

# Cation-ratio dating of rock-engravings from the Olary Province of arid South Australia

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*Desert varnish, the distinctive coating on exposed rock surfaces in arid regions, can be dated by cation ratios, providing a rare means directly to date petroglyphs. A first application of the method, much used in north America, is here reported from Australia, where it indicates minimum ages up to 30,000 years old. And it also shows that the style of figures, so often taken as a measure of chronology, is in this instance largely independent of age.*

Surface artefacts, petroglyphs and ground drawings constitute a common form of evidence of occupation in arid Australia, and other desert regions (Binford *et al.* 1980; Maynard 1979; Bettinger 1982; Rosenfeld 1982). Unless the artefact is made of obsidian, or unless there is an unusual circumstance where the rock-engraving is in direct contact with datable material (cf. Butzer *et al.* 1979; Dragovich 1986; Guidon & Delibrias 1986), the vast majority of these cultural features have not been datable until recently. The rock varnish that coats exposed surfaces of archaeological material, as well as Quaternary geomorphological surfaces, can be dated by relatively new methods. We report here the first cation-ratio (CR) dates on rock varnishes formed on engravings outside of North America, in the Olary Province of South Australia (FIGURE 1). The 24 radiocarbon-calibrated ages presented here represent the first results of a long-term project to date rock-art in arid Australia. These results are preliminary in that the varnish CRs at the Karolta site, South Australia, require more radiocarbon calibration points for greater certainty, and that the CR dating method is being refined continuously.

## Cation-ratio dating of rock varnish on petroglyphs

Basedow observed in 1914 that older petroglyphs in the arid region of Australia are covered with a coating of rock varnish. Later, its composition was determined to be manganese- and iron-oxides, clay minerals (Potter & Rossman 1979) and a suite of trace elements (Dorn & Oberlander 1982). The deposition and cementation of rock varnish is catalysed by manganese- and iron-oxidizing micro-organisms (Krumbein & Jens 1981; Dorn & Oberlander 1982; Palmer *et al.* 1985).

The age-determination of rock-engravings by rock varnish is based on the premise that the varnish starts to form soon after the petroglyph is engraved. Dating the rock varnish, therefore, provides a minimum-limiting age for the exposure of the underlying petroglyph. How closely the age of the varnish reflects the age of exposure has been tested. Although Dragovich (1986) correctly points out that the onset of varnishing on petroglyphs could be delayed by an uncertain period of time, scanning electron microscope (SEM) observations of historic engravings at the Karolta site (FIGURE 1) examined in this study indicate the time-lag between

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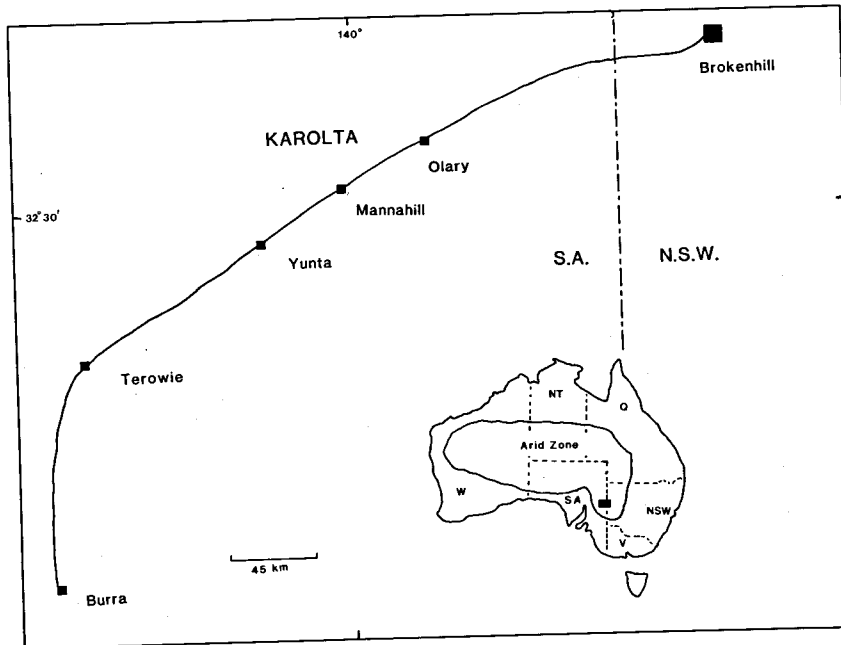


FIGURE 1. Location of the Karolta site in arid South Australia.

the engraving of the rock and the onset of varnishing is about 100 years (FIGURE 2a). About 60–100 years is typical for the time-lag of varnish formation in the arid western United States (Dorn & Whitley 1984; Dorn, unpublished data).

