The absolute age of the Côa valley rock-engravings: two physical-science studies

In December 1995, ANTIQUITY published contrary reports on the age of the animal and other figures engraved on open-air schist surfaces of the Côa valley in northern Portugal. João Zilhão (1995) contended that the figures, Palaeolithic in their look, are indeed of Palaeolithic age: they belong with the other Iberian sites where Palaeolithic petroglyphs survive on open-air surfaces. Robert Bednarik (1995), using his own and others' physical-science studies, contended they were certainly under 3000 years old: the Palaeolithic presumption — and stylistic dating as a method — is false.
We here print together two studies concerning the age of the Côa Valley rock-surfaces, and of the figures they bear.

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Maximum ages of the Côa valley (Portugal) engravings measured with Chlorine-36

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Panel faces in the Côa valley, Portugal, were available for engraving during the Upper Palaeolithic, according to ^{36}Cl exposure ages of 16,000 to 136,000 years.

Introduction

The Côa valley petroglyphs in Portugal have a style indicative of a Palaeolithic age (Bahn 1995; Clottes *et al.* 1995; Zilhão 1995; Züchner 1995). These engravings have become controversial because they were in danger of being flooded by a proposed dam, and because radiocarbon (Watchman 1995; 1996) and microerosion (Bednarik 1995a; 1995b; 1995c; 1995d) dating results suggest that they are Holocene in age.

There are also claims that the geomorphic system in the Côa valley is too unstable to support Palaeolithic art on the grounds of 4000–6000 b.p. luminescence ages for inset river sediments; close proximity to the river channel and flooding; and slope instability (Bednarik 1995c; 1995d; Watchman 1996). Bednarik (1995b: 98) writes, 'in summary, there is not one iota of evidence supporting a Pleistocene antiquity of the petroglyphs, be

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petroglyph panels:	**FC-95-14-1 Canada do Inferno (panel 14)**	**FC-95-15-1 Canada do Inferno (panel 15)**	**FC-95-3-2 Penascosa**	**FC-95-2H-5 Ribeira dos Piscos**	*context ages:*	**FC-95-2H-6 Ribeira dos Piscos (middle joint face)**	**FC-95-2H-7 Ribeira dos Piscos (outermost joint face)**	**FC-95-3-3 Penascosa hilltop**	**FC-95-CM-8 Castelo Melhor**	**FC-95-BD-4 Below dam sample (back ground)**
zero erosion age (ka)	16·2±1·5	55·5±10·4	136±70	99·3±20·0		91·0±9·4	170±34	57·0±8·2	28·3±1·7	min: 0·795 max: 2·77
exposure age (ka) (2 mm/ka erosion rate)	17·2±1·6	73·5±21·2	355 + ∞ −174	153±67		132±24	∞	63·0±10·2	29·4±1·8	min: 0·795 max: 2·78
elevation (m)	130	153	140	131		131	131	240	440	110
S_T (unitless)	0·43	0·43	0·39	0·40		0·40	0·04	0·99	1·0	1·0
^eff (g cm^{-2})	67	67	92	93		94	94	169	170	170
^{36}Cl (10^5 atoms/g)	0·435±·039	0·841±0·15	2·48±1·0	1·78±0·31		1·73±0·16	2·88±0·46	2·71±0·36	2·30±0·13	0·0486±0·025
Cl (ppm)	16·1	8·81±0·17	11·8±1·9	6·56±0·39		4·81±0·19	3·33±0·22	4·70±0·10	8·55±0·25	1·78±0·75
SiO_2 (%)	64·7	68·5	59·7	61·1		59·8	62·2	63·7	59·8	64·3
Al_2O_3 (%)	17·0	14·5	20·1	18·6		19·4	18·7	17·5	18·8	16·5
K_2O (%)	3·45	2·79	4·01	3·71		3·99	3·89	3·40	4·66	4·15
Na_2O (%)	1·74	1·85	1·37	1·88		1·75	1·88	1·53	0·16	1·20
CaO (%)	0·07	0·13	0·22	0·29		0·12	0·12	0·11	0·01	0·78
MgO (%)	2·01	2·13	2·21	2·22		2·50	2·20	2·11	1·73	2·61
Fe_2O_3 (%)	6·78	6·07	8·06	7·18		7·51	6·80	7·30	9·06	6·86
MnO (%)	0·09	0·08	0·06	0·08		0·05	0·06	0·08	0·10	0·08
TiO_2 (%)	0·97	0·868	1·19	1·17		1·15	1·09	1·31	1·38	0·73
P_2O_5 (%)	0·06	0·05	0·08	0·03		0·04	0·03	0·07	0·15	0·11
Cr_2O_3 (%)	0·01	0·01	0·01	0·01		0·01	0·01	0·01	0·01	0·01
LOI (%)	3·30	3·05	3·40	3·20		3·60	3·00	3·05	3·95	3·50
B (ppm)	66·5	108	99·5	86·0		88·0	97·5	155	41·0	125
Gd (ppm)	9·5	18	19·5	5·5		8·0	7·5	16	7·0	12
Th (ppm)	16	36	37	41		36	44	38	47	31
U (ppm)	3·1	2·8	3·5	3·0		3·7	4·3	3·6	3·0	3·2

TABLE 1. *Cl ages for the exposure of panel faces and associated features. S_T is the scaling factor for shielding from cosmic radiation and ^eff is the effective attenuation length for fast neutrons. 1 ka = 10^3 years.*

it quantifiable or circumstantial, deductive or inductive.'

