plant resin with a little wax (Morwood et al., 2010). It is generally assumed that only fresh, malleable substances were applied to the rock surface. Therefore, the radiocarbon age of these substances should be close to the time they were produced and subsequently applied to the rock surface. In the Kimberley, they range from modern to 3780 $\pm$ 60 years BP (Watchman, 1997; A. Watchman, 2000; Morwood et al., 2010). Some dated wax pellets were also found overlying and underlying stylistically diagnostic paintings, and thereby provide minimum and maximum ages for these paintings respectively (Morwood et al., 2010).

In the Kimberley, charcoal pigment was sometimes used for painting and drawing. Charcoal is a result of the imperfect combustion of wood, bones, and other organic matter. Radiocarbon dating of charcoal indicates a time since the organic matter ceased exchanging carbon with the biosphere. This time is generally assumed to be the death of the organic matter but this is not necessarily the case. Trees grow by the addition of rings, and these rings stop exchanging carbon with the biosphere once they are laid down. Therefore, if charcoal from long-lived tree species was radiocarbon dated, the difference between the time of growth and the time of death could be up to several hundreds of years. There could also be a significant amount of time between the death of the organic matter, its combustion to charcoal and its subsequent use in a painting or drawing. Radiocarbon age estimates for charcoal pigment in the Kimberley seem to indicate that the associated 'Wanjina-style' figures range from modern to 1210 ± 140 years BP (Watchman, 1997; Watchman et al., 1997; A. Watchman, 2000; Morwood et al., 2010).

Oxalate salts in mineral crust from the base of a pecked cupule (Watchman, 1997; A. Watchman, 2000; Morwood et al., 2010) and two 'oxalate accreted paint layers' were dated using radiocarbon (Watchman, 1997; Watchman et al., 1997; A. Watchman, 2000). In mineral crusts and prehistoric paint, calcium oxalate can be found as hydrated minerals (whewellite and weddellite) within a mixture of other minerals (cf. Watchman et al., 2005). It is assumed that these oxalate minerals are precipitated as a result of microbiological production of oxalic acid, whose carbon is derived from atmospheric sources, which reacts with calcium in the substrate or in aerosols to form calcium oxalate. If this biogeochemical pathway is the only mechanism involved in the production of these oxalate minerals (the microorganisms involved in the production of these oxalate minerals have never been positively identified) and if they are the exclusive source of carbon analysed, radiocarbon dating could indicate the time of oxalate formation (which could be different than the time of crust formation and paint application).

This dating method has been tested at Carpenter's Gap where oxalate rich mineral crusts (not associated with rock art) at the surface of boulders are found buried in a dated stratified sedimentary deposit. After chemical separation of oxalate minerals from the crusts, radiocarbon dating produced age estimates marginally older than the covering sediments (Watchman et al., 2005). In the Kimberley, oxalate salts from three mineral crusts (one at the surface of a pecked cupule and two encapsulating distinct paint layers) were radiocarbon dated. After chemical separation of oxalate minerals, they provided age estimates of 2200 ± 100, 3140 ± 350, and 3880 ± 110 years BP for the associated cupule, 'Irregular Infill', and 'Cane Bradshaw' figures respectively (Watchman, 1997; Watchman et al., 1997; A. Watchman, 2000; Morwood et al., 2010).

Three radiocarbon measurements are also available for carbon-bearing substances in amorphous silica skin overlying a painting and in the 'silicate accreted paint layer'. Measurements of 1490 ± 290 and 1490 ± 50 years BP (duplicates sent to two independent laboratories) are from a layer immediately above the paint containing diatoms and other algal matter with possible unidentified organics. The third sub-sample (1430 ± 180 years BP), is from unidentified organics in silica that encloses the same paint layer and is an average from mostly over, as well as under and in the paint layer (Watchman pers. comm.). That particular sample is shown to be under paint in previous publications (Watchman, 1997; Watchman et al., 1997). These analyses provide minimum age estimates for the associated 'Tassel Bradshaw' figure (Watchman, 1996, 1997; Watchman et al., 1997; A. Watchman, 2000).