It is possible to date the rock varnish by knowing the age of the underlying geomorphic surface, such as a K-Ar-dated basalt flow or an erosional shoreline of a prehistoric lake dated by conventional radiocarbon methods. Alternatively, the rock varnish can be radiocarbon dated directly by accelerator mass spectrometry (AMS) analysis (Jull *et al.* 1986) of organic matter extracted from the lowest layer in the varnish. The organic matter in varnish is concentrated by removing the non-organic components by HCl, HF, dithionite, and hydroxylamine hydrochloride (Dorn *et al.* 1986). What remains for analysis by AMS is mostly plant detritus and organic matter reworked by varnish-forming micro-organisms (Dorn & DeNiro 1985).

Radiocarbon dating of varnish on the engravings, unfortunately, is not possible at this time. The surface area of varnish on most petroglyphs is far too small to accumulate enough organic matter for even AMS analysis. A minimum of 1/10th of a square metre of surface is required for AMS radiocarbon dating of varnish, and

sometimes over a square metre. That is why the indirect method of cation-ratio dating is used.

Cation-ratio (CR) dating of petroglyphs is based on calibrating the chemistry of varnishes with the known ages of the underlying geomorphic surfaces. The elemental ratio of (K+Ca)/Ti in varnish is calibrated by numerical ages (dating terminology from Colman *et al.* 1987) that are provided by K-Ar, conventional radiocarbon, AMS radiocarbon, or other methods. AMS radiocarbon-dating of varnish is used in this study because no conventional dates on geomorphic surfaces were available in the study area. CR dating is the only procedure known at present of estimating the ages of most rock-engravings. CR dating can also be used to estimate the minimum ages of artefacts exposed at the surface in arid regions (Dorn *et al.* 1986).

CR dating is based on empirical observations that certain cations (such as calcium, potassium and sodium) are more mobile in the terrestrial weathering environment than cations such as titanium and zirconium (Marchand 1974; Yaalon *et al.* 1974; Colman 1982). The particular cation-ratio used, potassium plus calcium divided by titanium (K+Ca)/Ti, was selected because it produces the best correlations with known age, and microgram samples of varnish can be accurately and precisely measured for this CR by the particle-induced X-ray excitation

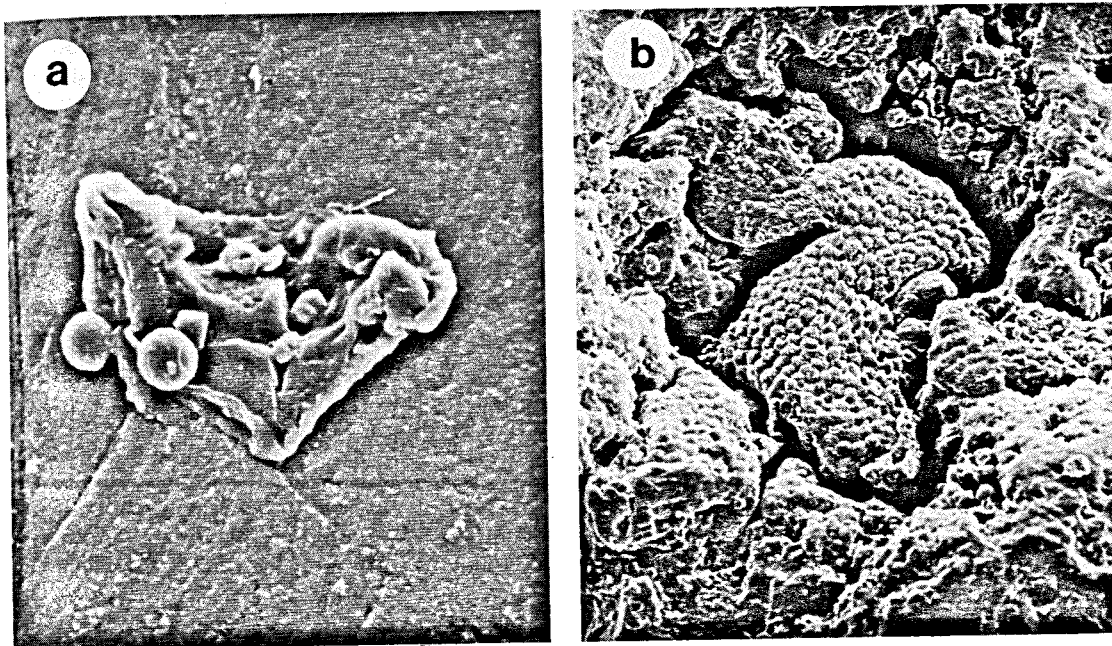


FIGURE 2. Scanning electron micrographs of rock varnish at Karolita.

