

A GEOMORPHOLOGY OF MEGALITHS: NEOLITHIC LANDSCAPES IN THE ALTO ALENTEJO, PORTUGAL

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ABSTRACT: *The Alentejo region of Portugal is known for a high concentration of Neolithic-aged megalithic monuments: tombs (dolmens or antas) and ceremonial features such as standing stones (menhirs) and stone circles (cromleques). Concentrations of these monuments tend to be found on or near weathered granite terrains. Unloading slabs and remnant corestones appear to be the stones of preference for megalith makers in the Alentejo district of Portugal. Some of the stones may have been imported from distant sources, but most appear to be of local origin. In general, most stones do not appear to have been altered much from their original state as field stones. Weathering tests demonstrate that menhirs are essentially identical to native corestones. Many menhirs still exhibit a soil line. The former subaerial side of the stone usually retains a thick growth of lichen, while the soil side remains oxidized. Newly exposed, antas and menhirs now suffer from enhanced weathering and erosion from atmospheric and biological agents. This deterioration is often difficult to discern from the inherited decomposition of pre-megalithic time.*

INTRODUCTION

The monuments at Stonehenge, Avebury, and Carnac are perhaps the best known examples of "megaliths", great stone monuments constructed during the Neolithic ("New Stone Age") and Calcolithic (transition to copper metallurgy) periods in western Europe. Though not necessarily as notable as the famous English and French examples, thousands of megaliths may be found across Atlantic and Mediterranean Europe. Portions of the western Iberian peninsula are dense with megalithic sites (Figure 1). The Alentejo region of southeast Portugal, among the most notable for Iberian megaliths, provides the focus for this paper.

Megaliths provide useful information for a period of human prehistory that otherwise contains relatively limited archaeological evidence (Sherratt, 1990). Along with artifacts and human remains associated with the sites, megaliths provide insight into the culture's technological and scientific advancement, funerary practices, and resource use. The geoarchaeological information that can be

derived from megalithic sites is often overlooked. Megaliths reflect an association between geomorphology and available resources. Furthermore, as early examples of quarried stone, megaliths afford an opportunity to assess how rock adjusts to the atmospheric and biotic environment. Geomorphologists, archaeologists, and stone conservators are just now realizing the wealth of information that may be obtained by studying the deterioration of these ancient monuments (Delgado Rodrigues, 1994; Silva et al. 1994; Romão and Rattazzi, 1995; Sellier, 1997).

Using information on geomorphology and the weathering characteristics of the stones, one can see that Alentejan megalith stones have not been imported from long distances, and appear to be of local origin, taken from weathered granitic outcrops. Post-megalithic weathering impacts (over ~6000 years) appear to override millions of years of inherited weathering accumulated on the rock prior to

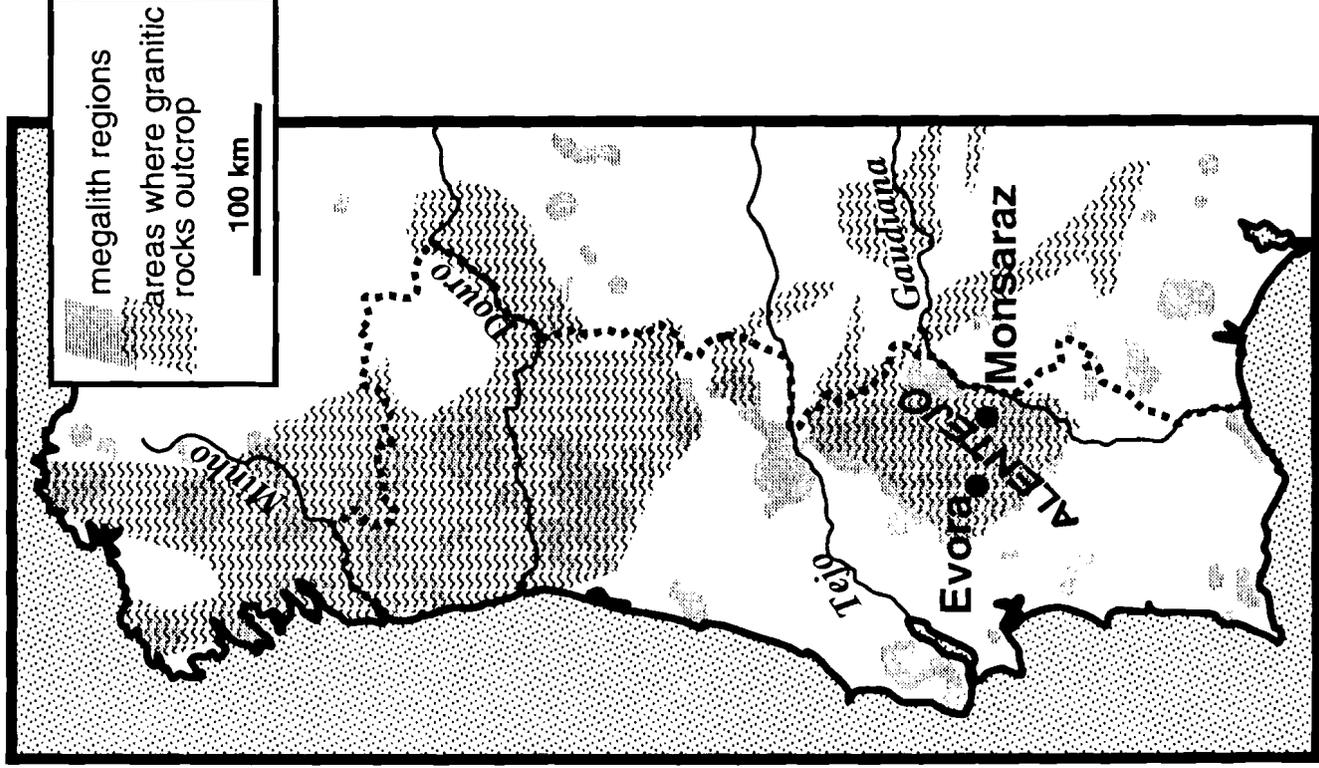


Figure 1. Locations of megalithic monuments in western Iberia. Locations where granitic rock may be found are also shown, and tend to correspond to megalithic areas.

quarrying or unearthing. This information provides an insight into the rates and equilibrium processes of weathering.