Carbon isotopes from four pollen samples from a mud-wasp nest overlying a 'Wanjina-style' painting were also measured for dating. Analysis revealed that two of the samples have ages that are indistinguishable from modern (consistent with optically stimulated luminescence (OSL) age estimate from quartz grains from the same nest). The other two revealed ages of 990 ± 60 and 640 ± 95 years BP and "finely comminuted contaminants are presumably involved" (Roberts et al., 1997, Table 1). The other rock art-associated nests analysed for OSL dating yielded an insufficient quantity of material for radiocarbon dating (Roberts et al., 1997).

There are various factors complicating the radiocarbon dating of rock art. Some of these concern the age of the organic materials when they were put on the wall or incorporated in mineral deposits. Others involve sources of contamination, both in the form of bacteria, algae and other organic activity, or the intrusion of modern or ancient carbon through the activity of environmental factors such as water or wind. Watchman has reviewed the major carbon-bearing components (organic and inorganic) found in rock surface deposits and their typical formation conditions and ages (A.L. Watchman, 2000). It is important to note that if the mineral deposits (and associated rock art) have remained closed systems for carbon and that no contamination occurred in sample extraction and preparation, most of the factors presented above could potentially overestimate the radiocarbon age but not underestimate it. In general, the problems are so severe with radiocarbon dating of rock art that, unless the source of carbon can be identified and isolated prior to analysis, radiocarbon dates on related art and/or associated mineral deposits should be taken as of unknown accuracy.

### 2.5. Optically stimulated luminescence (OSL)

In a pioneering study by Roberts et al. (1997), optically stimulated luminescence (OSL) dating of quartz grains from mud-wasp nests was used to obtain minimum ages for underlying paintings in the Kimberley. Three 'Wanjina-style' paintings were dated in this fashion. The first two dates are from quartz grains sampled from the core of individual nests overlying separate paintings. They provided minimum ages of about 100 and 150 years for these paintings. The age of the third nest is from grains sampled from multiple layers providing a sequence of OSL ages ranging from about 100 to 600 years. Four additional nests were dated: two were not associated with any paintings and the other two (KERC4 and KERC5) are said to be associated with a painting that "may be related to the Bradshaw style" (Roberts et al., 1997, 697).

OSL dating provides an estimation of the time since grains of quartz or feldspar were last exposed to sunlight. The method is based on the time dependent accumulation of trapped electrons in the crystal lattice of these minerals and their proportional discharge once exposed to sufficient light. The time since the last discharge is obtained by dividing the estimated dose acquired by the sample (palaeodose) by the estimated amount it receives per year (environmental dose rate). For more details on the method and its applications see e.g. Aitken (1998) and Elias (2007).

The age of nests KERC4 and KERC5 is of the utmost importance for rock art research in Australia as it implies a Pleistocene antiquity for the 'underlying' painting. Roberts et al. (1997, 697) report that "the residual stump of a heavily cemented, probably *S. laetum*, nest (KERC4) directly overlay the head-dress of a mulberry-coloured human figure (which, in turn, overlay a hand stencil), and this nest thickened laterally into a much larger but similarly indurated nest (KERC5)". Roberts (2000, 48) further reports that "the stump (only 5 mm thick) of a heavily cemented nest (KERC4) directly overlay the head-dress of a mulberry-coloured human figure, and this nest thickened over a distance of 6 cm into a much larger but similarly fossilised nest (KERC5)". These descriptions suggest that the two nests are related but no photos were originally provided although one was subsequently published in Roberts (2000). In this photo, nests KERC5 and KERC4 do not appear to be physically connected and KERC5 is clearly seen several centimetres distant from the painting. The relationship between KERC4 and the painting appears also unclear on the photo, the nest being located at the margin of the paint. Confusion also arises from the fact that in the figure caption KERC4 is mislabelled as KERC5 and vice versa.