a Varnish on 1884 inscription at Karolita. Since no varnish was found on a 1930 inscription, varnishing probably starts between 50 and 100 years at Karolita. This lag time is similar to findings for the deserts in southwestern North America (Dorn & Whitley 1984; Dorn, unpublished data).

b Microcolonial fungi (cf. Taylor-George et al. 1983; Staley et al. 1983) at Karolita, eroding a bioetch pit into varnish. Microcolonial fungi were avoided in sampling; paleo-pits from microcolonial fungi were avoided by SEM and optical thin-section analyses of cross-sections (e.g. Dorn et al. 1987a).

method (PIXE) (Cahill 1980; Cahill et al. 1984). On Quaternary surfaces of known relative age, the CR of  $(K+Ca)/Ti$  declines with age. Even though new K and Ca are added continuously, there is a net decrease with time. When the CR is correlated with established ages, provided by numerical dating methods, a semilog relationship (called a cation-leaching curve, or CLC) has been found, where the CR is on a linear scale and age is logarithmic (Dorn 1983; Dorn et al. 1987a; Glazovskiy 1985; Harrington & Whitney 1987). CLCs have been established for 10 areas in southwestern North America. (Dorn, in preparation). FIGURE 3 illustrates the sequence of steps in cation-ratio dating.

We present here the first CLC for an area outside of North America (FIGURE 4), and use it to assign limiting-minimum ages to rock varnish on petroglyphs. The CLC at Karolita in FIGURE 4 is roughly similar to the North American curves, but it has a steeper slope that reflects

a faster rate of leaching the mobile cations and a slightly higher initial cation ratio. The higher initial ratio probably reflects the chemistry of the aerosols deflated from soils in the area. The steeper slopes may be from the summer precipitation at Karolita. The steepest curves (west Texas, USA and Pinacate, Mexico) in North America are both in areas where summer precipitation is important, as in the Olary region of South Australia. The other curves, as for the Coso Range, eastern California where previous petroglyph dating work was completed (Dorn & Whitley 1984) are in areas of mostly cold-season precipitation at present. Faster removal of the more mobile potassium and calcium may be from moisture being available at higher temperatures, at least during the Holocene, if not during the late Pleistocene as well. (cf. Spaulding & Graumlich 1986).

A substantial uncertainty with the CR dating of varnish on petroglyphs revolves around