ARCHAEOLOGICAL AND GEOMORPHIC SETTING

Archaeological Setting

The European Megalithic tradition spans an era from ~7000 to 2500 YBP, from the end of the Neolithic into the Chalcolithic periods (Daniel, 1958; Service and Bradbery, 1979; Joussaume, 1988). Megalithic monuments are therefore not diagnostic of a specific culture (Sherratt, 1995), although they are associated with the rise of organized agriculture in Western Europe (Joussaume, 1988). Since Iberia was a seat of initial agriculture development in Europe, it has been suggested (MacKie, 1977; Joussaume, 1988) that the entire megalithic tradition emanated from Iberia as well. Aside from some engraving and a few examples of shaping, most of the Alentejo megaliths are barely altered, unlike the roughly rectangular hewn stones known at Stonehenge and Malta or the graceful ellipsoids of Carnac. Carvings on some megaliths are similar across the region, irrespective of chronology (Buena Ramirez, 1992). Megalith development is said to have evolved along several phases (Holtorf, 1998). Cromleque dos Almendres (near Évora) had three separate phases of construction from Early to Late Neolithic (M. Gomes, 1997a), and re-facing of some menhirs at Vale Maria de Meio (also near Évora) occurred late in the Neolithic (M. Gomes, 1997b). Further details on the megalithic archaeology of the Évora region may be found in Sarantopoulos (1997).

As elsewhere, Portuguese megaliths may be classified by type into (1) single oblong or rectangular standing stones (menhirs), (2) closed circles, ellipses, or squares of smaller menhirs (*cromleques* in Portuguese, Figure 1), and (3) chambers constructed of large leaning rock slabs (dolmens, known as *antas* in Portuguese, Figure 2). Archaeologists agree that megaliths probably had ceremonial significance. Antas are known to be

burial chambers; cromleques are oriented in cardinal directions and may have been used in astronomical calculations; single menhirs may have been used for surveys or landmarks (Daniel, 1958; Service and Bradbery, 1979; Joussaume, 1988). Menhirs and cromleques are free-standing (or toppled over the years). Many antas, however, were buried for some period. Exposed antas today were either excavated or their cover mounds eroded over time.

Geomorphic Setting

The western Iberian Peninsula is dominated by folded Paleozoic metamorphic rocks with regions of plutonic rock emplaced during the Hercynian (also known as Variscan, late Paleozoic) orogeny (Krebs, 1976). Regional maps (Congrés Géologique International, 1981) portray late-tectonic granitic masses dispersed through Carboniferous metasediments across Alto Alentejo. Some folding and faulting occurred with the later Alpine orogeny, but the region remained relatively undeformed. As a result, the bedrock was able to weather and erode during the Mesozoic and Cenozoic eras.

There are few geomorphic studies of the Alentejo region published outside of Portugal (cf. Feio, 1952; Martins and Barbosa, 1992; Pimentel and Azevedo, 1992). In his regional geography monograph, Houston (1967, p. 175-176) cites Feio (1952) in explaining the Alentejo tableland as a Tertiary erosion surface, dissected at the edges of the plateau and near the major river valleys. Long-term weathering of granites is recognized across Atlantic Europe, including coastal and northern Portugal (Sequeira Braga et al., 1990) and western Spain (Molina et al., 1987) to produce deep saprolites ("arenas"). The granite weathering profiles identified in the Évora and Monsaraz regions currently fall under a more xeric climate. If we accept Sequeira Braga's et al. (1990) hypothesis that mid-latitude weathering profiles are controlled by temperature, then the Alentejo saprolites probably most resemble those of western Spain (Molina et al., 1987). There, the weathering mantle is said to be up to 58 million years old, with secondary weathering mantles produced during the middle and late Tertiary period. More resistant granite produces spheroidally weathered corestones and, in larger masses,

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Figure 2. Cromleque and menhir at Xerez, near Monsaraz. Center menhir is approximately 4 meters high.



Figure 3. Partially toppled anta at Pinheiro do Campo, near Évora. Front slab is approximately 2 meters high.

inselbergs and tors (Twidale, 1982). These are commonly found in the granitic landscapes of Alentejo. How long these remnant rock masses have been exposed is unknown.

The Alentejo region presently exists in a "Mediterranean-Iberoatlantic" climatic province (C. Gomes, 1997) with subhumid, winter-dominant precipitation (600-900 mm). During the period since the megaliths were made, the climate has been roughly equivalent, perhaps deviating slightly toward more precipitation during cooler periods.

METHODS

Twelve sites were surveyed in two regions of Alto Alentejo: Évora, and Monsaraz (Table 1). Non-megalith field stones at four sites, similar in shape and size to the stones used in megaliths, provided a baseline for comparison with the megaliths. Megalith rock type was recorded in the field, and compared to nearby natural rock outcrops. Further laboratory petrographic characterization was not attempted, as it was not possible to collect samples from the megaliths because of their archaeological sensitivity.