Roberts (pers. comm.) considers that the two nests may have been physically connected but remained two distinct nests. He also thinks that only the 'lip' of nest KERC4 (a few millimetres wide and less than a millimetre thick) may have directly overlaid the

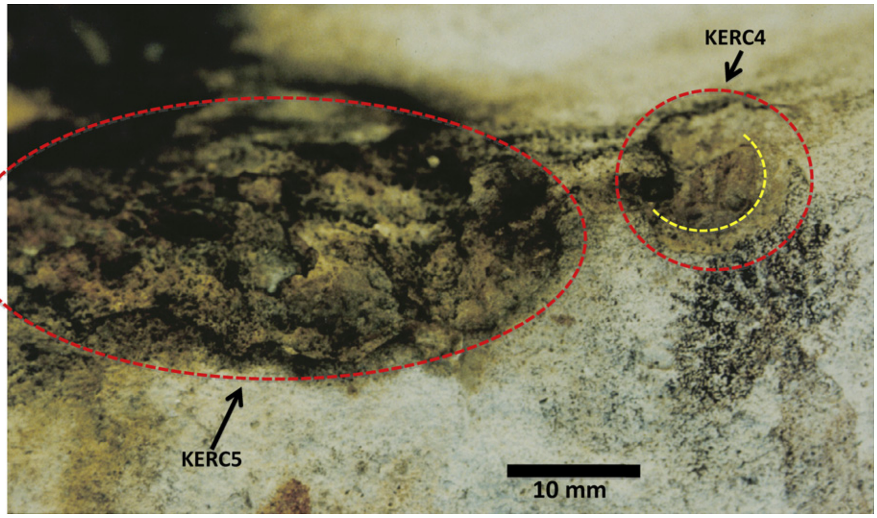


**Fig. 1.** Nests KERC5 and KERC4 collected for OSL dating. Note that KERC5 does not overlie the painting and that KERC4 is located at the margin of the paint. The 'lip' of the nest, where the painting is located (outside of the yellow dot semicircle), was not collected for dating (Photo: Richard Roberts modified by M. Aubert). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

painting. This portion of the nest was not collected as it was too thin to provide suitable grains for dating and its removal could have damaged the painting (Roberts pers. comm.) (Fig. 1).

The OSL age of KERC5 (17,500 ± 1800 years) is unrelated to the painting and was obtained from quartz grains sampled from the core of the nest (i.e. the portion that was attached to the shelter wall). The OSL age of KERC4 comes from quartz grains extracted from the whole nest (minus the portion left on the rock wall). Because of its small size (5 mm thick compared to 20–40 mm for the other nests), nest KERC4 was completely disaggregated and a single-grain approach was devised. This approach was used to distinguish the grains that would have been exposed to modern sunlight on the outer surface of the nest to the grains that would have originated from the assumed light-safe innermost portion of the nest. The single-grain analysis showed two 'populations' of grains: 25% of the grains had small palaeodoses in the range of 0.5–8 Gy and the other 75% were in the range of 14–75 Gy. The first 'population' was discarded as being partially bleached due to their presumed location near the surface of the nest. The remaining grains (33 grains with palaeodoses of 14–56 Gy and three grains with additive-dose palaeodoses of ~75 Gy) showed broad equivalent-dose distributions and the mean values of 21 grains (45 ± 4 Gy) and 15 grains (31 ± 3 Gy) were used in the age calculation resulting in mean ages of 23,800 ± 2400 years (for those measured with additive-dose protocol) and 16,400 ± 1800 years (for those measured with regenerative-dose protocol) respectively. The oldest age is influenced by the inclusion of the three grains with palaeodoses of ~75 Gy; their omission would reduce the mean age to ~21,200 years (Roberts, 1997). Because of the paucity of mud available, the nest-derived dose rate for KERC4 could not be measured and is assumed to be the same as that determined for KERC5.

The OSL dating method applied to mud-wasp nests was an innovative and promising avenue for rock art dating. However, in order to accurately date rock art with this approach, the relationship between the OSL dated quartz grains and the art needs to be clearly demonstrated. This is further complicated by the observation that mud-dauber wasps prefer to build nests near existing nests and on the stumps of abandoned nests, rather than on a bare rock surface (Naumann, 1983; Waterhouse, 1991). Also, it appears that this method is best suited to large nests where grains can be extracted from the nest core. Whether or not the Kimberley has Pleistocene aged rock art remains debatable and requires additional dated motifs.