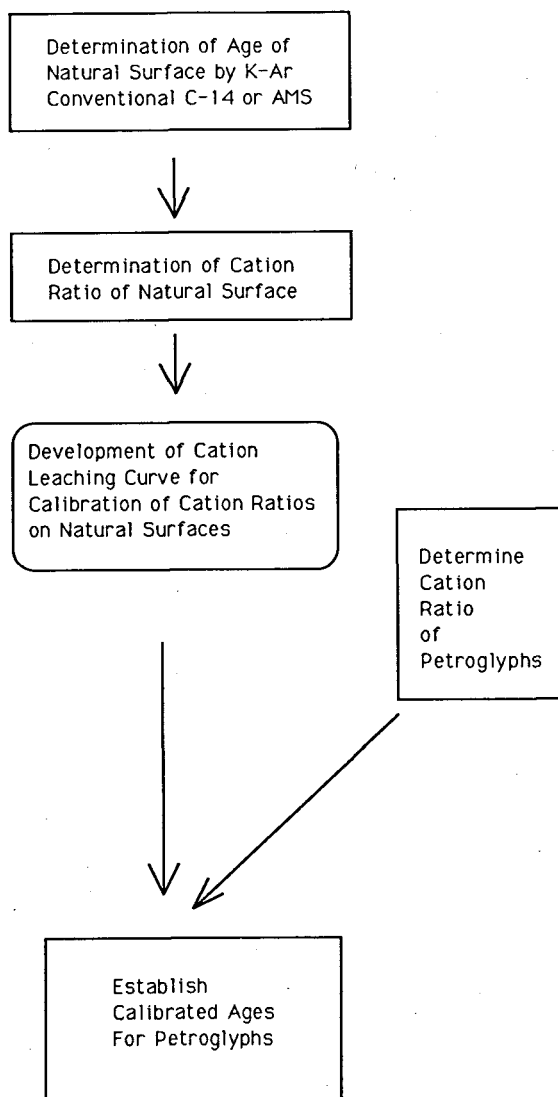


FIGURE 3. Steps in assigning a radiocarbon-calibrated cation-ratio date to a rock engraving.

assessing the accuracy of the numerical method used to calibrate the cation-ratios, in this case AMS  $^{14}\text{C}$  dating of varnish. In tests of radiocarbon dating of varnish where the conventional radiocarbon age is known, the varnish age has been found to be about 10% younger (Dorn *et al.* 1987b; Dorn, Jull *et al.*, unpublished data). This lag is to be expected since the AMS radiocarbon date is of the lowest layer in varnish. This layer formed over a period of time after the exposure

of a surface. To correct for this effect, 10% has been added back to the radiocarbon calibrations in TABLE 1. The cation-ratio dates reported here for the petroglyphs are based on the radiocarbon dates corrected for this net lag. This correction may be refined slightly by on-going tests, as in any developing dating method, but we feel the correction will probably not change substantially.

A second major uncertainty involves the mechanics of CR changes. The assumptions and limitations of CR dating are elaborated more fully in Dorn (1983), and Dorn *et al.* (1986; 1987a; 1987b). Since CR changes in varnish involve biological and geochemical processes, they are subject to environmental effects (Dorn 1983; Dorn *et al.* 1987a). Great care, therefore, has been taken in sampling and sample processing to insure that the varnishes at the calibration sites yield CRs that are comparable to the varnish CRs at the petroglyph sites. For example, the microcolonial fungi that are common in Australia (Staley *et al.* 1983) can erode varnish (see FIGURE 2B; also Dorn 1986). Microcolonial fungi, and other sources of CR anomalies (see Dorn *et al.* 1987a), were avoided in this study because erosion of varnish would invalidate a comparison of CRs. Microcolonial fungi and other microenvironmental effects were avoided in this study.

The CR ages of 24 motifs at the Karolita site (TABLE 1) are based on the CLCs in FIGURE 4. These curves are developed by calibrating rock varnish CRs on natural geomorphic surfaces by the corrected radiocarbon dates of the onset of varnish formation. The central CLC is a semilog least-squares regression of the mean AMS radiocarbon dates (with 10% correction) and the mean varnish CRs:

$$Y = 15.27 - 2.36 \log_{10} X \quad (1)$$

Central curve where  $X$  is radiocarbon years b.p. and  $Y$  is the  $(\text{K} + \text{Ca})/\text{Ti}$  ratio of the varnish. The central curve was used to assign the mean petroglyph dates in TABLE 1, using the average of three separate CR age-estimates for three different PIXE analyses, each of distinct varnish samples of a petroglyph.

Two types of dating errors are listed in TABLE 1. The 1 standard error (SE) for the date is based on the standard error of the three separate CR ages. This error reflects variations in estimates using only the central regression. The most conservative error (Extreme Error listed in