The type and degree of weathering provided evidence of exposure history and human alteration of megalithic stones. Categorical information was recorded at each stone: presence and extent of lichens, discoloration (e.g. from oxidation), weathering morphology (such as spalls, pits, fissures, granular disintegration), and obvious human alteration such as carving, abrasion, or dressing. Orientation with respect to solar radiation was recorded. While most of the megalith sites surveyed were in a state of deterioration, several had been excavated and partially restored during recent archaeological surveys. This presented a problem for knowing the original placement and orientation of the stones (particularly the larger menhirs). Stones that were obviously displaced from their original position were not included as part of the orientation data subset. All other stones were assumed to be in their original position, or if restored, placed in their correct orientation by archaeologists.

Quantitative weathering data were derived with a type-L Schmidt hammer. The Schmidt

hammer recorded the rebound of a constant-force impact on the rock, thereby measuring rock hardness. Weathering creates softer rock by decomposition, or harder rock if precipitated weathering products indurate the rock surface. Examples of its use in geomorphic contexts are presented in Day (1980), Sjöburg (1994), and Tang (1998). Schmidt hammer testing is problematic for coarse-grained rocks (such as granites), in that the large crystals of varying mineralogy tend to yield data with a broad statistical spread. At least ten readings, sampled within a confined area on the rock (~50cm x 50cm) were necessary to account for statistical spread. Other methods of weathering assessment achieve better data on megalith weathering (cf. Delgado Rodrigues, 1994, for tomography; Silva et al., 1994, for petrographic analysis; and Sellier, 1997, for surface recession). However, the type-L Schmidt hammer is considered a "low impact" testing device, resulting in little or no visible scarring on soft or sensitive materials. Furthermore, the Schmidt hammer had advantages over these in that it was inexpensive, portable, provided consistent quantitative data, and did not require elaborate set-up or physical samples.

RESULTS AND DISCUSSION

Megaliths and Landscape

Weathered granite forms a major portion of the landscapes surrounding the megaliths of Évora and Monsaraz. It is interesting to note that megalith concentrations throughout western Iberia tend to appear in areas where granitic rocks outcrop nearby (Figure 1). We cannot speculate on whether granite was somehow significant to megalith builders, but we did note that granitic rock seems to be the stone of preference in the Alto Alentejo, despite the availability of other rock types. Western European megaliths are composed of many rock types, although granitic landscapes are prominent in two noteworthy megalith regions, Brittany (Sellier, 1997) and Dartmoor (Bradley, 1998).

While ancient granitic quarry sites for the region are uncertain (J. Delgado Rodrigues, personal communication), natural outcrops are abundant.

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Table 1. Locations surveyed for this study.

Feature	Location	ID	# of stones*
Cromleque dos Almendres	Guadalupe, Évora	EV-CDA	5
Anta do Zambujeiro	Valverde, Évora	EV-ADZ	4
Cromleque de Portela de Mogos (incl. 1 field stone)	São Matias, Évora	EV-PDM	4
Menhir do Oliveirinha	Graça do Divor, Évora	EV-OLI	1
Cromleque Vale Maria do Meio	São Matias, Évora	EV-VMM	2
Anta de Pinheiro do Campo (incl. 1 field stone)	Giesteira, Évora	EV-APC	3
Menhir do Casbarra	São Matias, Évora	EV-CAS	1
Menhir do Outiero	Outiero, Monsaraz	MS-OUT	1
“menhir” at Sao Brisos†	São Brisos, Monsaraz	MS-SBR	1
Cromleque de Xerez,	Xerez, Monsaraz	MS-XER	2
Anta 2 do Olival de Pega	Telheiro, Monsaraz	MS-AOP	2
field stones (no megaliths)	São Pedro do Corval, Monsaraz	MS-SPC	4
quarried granite	Valverde, Évora	EV-VGQ	1

menhir = single oblong standing stone; generally >2m in height, may be toppled

cromleque = elliptical, circular, or rectangular alignment of standing stones (menhirs), most stones <2m in height, but may be toppled

anta = dolmen tomb, slabs of rock set on edge, capped with 1 or more roof slabs

field stones = naturally occurring, exposed remnants from bedrock: not megaliths

* “# of stones” refers to the number surveyed, some locations had many more stones

† The “menhir” at São Brisos is actually a “mushroom rock” excavated to a depth of ~3m. It is essentially an exposed granite bedrock outcrop, and not at all similar to other oblong menhirs.

Ample material for megalith construction existed with the remnant corestones and exfoliation slabs eroding out of the regolith and bedrock. Barely altered and encrusted with lichens, an untrained eye could mistake a collapsed dolmen for an angular tor, or a downed menhir as one of the ubiquitous corestones. Bradley (1998) suggested that dolmens of southwest England were purposely built to mirror nearby granite outcrops. This contrasts with the views of Calado (1997), who remarked that cromleque stones at Vale Maria do Meio were specifically selected to contrast with the local soil and bedrock of the site, “to establish clearly their nature as being artificial, cultural, belonging to sacred space” (p. 47). It is true that some megalith stones were imported. Kalb (1996) stated that specific types of stone were imported over distances up to 8 km for megaliths at Vale de Rodrigo (southwest of the Almendres and Zambujeiro sites). This was consistent with our observations, particularly at Cromleque dos Almendres, where several types of granite were noted. Criado Boado and Fábregas Valcarce (1994) contend that adjacent outcrops were seldom used as quarries for megaliths in Galicia. However, minimal

damage to surface weathering features on most megalith stones (discussed below) suggested that the stones were not dragged or rolled long distances (at least without the aid of sledges or other mechanical aids). Therefore, we feel that most source material (or all source material on smaller monuments) was derived from nearby outcrops if not on-site (particularly in the Monsaraz region).