## 3. Future directions

Natural calcite laminations and amorphous silica skins underlying and overlying rock paintings and petroglyphs have been observed in the Kimberley landscape and can provide estimates of the maximum and minimum ages of pigment layers and petroglyphs using high-resolution uranium-series dating methods. This is possible because the sub-millimetre-thick laminations can now be precisely and accurately studied, chemically and isotopically analysed, and dated at extraordinary and unprecedented spatial and temporal resolutions using multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS) (Aubert et al., 2007; Taçon et al., 2012). This has so far never been applied to Australian rock art sites but is the focus of a novel Kimberley rock art dating program financed by the Australian Research Council.

The viability of this approach to date finely layered calcite deposits has recently been demonstrated, where only micrograms of samples are needed (Aubert et al., 2007; Taçon et al., 2012). Calcite coatings are formed from the deposition of dissolved calcium bicarbonate from saturated solution. Because $^{238}U$ and $^{234}U$ isotopes are soluble in aqueous solutions but $^{230}Th$ is not, calcium carbonate ($CaCO_3$) crystals precipitated in calcite coatings will initially not contain any $^{230}Th$. Subsequently, $^{234}U$ will decay to $^{230}Th$. The measurement of the $^{230}Th$, $^{238}U$, and $^{234}U$ isotopes allows calculation of the age of the carbonate host because the decay rate is known (Bourdon et al., 2003).

Hydrated amorphous silicon dioxide ($SiO_2.nH_2O$), or opal-A, is deposited naturally from seepage and runoff water as white or brown rock surface coatings, called 'skins' (Watchman, 1996). Uranium-series analysis of pedogenic silica coating pebbles shows that these silica skins are well suited for this dating method (Ludwig and Paces, 2001), but as yet this has never been applied to rock art dating.

## 4. Conclusions

The Kimberley rock art is part of an important cultural, natural and economic landscape and its accurate dating would have significant implications for the region. Having reviewed all the scientific literature available on the subject, we are forced to conclude that, at the moment, there is no substantial evidence to support a Pleistocene age for the rock art. Cutting-edge rock art dating methods, such as high-resolution uranium-series and compound-specific radiocarbon, are needed and should provide an enhanced understanding of the status, importance and spread of rock art traditions as well as providing crucial information for the conservation and management of Australia's indigenous cultural heritage.

The problem of rock art dating is one experienced by researchers around the world and the particular problems identified with the techniques discussed here are universal and have implications for rock art dating worldwide.