We focused on the question of whether the rock panels were available for engraving during the Palaeolithic. We address this issue by measuring the accumulation of cosmogenic ^{36}Cl in samples from petroglyph panels.

Overview of ^{36}Cl analysis at Côa

One clear test of the age of the Côa petroglyphs is to determine the time at which the rock faces containing the art were exposed. The age of the carvings cannot exceed that of the rock surfaces: a Holocene age for the exposure of panels would preclude a Palaeolithic date for the art.

The maximum age can be determined in a straightforward fashion using the accumulation of cosmogenic nuclides in minerals at the rock face. Cosmogenic nuclides are produced by reactions of cosmic-ray particles with elements in the atmosphere or rock (Cerling & Craig 1994). One to two metres of rock will block most cosmic radiation; where thick slabs of rock spall off to expose fresh faces, the accumulation of cosmogenic nuclides will be initiated at the fresh face at the time of the spall event. This condition is well met in the Côa Valley where the panels on which the art was engraved are created by slabbing along joint planes in schist spaced at approximately 1·5-m intervals.

Methods

Samples for ^{36}Cl measurement were taken from two engraved panels at the Canada do Inferno site, one at Penascosa, and one at Ribeira de Piscos. In addition, two unengraved joint faces at Ribeira de Piscos, the top of the hill above the Penascosa site, and a medieval castle were sampled to help assess rates of erosion in the area.

One sample (FC95-BD-4) was collected from the dam excavation, 16 m below the riverbed. This sample assesses background concentrations of ^{36}Cl. The ^{36}Cl concentration of this sample, one to two orders of magnitude less than the surface samples, indicates a 'background' signal of no more than a few thousand years.

Samples were prepared by dissolution in HF and HNO_3; the chlorine was extracted and purified using standard procedures (Zreda *et al.* 1991). A ^{35}Cl-labelled carrier was added during dissolution; ^{36}Cl and total chlorine were then determined simultaneously by isotope dilution during the accelerator mass spectrometric (AMS) analysis (Elmore & Phillips 1987) at PRIME Laboratory, Purdue University (TABLE 1). Exposure ages were calculated for panel surfaces, exposed by spalling events, assuming a minimum erosion rate of zero and a maximum erosion rate of 2 mm/ka (where 1 ka=10^3 years) — using ^{36}Cl production rates (Phillips *et al.* 1996) and erosion corrections (Liu *et al.* 1994b); this is because higher rates of surface erosion would have obliterated the engravings.

Results for panel faces

The senior author intuitively anticipated that engraved joint surfaces were exposed in the Holocene. This opinion was based on geomorphic characteristics of the sites, including:

i proximity to fluvial processes that undercut slopes;

ii occurrence of petroglyphs on the youngest faces in a relative sequence of spalls;

iii paucity of epilithic organisms (e.g. lichens) on engraved joints; and

iv paucity of a 'flaking' style of schist erosion — a ubiquitous process on older, lichen-covered joint spalls.

These observations are in agreement with geomorphological arguments that the Côa rock faces were too young to have been engraved in the Pleistocene (Bednarik 1995c; 1995d; Watchman 1996).

Despite these deductive and intuitive arguments, cosmogenic ^{36}Cl build-up ages provide clear evidence that panels were available for engraving during the Palaeolithic. Côa panels have been exposed for 16,000–136,000 years (TABLE 1), demonstrating that carved joints were available for engraving during the Upper Palaeolithic. Rates of surface modification and erosion are slow enough to preserve Palaeolithic petroglyphs. Pleistocene ^{36}Cl ages for the engraved panels, adjacent joint faces, and the hilltop site also falsify deductive geomorphic arguments that sites were too unstable to host Palaeolithic art.

Part of the reason why this intuition was in error, and an important reason why cosmogenic nuclides can be used at Côa, has to do with the style of schist weathering and subsequent erosion. Spalling of ~1·5-m blocks exposes a joint (panel) face. Unlike panels in other lithologies such as basalt or sandstone, subsequent millimetre-scale erosion of joint faces does not occur parallel to a face. Instead, erosion occurs along weaknesses in schist foliations, and these are oriented obliquely to joints. A panel face undergoing erosion has a 'flaky' appearance. In other lithologies, millimetre-scale erosion parallel to rock faces could readily produce a situation of ^{14}C ages younger than ^{36}Cl — simply by eroding a few centimetres off a panel face and re-setting the ^{14}C clock. Yet at Côa, if schist erosion did occur on panel faces, the surface would appear rough and 'flaky'. They do not, as Bednarik and Watchman also note. Hence, Côa offers a good opportunity to compare ^{36}Cl with ^{14}C in a context where we can be reasonably certain that host panel faces have not eroded.