One of the most visible features on the individual menhir and cromleque stones was the “soil line”, which vertically divided the former subaerial (above soil) side from the former buried side of the upended stones (Figure 4 schematic, Figure 5 photograph). On stones unaltered by polishing, dressing, or engraving, the former subaerial side often retained a biotic growth of lichen, while the former buried side exhibited an oxidized orange color. The soil line between these disparate zones was usually prominent, and only a few stones had lichens colonizing into formerly buried areas. Given this dichotomous appearance, Schmidt hammer tests were used to determine if post-Megalithic weathering inherited characteristics from the stone.

Table 2. Chi-square cross-tabulation between weathering factors, testing for independence between factors. Each comparison of factors lists number of cases (N), Pearson's chi-square value (χ^2), and probability of error (p). Factors that are statistically independent are in boldface.

	soil position (subaerial / buried)	human alteration (altered / unaltered)	lichen coverage (1 least - 3 most)	cardinal exposure orientation
type of stone (megalith / field stone)	N = 44 $\chi^2 = 0.155$ $p = 0.694$	N = 66 no field stones were altered	N = 63 $\chi^2 = 1.874$ $p = 0.392$	N = 45 $\chi^2 = 2.485$ $p = 0.962$
soil position (subaerial / buried)		N = 44 $\chi^2 = 0.037$ $p = 0.694$	N = 44 $\chi^2 = 27.623$ $p = 0.000$	N = 30 $\chi^2 = 13.225$ $p = 0.040$
human alteration (altered / unaltered)			N = 63 $\chi^2 = 20.703$ $p = 0.000$	N = 45 $\chi^2 = 16.561$ $p = 0.172$
lichen coverage (1 least - 3 most)				N = 45 $\chi^2 = 30.546$ $p = 0.015$

Weathering of Megaliths

Superficial weathering features on the megaliths were similar to those seen on field stones. While we made no attempt to specifically differentiate between weathering processes, it was apparent that several weathering processes were active. Oxidation of biotite and dissolution of feldspars and biotite contributed to granular disintegration. Several megaliths were extensively weathered by granular disintegration, notably at São Brisos and at Cromleque dos Almendres. Weathering pits were less common on fieldstones, cromleques, and single menhirs, but more commonly observed on the slabs used in antas. Pressure unloading combined with the weakening effects of chemical weathering produced exfoliation and spalling. Natural joints provided avenues for further weathering, and often exhibited oxidation. Freeze-thaw mechanisms could have contributed to mechanical weathering during occasional winter cold spells. In the relatively sunny climate, solar heating probably contributed as a catalyst to chemical weathering if not to thermal expansion mechanical weathering. Finally,

anthropogenic impacts such as abrasion and carving altered the weathering environment. Polishing on some stones created a protective silica seal on the granite, and stones that appeared polished were resistant to weathering. Many of the superficial weathering forms observed here were also observed by Sellier (1997) on granitic megaliths at Carnac, though not to the advanced degree observed in that region. The differences may be due to rock mineral composition and/or wetter climate of northwest France. Sellier did not make any comparisons with natural field stones.

Before discussing correlations between weathering and various weathering factors, it is necessary to mention relationships between these parameters, and to test for covariance. These comparisons are represented by chi-square cross-tabulations in Table 2. Random testing insured that data from megaliths and field stones were not preferentially oriented to an exposure direction, nor was there a preference in sampling former subaerial or former buried surfaces. Though not exclusively, engravings and stone dressing were marginally related to exposure direction ($\chi^2 = 16.561$, $p =$

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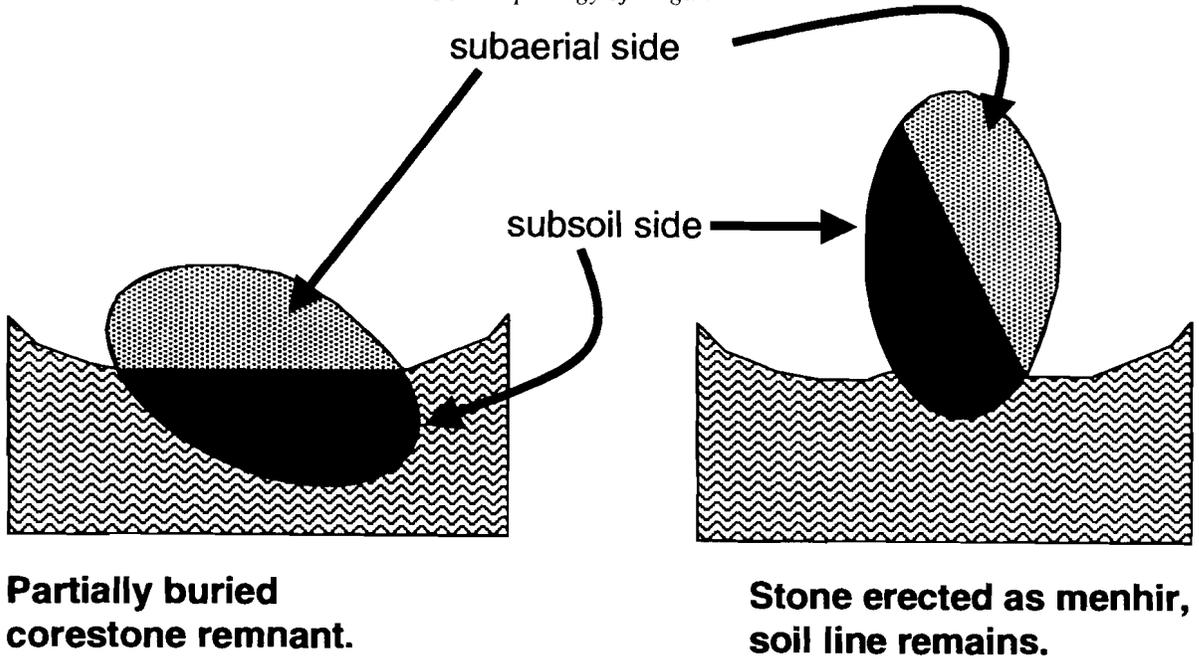