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## References

AAA, 1995. Press release, Australian Archaeological Association, 6 December 1995.
Aitken, M.J., 1998. An Introduction to Optical Dating: the Dating of Quaternary Sediments by the Use of Photon-stimulated Luminescence. Oxford University Press, Oxford.
Akerman, K., 1998. A rock painting, possibly of the now extinct marsupial *Thylacoleo* (marsupial lion), from the north Kimberley, Western Australia. The Beagle, Records of the Museum and Art Gallery of the Northern Territory 14, 117–121.
Akerman, K., 2009. Interaction between humans and megafauna depicted in Australian rock art? Antiquity 83 (322). http://antiquity.ac.uk/projgall/akerman322/.
Akerman, K., Willing, T., 2009. An ancient rock painting of a marsupial lion, *Thylacoleo carnifex*, from the Kimberley, Western Australia. Antiquity 83 (319). http://antiquity.ac.uk/projgall/akerman319/.
Aubert, M., O'Connor, S.M., McCulloch, M.T., Mortimer, G., Richer-LaFlèche, M., 2007. Uranium-series dating rock art in East Timor. Journal of Archaeological Science 34, 991–996.
Australian Story, 2002. Australian Story: Rock Heart (ABC TV Broadcast 14 October 2002). Australian Broadcasting Corporation, Sydney.
Bourdon, B., Turner, S.P., Henderson, G.M., Lundstrom, C.C. (Eds.), 2003. Uranium-series Geochemistry. Reviews in Mineralogy and Geochemistry 52.
Chalarimeri, A.M., 2001. The Man from the Sunrise Side. Magabala Books, Broome W.A.
Crawford, I.M., 1968. The Art of the Wandjina. Oxford University Press, London.
Crawford, I.M., 1977. The relationship of Bradshaw and Wandjina art in north-west Kimberley. In: Ucko, P.J. (Ed.), Form in Indigenous Art. Australian Institute of Aboriginal Studies, Canberra, pp. 357–369.
Doring, J. (Ed.), 2000. Gwion Gwion: Secret and Sacred Pathways of the Ngarinyin Aboriginal People of Australia. Konemann, Koln.
Dortch, C., 1977. Early and late industrial phases in Western Australia. In: Wright, R.V.S. (Ed.), Stone Tools as Cultural Markers. Australian Institute of Aboriginal Studies, Canberra, pp. 104–132.
Elias, S.A. (Ed.), 2007. Encyclopedia of Quaternary Science. Elsevier Scientific Publishing, Amsterdam.
Gale, S.J., 2009. Event chronostratigraphy: a high-resolution tool for dating the recent past. Quaternary Geochronology 4, 391–399.
Gollan, K., 1984. The Australian dingo: in the shadow of man. In: Archer, M., Clayton, G. (Eds.), Vertebrate Zoogeography and Evolution in Australasia. Hesperian Press, Western Australia, pp. 921–928.
Langley, M., Taçon, P.S.C., 2010. The age of Australian rock art: a review. Australian Archaeology 71, 70–73 (and supp. online info.).
Ludwig, K.R., Paces, J.B., 2001. Uranium-series dating of pedogenic silica and carbonate, Crater Flat, Nevada. Geochimica et Cosmochimica Acta 66, 487–506.
Morwood, M.J., Walsh, G.L., Watchman, A., 2010. AMS radiocarbon ages for beeswax and charcoal pigments in north Kimberley rock art. Rock Art Research 27 (1), 3–8.
Naumann, I.D., 1983. The biology of mud nesting Hymenoptera (and their associates) and Isoptera in rock shelters of the Kakadu region, Northern Territory. In: Gillespie, D. (Ed.), The Rock Art Sites of Kakadu National Park and Some Preliminary Research Findings for their Conservation and Management. In: Special Publication, vol. 10. Australian National Parks and Wildlife Service, Canberra, pp. 127–189.
O'Connor, S., 1996. Thirty thousand years in the Kimberley: results of excavations of three rockshelters in the coastal west Kimberley, W.A. In: Veth, P., Hiscock, P. (Eds.), Archaeology of Northern Australia. In: Tempus, vol. 4. Anthropology Museum, University of Queensland, Brisbane, pp. 26–49.
O'Connor, S., Fankhauser, B., 2001. Art at 40000 bp? One step closer: an ochre covered rock from Carpenter's Gap Shelter 1, Kimberley region, Western Australia. In: Anderson, A., Lilley, I., O'Connor, S. (Eds.), Histories of Old Ages. Essays in Honour of Rhys Jones. Pandanus Books, Australian National University, Canberra, pp. 287–300.
O'Connor, S., Arrow, S., 2008. Boat images in the rock art of northern Australia with particular reference to the Kimberley, Western Australia. In: Islands of Inquiry: Colonisation, Seafaring and the Archaeology of Maritime Landscapes. In: Terra Australis, 29. Australian National University.