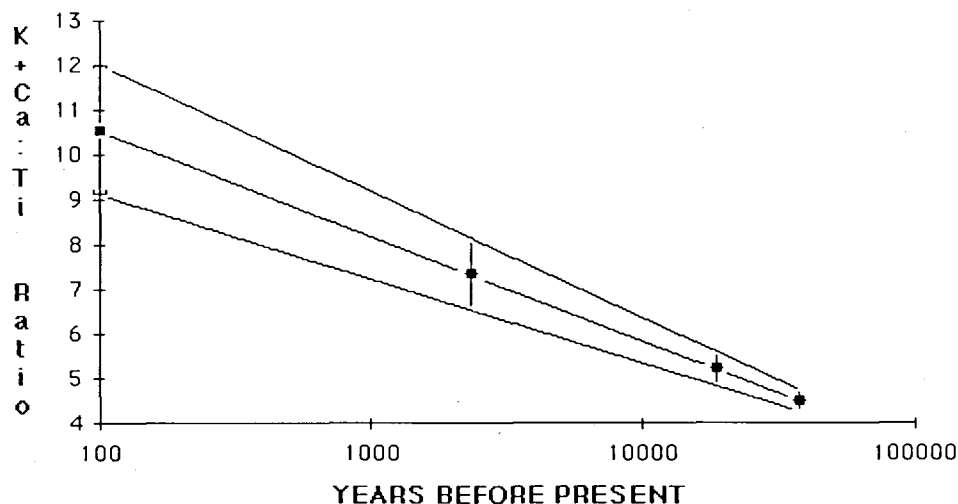


FIGURE 4. Cation-leaching curve for the Karolita rock-engraving site. The 100-yr-old calibration point comes from an average of the (K+Ca)/Ti ratio of the  $t > 2$  micron fraction of aeolian fallout collected at the engraving sites and the calibration locales. Based on previous work (Dorn 1983; Dorn et al. 1987a), this ratio approximates the initial ratio for rock varnish. The three older calibration points were collected from an alluvial fan and the hillslope at Oulnina Bluff, near Mannahill (FIGURE 1).

Horizontal bars represent 2 sigma age-uncertainties; vertical bars represent 2 sigma cation-ratio uncertainties. Each CR in this calibration represents the average of 5 PIXE analyses of varnish from that calibration site. The central and 2 sigma error least-squares regressions are discussed in the text.

TABLE 1) is obtained by using 2 SE for the 3 varnish CRs of a single petroglyph and the upper and lower 2 sigma error curves in FIGURE 4. The upper and lower curves were generated empirically by least-squares regressions of data points of the  $+2SE$  of the CRs and  $+2SE$  of the radiocarbon dates for an upper curve:

$Y = 17.71 - 2.86 \log_{10} X$  (2) Upper curve  
and  $-2SE$  of the CRs and radiocarbon dates for a lower curve:

$Y = 12.85 - 1.85 \log_{10} X$  (3) Lower curve

By using equations 2 and 3, errors are empirically estimated with a 95% confidence interval. It is likely that the Extreme Errors in TABLE 1 will be enlarged slightly in technique refinements. For example, as the 10% correction (for the difference between AMS radiocarbon date and the onset of varnishing) is refined, it will have a  $\pm$  that would be added to the analytical error for each AMS radiocarbon calibration.

#### Results at Karolita

The site from which 24 randomly selected petroglyphs were sampled is Karolita (FIGURE 1). It is one of the major petroglyph locales in

the Olary region of arid South Australia (Nobbs 1984). Dolomitic siltstone (Campana & King 1958) is the preferred lithology for rock-engravings in the region. Karolita was selected for study for historical reasons as it was the first site reported in South Australia, and because over 1800 motifs have been documented (Nobbs 1984).

Varnishes on petroglyphs were scraped in the field with a tungsten-carbide needle. The scrapings were cleaned of rock contamination in the laboratory by nucleopore filters. The quantitative chemical and volumetric contamination is estimated here at less than 3% by methods noted in Dorn et al. (1987a). We note that the damage done to a petroglyph by the sampling procedure is minimal. The location of varnish removal can be detected by a close inspection only after the sampled area is pointed out. It can be further argued that this scraping only returns the rock-engraving to its original, unvarnished condition. As noted above, 3 separate samples are collected for three different 3 PIXE analyses (Cahill 1980; Cahill et al. 1984).

**Calibration data**

materials	corrected date	cation ratio	uncorrected AMS date
Initial ratio	100	10.54±0.77	—
Small fan	2330	7.43±0.18	2120±150 (ETH-2804; Beta-19888)
Bluff slope	23,700	4.93±0.11	21,550±240 (ETH-2941; Beta-20569)
Bluff slope	38,000	4.51±0.12	34,590±560 (ETH-2940; Beta-20568)