Figure 4. Schematic of remnant corestones and their configuration as menhirs.



Figure 5. Small (1.5 m) menhir at Cromleque dos Almendres, with a planed off top and polished "cup" depressions. The planed top and cups were distinctly harder than the rest of the rock. This stone also shows a distinct lichen-encrusted former subaerial side (to the right) and a pale, oxidized buried side (to the left). The flat-faced menhir in the background has also been planed off.

Table 3. Analysis of variance (ANOVA) statistical comparison of rock hardness (R-value) against weathering factors, stating number of cases (N), ANOVA F statistic, and probability of error (*p*). "Mean R-values" are calculated with a set (usually 10) of hammer tests per rock location. "Individual R-values" consider each hammer strike individually. Statistically significant relationships (*p* < 0.100) are shown in boldface.

Data set	type of stone (megalith / field stone)	soil position (subaerial / buried)	human alteration (altered / unaltered)	degree of lichen coverage (1-3)	cardinal exposure orientation
full data set	N = 66	N = 44	N = 66	N = 63	N = 45
mean R-values (from each stone)	F = 0.301 <i>p</i> = 0.585	F = 0.013 <i>p</i> = 0.960	F = 0.690 <i>p</i> = 0.409	F = 0.914 <i>p</i> = 0.407	F = 1.862 <i>p</i> = 0.097
full data set, individual R-values	N = 692 F = 2.032 <i>p</i> = 0.155	N = 451 F = 0.941 <i>p</i> = 0.332	N = 692 F = 5.255 <i>p</i> = 0.022	N = 656 F = 10.271 <i>p</i> = 0.000	N = 419* F = 10.158 <i>p</i> = 0.000
unaltered stones mean R-values (from each stone)	N = 45 F = 0.527 <i>p</i> = 0.472	N = 40 F = 0.056 <i>p</i> = 0.815	---	N = 45 F = 0.091 <i>p</i> = 0.913	N = 27 F = 1.197 <i>p</i> = 0.340
unaltered stones individual R-values	N = 487 F = 1.117 <i>p</i> = 0.291	N = 427 F = 1.083 <i>p</i> = 0.299	---	N = 487 F = 2.248 <i>p</i> = 0.107	N = 302 F = 8.612 <i>p</i> = 0.000
unaltered megaliths only mean R-values (from each stone)	---	N = 28 F = 0.217 <i>p</i> = 0.645	---	N = 32 F = 0.020 <i>p</i> = 0.981	N = 25 F = 0.866 <i>p</i> = 0.501
unaltered megaliths only, individual R-values	---	N = 325 F = 0.043 <i>p</i> = 0.835	---	N = 550 F = 3.341 <i>p</i> = 0.068	N = 386 F = 9.569 <i>p</i> = 0.000
field stones only mean R-values	---	N = 9 F = 0.143 <i>p</i> = 0.716	---	N = 10 F = 0.473 <i>p</i> = 0.641	(insufficient data)
field stones only individual R-values	---	N = 104 F = 6.189 <i>p</i> = 0.014	---	N = 116 F = 7.530 <i>p</i> = 0.001	N = 23 F = 4.234 <i>p</i> = 0.052

0.172). Engravings and facing tended to face southeast to southwest; and this may be relevant in that these stones could have been placed so for astronomical observations (Service and Bradbery, 1977). Engravings and stone dressing were not preferentially placed on buried or subaerial surfaces ($\chi^2 = 0.037$, *p* = 0.694).

Almost exclusively, lichens were confined to former subaerial surfaces ($\chi^2 = 27.623$, *p* = 0). As expected, carved and dressed surfaces had very little lichen growth ($\chi^2 = 20.703$, *p* = 0), and on both field stones and unaltered megalith stones, lichen occurrence was essentially similar ($\chi^2 = 1.874$, *p* = 0.392). Comparisons between lichen degree and exposure orientation were statistically significant;

most lichen-bare faces on unaltered stones were preferentially oriented to the south and west ($\chi^2 = 30.546$, *p* = 0.015). This lichen orientation may reflect a purposeful placement, but more likely the relationship reveals an ecological preference of lichen growth toward cooler, moister conditions to the north and northeast.

While weathering can produce hard, indurated surfaces, R-value data here were consistent with rock softening due to weathering. Individual R-values (each individual hammer test) and mean R-values (means of 10 or more hammer tests on one area of the stone) were compared against weathering factors such as degree of lichen coverage, presence of human alteration (dressing, polishing, or engraving),

type of stone (megalith vs. field stone), former soil position (buried vs. exposed subaerial), and exposure orientation (after construction). These comparisons are summarized in Table 3. Mean R-values tended to be less than statistically significant, while the set of individual (not averaged) R-values did reveal statistical significance with several weathering factors. Ordinarily, we favor the mean data over the individual data because mean data compensate for the variation in R-value readings caused by the heterogeneity of granite. However, the statistical relationships revealed by the individual R-value data set are intriguing, and warrant discussion.