Prideaux, G.J., Gully, G.A., Couzens, A.M.C., Ayliffe, L.K., Jankowski, N.R., Jacobs, Z., Roberts, R.G., Hellstrom, J.C., Gagan, M.K., Hatcher, L.M., 2010. Timing and dynamics of Late Pleistocene mammal extinctions in southwestern Australia. Proceedings of the National Academy of Sciences of the United States of America 107, 22157–22162.
Roberts, R., 1997. Luminescence dating in archaeology: from origins to optical. Radiation Measurements 27 (5/6), 819–892.
Roberts, R., 2000. Luminescence dating of Kimberley rock art. In: Walsh, G. (Ed.), Bradshaw Art of the Kimberley. Takarakka Nowan Kas Publications, Kenmore QLD, pp. 46–49.
Roberts, R., Walsh, G.L., Murray, A., Olley, J., Jones, R., Morwood, M.J., Tuniz, C., Lawson, E., Macphail, M., Bowdery, D., Naumann, I., 1997. Luminescence dating of rock art and past environments using mud-wasp nests in northern Australia. Nature 387, 696–699.
Rosenfeld, A., Smith, C., 1997. Recent developments in radiocarbon and stylistic methods of dating rock art. Antiquity 72 (272), 405–411.
Sunday Program, 1996. The Sunday Program (Broadcast 16 December 1996). Nine Television Network, Sydney.
Taçon, P.S.C., Aubert, M., Gang, L., Decong, Y., Hong, L., May, S.K., Fallon, S., Xueping, J., Curnoe, D., Herries, A.I.R., 2012. First uranium-series minimum and maximum age estimates for rock art in China. Journal of Archaeological Science 39, 492–499.
Veitch, B., 1996. Evidence for mid-Holocene change in the Mitchell Plateau, northwest Kimberley, Western Australia. In: Veth, P., Hiscock, P. (Eds.), Archaeology of Northern Australia. In: Tempus, vol. 4. Anthropology Museum, University of Queensland, Brisbane, pp. 66–89.
Walsh, G.L., 1988. Australia's Greatest Rock Art. E.J. Brill/Robert Brown and Associates, Bathurst.
Walsh, G.L., 1994. Bradshaws: Ancient Paintings of North-west Australia. Carouge, Geneva.
Walsh, G. (Ed.), 2000. Bradshaw Art of the Kimberley. Takarakka Nowan Kas Publications, Kenmore QLD.
Walsh, G.L., Morwood, M.J., 1999. Spear and spearthrower evolution in the Kimberley region, N.W. Australia: evidence from rock art. Archaeology in Oceania 34 (2), 45–59.
Watchman, A., 1996. Properties and Dating of Silica Skins Associated with Rock Art. Unpublished PhD thesis, the University of Canberra.
Watchman, A., 1997. Dating the Kimberley rock paintings. In: Kenneally, K.F., Lewis, M.R., Donaldson, M., Clement, C. (Eds.), Aboriginal Rock Art of the Kimberley. The Kimberley Society, Perth, pp. 39–45.
Watchman, A., 2000. AMS $^{14}C$ dating of Kimberley rock paintings. In: Walsh, G. (Ed.), Bradshaw Art of the Kimberley. Takarakka Nowan Kas Publications, Kenmore QLD, pp. 38–41.
Watchman, A.L., 2000. A review of the history of rock varnish dating. Earth Science Reviews 49, 261–277.
Watchman, A., Walsh, G.L., Morwood, M.J., Tuniz, C., 1997. AMS radiocarbon age estimates for early rock paintings in the Kimberley, N.W. Australia: preliminary results. Rock Art Research 14 (1), 18–26.
Watchman, A., O'Connor, S., Jones, R., 2005. Dating oxalate minerals 20–45 ka. Journal of Archaeological Science 32, 369–374.
Waterhouse, D.F., 1991. The Insects of Australia: a Textbook for Students and Research Workers, second ed. Melbourne Univ. Press, pp. 221–235.
Welch, D., 1993a. Early 'naturalistic' human figures in the Kimberley, Australia. Rock Art Research 10, 24–37.
Welch, D., 1993b. The early rock art of the Kimberley, Australia: developing a chronology. In: Steinbring, I., Watchman, A. (Eds.), Time and Space. In: Occasional AURA Publication 8. Australian Rock Art Research Association, Melbourne, pp. 13–21.
Welch, D., 1993c. Stylistic change in the Kimberley rock art, Australia. In: Lorblanchet, M., Bahn, P. (Eds.), Rock Art Studies: the Post Stylistic Era, or Where Do We Go from Here? In: Oxford: Oxbow Monograph 35, pp. 99–113.
Welch, D.M., 1999. Cultural change in the Kimberley rock art, Western Australia. Bollettino del Centro Camuno di Studi Preistorici 31–32, 288–312.
Wilson, R., 1995. Mystery race claim sparks controversy. Weekend Australian (16 December 1995).