**Petroglyph age-estimates**

petroglyph	average cation ratio	average of 3 CR PIXE dates	2 sigma extreme error range
K-13	7.89±0.22	1400± 300	350– 3300
K-6	7.40±0.20	2250± 500	700– 4800
K-5	6.63±0.18	4700± 850	1900– 8700
K-17	6.47±0.16	5600± 825	2300– 9800
K-8	6.45±0.16	5675± 850	2400–10,000
K-15	6.18±0.19	7400±1400	3200–12,700
K-14	5.97±0.15	9100±1300	4400–14,500
K-16	5.86±0.15	10,100±1400	5050–15,800
K-9	5.82±0.17	10,500±1700	5200–16,700
K-24	5.73±0.17	11,500±1900	5800–17,900
K-2	5.71±0.17	11,700±2000	5900–18,200
K-4	5.44±0.14	15,200±1950	8600–22,100
K-20	5.38±0.15	16,200±2450	9200–23,400
K-11	5.22±0.17	19,000±3050	10,100–27,000
K-19	5.19±0.15	19,600±2750	11,700–27,200
K-18	5.18±0.14	19,700±2700	12,000–27,200
K-10	5.11±0.17	21,200±3750	12,600–29,500
K-12	4.98±0.13	23,900±2900	15,500–31,700
K-22	4.94±0.15	24,800±3650	15,900–33,300
K-3	4.91±0.14	25,600±3500	16,700–33,900
K-21	4.90±0.14	25,900±3600	16,900–34,100
K-1	4.77±0.15	29,300±4100	19,700–38,200
K-7	4.73±0.13	30,600±3400	21,200–38,800
K-23	4.69±0.12	31,700±3700	22,500–39,800

TABLE 1. Calibration data for cation-leaching curve and cation-ratio dates on rock-engravings at Karolta, Olary Province, South Australia. The CR date reported for each petroglyph is an average (and 1SE error) of three CR dates determined by the three PIXE CRs on three separate varnish samples. They are quite similar to the CR dates that are based on first an averaging of the CRs and then a comparison with equation 1. (These are noted in FIGURE 5). All uncertainties are ±1 standard error, except where noted. All dates reflect radiocarbon years before present, either directly or by calibration, except the initial ratio which is based on an engraving with a calendar date.

The distribution of ages, from c. 1400 b.p. to c. 31,700 b.p. in TABLE 1, suggests that humans used the arid Olary Province in a more-or-less continuous fashion for at least the past c. 31,700 radiocarbon years. Basedow (1914) had thought that the engravings in the Olary region were very old and were made in a fairly short

time span. Given recent studies of the antiquity of humans in Greater Australia at about 40,000 b.p. (Groube *et al.* 1986) and in arid Australia at c. 22,000 b.p. (Smith 1987), the antiquity of petroglyphs found here should not be surprising. These age-estimates push back the use of arid Australia by about 8000–9000 radiocar-

bon years. Even with the extreme 2 sigma younger errors, the oldest CR dates indicate an age similar to Smith's radiocarbon analyses.

The range of CR dates for the engravings, randomly selected at Karolta, was surprising to us. Potential systematic errors in the CR dating method, however, cannot explain this range, as any errors would tend to make the ages more uniform. For example, if the varnishes had experienced an erosional episode, the CRs and radiocarbon dates would be similar: they would mark only the onset of varnishing after the last erosional period. The range of CRs and radiocarbon dates indicates this is not the case.