Biotic growths (such as bacteria, algae, lichens) are known to contribute to weathering, with penetrating root hyphae and release of powerful chemical weathering agents such as chelates and organic acids (Wakefield and Jones, 1998). Romão and Rattazzi (1995) discussed the rapid biodeterioration on megalithic tombs near Évora. As expected, we found significantly softer rock (in the individual R-value data set) in areas with more lichen. Differences in R-values were greatest between lichen class 2 and 3 (some to extensive lichens) and lichen class 1 (no lichens).

Megalithic stones found throughout Europe exhibit engravings and decoration (Bueno Ramirez, 1992). Of the megalithic stones surveyed here, most lacked visible human alteration. This may be due to weathering, which obliterated carved surface features, or may be due to the fact that not all stones were engraved or altered. Data here indicated that weathering was not capable of completely erasing

such carvings over the period of exposure (~6000 years). Engravings seen at the Almendres, Portela de Mogos, and Xerez cromleques and Casbarra and Outiero single menhirs were muted in appearance, but still visible. A few stones exhibited apparent stone dressing or abrasion, with flat – sometimes polished – surfaces (Figure 5). There was some difference in R-values between altered vs. unaltered stones. The difference was statistically significant for the entire data set of individual R-values. As expected, carving and stone dressing removed weathered surface material, exposing harder material. Pope (2000) presented similar findings regarding the weathering of petroglyphs.

There was no statistically significant difference in R-values, individual or mean, between megalith stones and field stones, implying that weathering impact was similar between the two. Two explanations could account for this correspondence: (1) weathering processes were slow, and weathering over the elapsed time since construction was not enough to over-ride the inherited impacts of millions of years of *in situ* weathering; or (2), weathering processes were relatively fast, such that the megalith stones reached an equilibrium weathering state similar to the native field stones. We favor the second scenario, based on soil position and exposure data, discussed below.

R-values were statistically similar between surfaces formerly buried and surfaces that were exposed to the air prior to megalith construction (Figure 6). Formerly buried anta slabs were as equally weathered as formerly subaerial cromleque

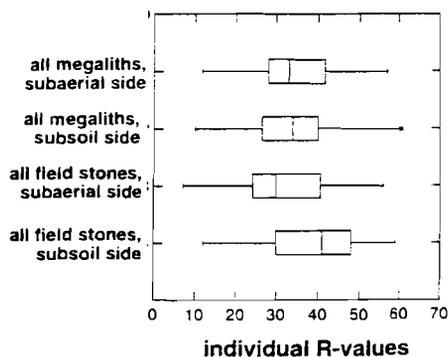


Figure 6. Differences in weathering (as shown through rock hardness R values) between subaerial and buried sides of the unaltered megaliths and field stones. There is no statistical difference between subaerial and buried sides on megaliths. The difference is statistically significant on field stones.

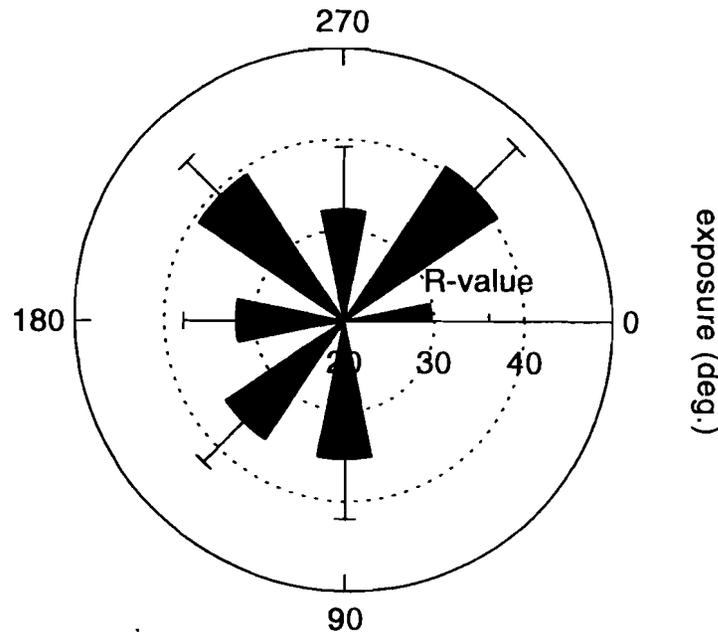


Figure 7. Differences in weathering (as shown through rock hardness R-values) at different exposures for a subset of megalith stones (n=364). Lower R-values (softer rock, hence, more weathered) appear in the quadrant from northwest to southwest.

and menhir stone surfaces. The unaltered field stones (not incorporated into megaliths) still exhibited marked differences in weathering between subaerial and buried sides (ANOVA $p = 0.014$), with more weathering on the subaerial side. On native field stones, subaerial weathering is apparently stronger than weathering in the soil environment. The important difference to note here is that field stones had not been exposed to the extremes of subaerial weathering that all sides of the megalith stones experienced for several millennia after emplacement.