Geomorphic context and ^{36}Cl results

We start our analysis of the geomorphic context by a study of three joint faces parallel to the Ribeira dos Pisco, a tributary of the Côa River. The three surfaces constitute a series of *en échelon* faces formed by spalls along joints successively set back from the valley axis. The outermost joint face (sample FC95-2H-7) was pitted over most of the surface with a maximum pit depth of ~50 mm. The middle joint face (sample FC95-2H-6) was set back from the first face about 2 m; approximately 10% of the surface is pitted with maximum pit depths ~5 mm. These two faces are not carved. The third panel (FC95-2H-5), set back about 1·2 m from the middle one and with only sparse pits ~1 mm deep, was used by artists to carve outlines of horses.

The outermost (sample #7) joint was first exposed by spalling around 170,000±34,000 b.p. Then, spalling exposed the middle (#6) and interior (#5) faces at about the same time; their ages are statistically indistinguishable at 91,000±9000 b.p. and 99,000±22,000 b.p., respectively. These younger ages do correspond with observed lighter erosion, compared with the heavily pitted outermost face. The slightly greater erosion of the middle panel, compared to the innermost, could result from exposure to a greater flux of solar radiation — which accelerates weathering (Paradise 1993).

To obtain information on general rates of landscape modification, as a comparison with the petroglyph panels, a sample (FC95-3-3) was collected from the ridge above the Penascosa petroglyph site. This sample comes not from a joint face, but rather from a horizontally oriented position at the crest of the hill. The schist, deeply etched and grooved along the foliation planes, was exposed by gradual weathering and erosion, as opposed to slab failure. The ^{36}Cl data are, therefore, most appropriately interpreted in terms of a steady-state erosion rate rather than an exposure age. We calculate a steady-state erosion rate of 10·0±1·6 mm/ka, using a method detailed elsewhere (Liu *et al.* 1994a). This rate is consistent with a geomorphic picture of general stability of Côa Valley hillslopes during the late Quaternary.

Sample FC95-CM-8 was collected from the side of an early medieval castle east of the Penascosa site in order to test the sensitivity of the ^{36}Cl method for young samples. This sample turned out to have a ^{36}Cl inventory similar to the Penascosa hilltop sample (FC95-3-3). The rock slab used in building the castle wall was probably collected from near the ground surface, rather than being quarried; this ^{36}Cl inventory likely reflects slow erosion rates in the vicinity of the castle.

Slow, steady styles of erosion can be compared to the style of slabbing erosion along joint planes. Panel ages indicate that an average time interval between slabbing events on the order of 100,000 years. Assuming an average slab thickness of about 1·5 m, the long-term average erosion rate is about 15 mm/ka — similar to steady-state erosion rates calculated for the Penascosa hilltop.

Although rates of surface modification are slower than we intuitively anticipated, little is known about the long-term stability of subaerial rock faces. We note that wetter cave and rock-shelter sites support Palaeolithic paintings (Valladas *et al.* 1992; Watchman 1993) — implying zero rates of rock erosion. Rates of rock-surface weathering are complex, depending upon a great number of factors other than time (Pope *et al.* 1995).

Steep slopes of the Côa river gorge, expanses of bare schist, and frequent floods that sweep the canyon bottom yield an impression that the landscape is unstable and that gorge walls are eroding rapidly. But this impression is deceptive. ^{36}Cl data, consistent throughout a wide range of samples, indicate that the tough, fine-grained schist is resistant to erosion. Average rates of denudation are in the range of 10 to 20 mm/ka, amounting to an average total loss of about 20 cm for the landscape since the Palaeolithic.

This range is not unusually low. Total denudation rates for 14 of 30 major river basins, reviewed by Summerfield & Hulton (1994), were less than 20 mm/ka . The engraved joints are oriented perpendicular to the schist fabric; due to the difficulty of weathering particles from this 'end grain' exposure and due to vertical and often protected aspects of joint faces, rates of pitting and roughening of joint faces are slow. These geomorphic characteristics favour preservation of Late Palaeolithic rock art, and ^{36}Cl data confirm that all of sampled panels were exposed during or prior to that period.

Conclusions

^{36}Cl ages reveal that Côa Valley petroglyph panels were available for engraving during the Palaeolithic. Furthermore, ^{36}Cl ages for associated joint faces and ^{36}Cl ages for Côa hillslope materials (TABLE 1) argue for a landscape that is stable enough to support Palaeolithic art.

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