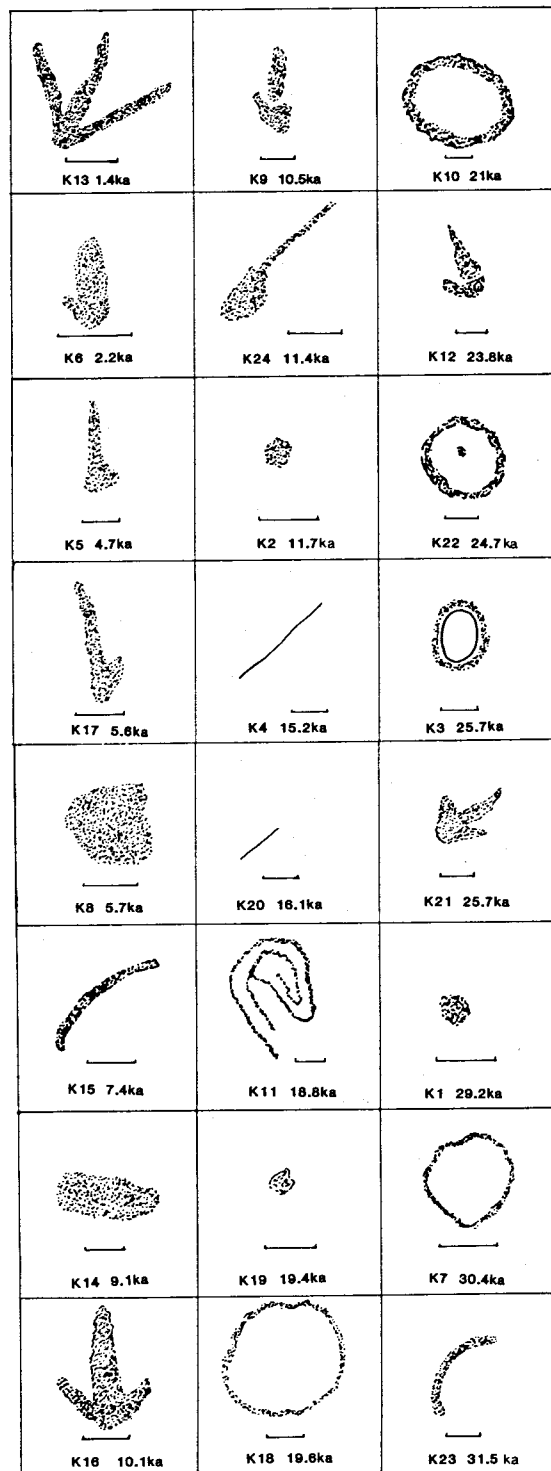
Internal tests of the accuracy of the calibrated-ages were conducted by sampling varnishes from outcrop surfaces that were not engraved at the Karolta site. These control samples yielded CRs much lower (older) than the varnish in the engravings. If the CLC in FIGURE 4 is extended beyond the last calibration point (a questionable procedure, but useful here for illustrative purposes) the CRs would yield ages of around 60,000 b.p. The CRs of the non-engraved varnish might represent the time when the dolomitic siltstone outcrops were last exposed to varnishing by erosion of the overlying material. Another test was to use superimposition of the petroglyphs. What little superimposition does occur at Karolta is consistent with the CR trends. For example, K5 (macropod track in FIGURE 5) at c. 4800 b.p. was engraved over K4 (abraded groove) at c. 15,200 b.p.

**Style and dates at Karolta**

In order to relate the CR calibrated-ages to the sampled engravings, the 'style' of the motifs in FIGURE 5 should be outlined. The simple geometric and non-figurative (e.g. lizards) designs at Karolta can be placed into six rough categories: tracks; circles; lines; dots;

FIGURE 5. Karolta rock-engravings dated by cation-ratio analysis, arranged according to age-estimate in thousands of years b.p. The age-estimates are based on the mean CR in TABLE 1 as compared to the mean cation-leaching curve in equation 1 and FIGURE 4. They differ slightly from the central estimate in TABLE 1, which is an average of 3 CR estimates of the 3 separate PIXE analyses for varnish cation-ratios.

Scale bars 5 cm.



'abstract' designs; and abraded grooves (Nobbs 1984). A distinct arrangement of motifs can be seen on some panels. For example, K21 is one of a line of six 'bird' tracks, crossed at nearly a right angle by another set of seven identical 'bird' tracks; both lines point away from a group of dots. Although speculative, it is possible that this reflects emus leaving their nest. At an age of about 26,000 b.p. the person(s) who engraved K21 appears to have had a clear perception of time, space and the nature of things. Another subjective observation is that the technique used to manufacture the motifs appears to be skillful and uniform. It is unlikely that the technique in the older motifs developed overnight. We therefore hypothesize the presence of still older petroglyphs in the region. Future work will investigate this possibility.

The 'style' of the engravings at Karolta appears to have changed little over time. All categories of style but one are present over the c. 30,000 year record. The exception is the abraded groove; the two samples of abraded groove came from separated outcrops but they have a similar age of 16,000 b.p. and 15,000 b.p. Given the limited sample set, however, it

is not possible to assess whether the abraded grooves were manufactured only during this relatively short time span.

The absence of substantial change in the style of the engravings at Karolta is similar to continuities observed in southern Africa (Lewis-Williams 1984), in the eastern Mojave Desert, USA, for the so-called 'curvilinear' style; (Whitley & Dorn 1987) and for the bighorn sheep 'representational' style of the Coso Range, USA (Dorn & Whitley, unpublished data). The notion that style necessarily changes with time is a common assumption. The general validity of the style concept of petroglyph interpretation may require a re-evaluation. Perhaps subtle changes can be detected with subsequent analyses. However, it is clear that gross changes in the patterns of the motifs have not been indicative of age at many sites studied thus far with age control from North America, southern Africa and now central Australia.

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