Degree of weathering varied according to exposure orientation (after emplacement). Exposure orientation was a significant factor, overriding the former soil position factor. Multiple variables come into play with the orientation factor: differences in lithology from one side of the stone to the other; shade; direction of precipitation; and solar angle. R-values on different exposures were generally lower in the quadrant from southwest to northwest (Figure 7). Three single stone exceptions with unique exposures (the center menhir at Cromleque de Portela de Mogos, and two peripheral menhirs and Cromleque dos Almendres) had anomalously high and variable R-values, departing from the trend. Excluding these anomalous stones, exposure orientation was

statistically significant as a factor for R-value for every subset of individual R-values. Many authors (Paradise, 1995; Warke et al., 1996; Robinson and Williams, 1999) note a weathering preference to the south or southwest. The weathering maxima we observe from the southwest to north may be due to a combination of afternoon insolation (Paradise, 1995) and direction of precipitation from passing weather systems or propensity for frost on more northern exposures (Meierding, 1993).

CONCLUSION

The granitic megalith stones of the Alto Alentejo are interesting for what they reveal about weathering rates. From this information, we can speculate about their origin and construction, and recommend practices for their conservation. The results are summarized below.

1) Naturally weathered outcrops provided material for these early megalith monuments, a practice possibly used in megalith construction across western Europe. Lack of damage to superficial weathering features suggests that, despite evidence of

importation into locations of differing lithology, the megalith stones were not transported long distances, or alternately, were transported with great care.

2) Weathering processes active on the megaliths included biotic, mechanical, and microclimate-influenced dissolution processes. While there is evidence of some human alteration (in the form of engravings or dressing) that removes original surfaces, most megaliths in the Alentejo region have superficial weathering features similar to the local field stones. Schmidt hammer data on rock hardness corroborate these results. Except where altered, megalith stones are statistically identical in weathering-controlled rock hardness to natural field stones. Stone dressing and polishing remain relatively clear, and engravings, while muted, are visible after more than 5000 years of exposure.

3) Visually, megalith stones still retain former subaerial and buried sides, despite their current placement. Lichens grow on surfaces formerly situated on the subaerial side of the stone, while oxidation staining prevails on the former buried side of the stone. Areas with lichen are more weathered, with softer rock. Lichen colonization is an obvious concern for conservators, but eradication can be a problem if doing so damages the stone surface and any engravings. Where lichens are not present, there is no difference in weathering (as detected through rock hardness) between former subaerial and former buried sides, counter to what might be expected (and what appears on recently unearthed non-megalith field stones).

4) Post-emplacement exposure may be a factor in the degree of weathering. There is a preference for softer rock in a quadrant from southwest to northwest, independent of the presence of lichens or former subaerial or buried characteristics. This exposure factor cannot have existed prior to megalith construction, and suggests that post-megalith weathering overrides characteristics inherited over a much longer pre-megalith weathering interval. Conservators can anticipate areas of concern on certain exposures, particularly after ruined monuments have been excavated and reconstructed.

As "the first public monuments of humankind" (M. Gomes, 1997a), megaliths provide unique opportunities to extend geomorphic theory

and conservation practice. Both geomorphic and built, megaliths exist at an age that promotes translation between studies of more recent building stone and more ancient natural landscapes. Further investigations in different climates (e.g. Brittany and Cornwall or Malta) and with different types of stone (sandstone, slate, etc.) can expand on the results presented in this initial investigation.

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REFERENCES

- Bradley, R. 1998. Ruined Buildings, Ruined Stones: Enclosures, Tombs, and Natural Places in the Neolithic of South-West England. *World Archaeology* 30: 13-22.
- Bueno Ramirez, P. 1992. Le Plaques Décorées Alentéjaines: Approche de Leur Étude et Analyse. *L'Anthropologie (Paris)* 96:573-604.
- Calado, M. 1997. Vale Maria do Meio and Neolithic Cultural Landscapes. In *Paisagens Arqueológicas a Oestede Évora*, ed. P. Sarantopoulos, pp. 49-51. Évora, Portugal: Câmara Municipal de Évora.

- Congr s G ologique International, 1981. *Carte Tectonique Internationale de l'Europe et des R gions Avoisnantes Feuille 13* (1:2,500,000). Moscow: USSR Academy of Sciences (Directorate of Geodesy and Cartography) and UNESCO.
- Criado Boado, F., and F bregas Valcarce, R., 1994. Regional Patterning Among the Megaliths of Galicia (NW Spain). *Oxford Journal of Archaeology* 13: 33-47.
- Daniel, G. 1958. *The Megalith Builders of Western Europe*. London: Hutchinson.
- Day, M. J. 1980. Rock Hardness: Field Assessment and Geomorphic Importance. *Professional Geographer* 32: 72-81.
- Delgado Rodrigues, J. 1994. Conservation of Granitic Rocks with Application to the Megalithic Monuments. In *Degradation and Conservation of Granitic Rocks and Monuments*, ed. J. Delgado Rodrigues 161-246. Brussels: European Commission.
- Feio, M. 1952. *A Evolu o do Relevo do Baixo Alentejo d Algrave; Estudo de Geomorphologia*. Lisbon: Centro Estudio Geographia.
- Gomes, C.J.P. 1997. Ecological Outline and Phytosociological Considerations. In *Paisagens Arqueologicas a Oestede  vora*, ed. P. Sarantopoulos, pp. 7-13.  vora, Portugal: C mara Municipal de  vora.
- Gomes, M.V. 1997a. The Cromlech of Almendres: One of the First Public Monuments of Mankind. In *Paisagens Arqueologicas a Oestede  vora*, ed. P. Sarantopoulos, pp. 33-34.  vora, Portugal: C mara Municipal de  vora.
- Gomes, M.V. 1997b. The Cromlech of Portela de Mogos: A Socio-Religious Monument. In *Paisagens Arqueologicas a Oestede  vora*, ed. P. Sarantopoulos, pp. 39.  vora, Portugal: C mara Municipal de  vora.
- Holtorf, C.J. 1998. The Life-Histories of Megaliths in Mecklenburg-Vorpommern (Germany). *World Archaeology* 30: 23-38.
- Houston, J.M. 1967. *The Western Mediterranean World*. New York: Frederick A. Praeger.
- Joussaume, R. 1985. Dolmens for the Dead. [translation by Chippindale, A., and Chippindale, C., 1988]. Ithaca: Cornell University Press.
- Kalb, P. 1996. Megalith-Building, Stone Transport and Territorial Markers: Evidence from Vale de Rodrigo,  vora, South Portugal. *Antiquity* 70:683-685.
- Krebs, W. 1976. The Tectonic Evolution of Variscan Meso-Europa. In *Europe from Crust to Core*, ed. D.V. Ager and M. Brooks, pp. 119-139. London: John Wiley and Sons.
- MacKie, E. 1977. *The Megalith Builders*. Oxford: Oxford University Press.
- Martins, A, and Barbosa, B.P. 1992. Planaltos do Nordeste da Bacia Terciaria do Tejo (Portugal). *Comunicacoes dos Sevcos Geologicos de Portugal* 78(1): 13-22.
- Meierding, T.C. 1993. Inscription Legibility Method for Estimating Rock Weathering Rates. *Geomorphology* 6: 273-286.

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- Molina, E., Blanco, J.A., Pellitero, E., and Cantano, M, 1987. Weathering Processes and Morphological Evolution of the Spanish Hercynian Massif. In *International Geomorphology* (part II), ed. V. Gardner, pp. 957-977. London: John Wiley and Sons.
- Paradise, T.R. 1995. Sandstone Weathering Thresholds in Petra, Jordan. *Physical Geography* 16: 205-222.
- Pimentel, N., and Azevedo, T.M. 1992. Sobre e Evolução do Relevo e Sedimentação Quaternária no Baixo Alentejo (Alvalade-Panoias). *Gaia* (Lisbon) 4: 21-24.
- Pope, G. A. 2000. Weathering of Petroglyphs: Direct Assessment and Implications for Dating Methods. *Antiquity*, in press.
- Robinson, D.A., and Williams, R.B.G. 1999. The Weathering of Hastings Beds Sandstone Gravestones in South East England. In *Aspects of Stone Weathering, Decay, and Conservation. Proceedings of the 1997 Stone Weathering and Atmospheric Pollution Network Conference (SWAPNet '97)*, ed. M.S. Jones and R.D. Wakefield. London: Imperial College Press.
- Romão, M.S.P., and Ratazzi, A. 1995. Biodeterioration on Megalithic Monuments: Study of Lichen's Colonization on Tapadão and Zambujeiro Dolmens (Southern Portugal). *International Biodeterioration and Biodegradation* 37: 23-35.
- Sequeira Braga, M.A., Lopes Nunes, J.E., Paquet, H., and Millot, G. 1990. Climatic Zonality of Coarse Granitic Saplrolites ("Arenes") in Atlantic Europe from Scandinavia to Portugal. In *Proceedings of the 9th International Clay Conference, Strasbourg, 1989, vol. I, Clay-Organic Interactions, Clay Minerals in Soils*, ed. V.C. Farmer and Y. Tardy. *Sciences Géologiques, Mémoire* 85: 99-108.
- Service, A., and Bradbery, J. 1979. *Megaliths and Their Mysteries*. New York: Macmillan Publishing Company.
- Sarantopoulos, P., ed. 1997. *Paisagens Arqueológicas a Oestede Évora*. Évora, Portugal: Câmara Municipal de Évora.
- Sellier, D. 1997. Utilisation de Mégalithes Comme Marqueurs de la Vitesse de l'Erosion des Granites en Milieu Tempéré: Enseignements Apportés par les Alignements de Carnac (Morbihan). *Zeitschrift für Geomorphologie, N.F.* 41: 319-356.
- Sherratt, A. 1990. The Genesis of Megaliths: Monumentality, Ethnicity and Social Complexity in Neolithic North-West Europe. *World Archaeology* 22: 147-167.
- _____. 1995. Instruments of Conversion? The Role of Megaliths in the Mesolithic/Neolithic Transition in North-West Europe. *Oxford Journal of Archaeology* 14: 245-260.
- Silva, B.M., Rivas, T., Prieto, B., Bello, J.M., Carrera, F. 1994. The Dombate Dolmen: A Case Study on the Development of Conservation Techniques for Megalithic Monuments. In *Degradation and Conservation of Granitic Rocks and Monuments*, ed. J. Delgado Rodrigues 367-372. Brussels: European Commission.

Sjöburg, R. 1994. Diagnosis of Weathering on Rock Carving Surfaces in Northern Bohuslän, Southwest Sweden. In *Rock Weathering and Landform Evolution*, ed. D.A. Robinson and R.B.G. Williams, pp. 223-41. Chichester, United Kingdom, John Wiley and Sons.

Tang, T. 1998. Field Testing of Rock Hardness and its Relationship to Limestone Dissolution in Guilin, Southern China. *Middle States Geographer* 31:15-22.

Twidale, C.R. 1982. *Granite Landforms*. Amsterdam: Elsevier.

Wakefield, R.D., and Jones, M.S. 1998. An Introduction to Stone Colonizing Micro-Organisms and Biodeterioration of Building Stone. *Quarterly Journal of Engineering Geology* 31: 301-313.

Warke, P.A., Smith, B.J., and Magee, R.W. 1996. Thermal Response Characteristics of Stone: Implications for Weathering of Soiled Surfaces in Urban Environments. *Earth Surface Processes and Landforms* 21:295-306