Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe

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Most radiocarbon dates for the earliest Neolithic cultures of west Mediterranean Europe are on samples of unidentified charcoal. If only results obtained on short lived samples (seeds, shells, and bone) of diagnostic material (domesticates, artifacts, and human remains) are considered, then the dates for the first appearance of the Neolithic package are indistinguishable statistically from central Italy to Portugal and cluster around 5400 calendar B.C. This rapidity of spread, no more than six generations, can be best explained in the framework of a maritime pioneer colonization model.

cardial | Neolithic | radiocarbon

A sound dating of the first appearance of agro-pastoral economies across Europe is a basic prerequisite to the evaluation of how, why, and when hunter-gatherer adaptive systems eventually disappeared from most of the continent in prehistoric times. The task, however, has not proved easy. Before the advent of accelerator mass spectrometer (AMS) radiocarbon dating, bulk samples of charcoal, bone, or shell had to be used, and in many instances the resultant dates were at odds with archaeological expectations based on stratigraphy and typology.

One source of problems was the use of shell samples, providing results biased by reservoir effects. This problem remains largely unsolved except for mid-Holocene marine samples from the western and southern Atlantic seaboards of Iberia. Through the comparison of results obtained by dating different kinds of samples from the same levels (44 shell and 20 charcoal or bone samples from 18 different archaeological contexts), it was possible to establish that the reservoir effect was of 380 ± 30 years for the most common mollusk species accumulated in the shell-middens of the time: *Cerastoderma* sp., *Patella* sp., and *Mytilus* sp. (ref. 1 and Marine Reservoir Correction database, http://radiocarbon.pa.qub.ac.uk/marine/). Thus, Portuguese and western Andalucian late Mesolithic and early Neolithic samples made up of these species can be calibrated now by using the curve for terrestrial samples (2) after subtraction of that apparent age from the raw before present (BP) result.

Another potential source of inaccuracy was the old wood effect, the impact of which was made apparent over the last decade, because the AMS direct dating of diagnostic material (bones from domestic animals and charred cereal seeds) became possible. In the case of the Linear Bandkeramik culture from central Europe, these AMS results suggested that its earliest phase dated to after ≈6400 BP, whereas dates on bulk charcoal samples suggested ages as early as ≈6900 BP (3, 4). AMS dating of domesticates has also shown that the beginning of agriculture in different parts of northwestern Europe was sometimes as much as 2 millennia later than thought previously on the basis of pollen diagrams and the assumption that appearance of "Neolithic" artifacts in the archaeological record could be used as a proxy for the introduction of agro-pastoral economies (5). Similar problems in the New World and Oceania were reported by Fritz (6) and Spriggs (7), respectively. The former noted that AMS dates on remains of the actual domesticated plants from sites in the Tehuacán valley and elsewhere in the Americas suggested the inception of agricultural practices much later than accepted previously on the basis of bulk charcoal samples from the levels containing those remains. The latter showed that "chronometric hygiene" was required for a correct understanding of the Lapita process and, hence, of the human colonization of Polynesia.

In west Mediterranean Europe (Fig. 1), problems inherent to the nature of the samples have been compounded by the fact that most archaeological evidence comes from caves and rock shelters (8). Postdepositional disturbance is commonplace in these kinds of sites; hence, when bulk charcoal samples are used, the association between the dated material and the historical events one wants to date cannot be taken for granted before appropriate critical filters are applied to evaluate the association (9, 10). When scrutinized from a taphonomic perspective, the very early chronology claimed for the inception of production economies in Mediterranean France and Spain must be rejected. The dates (some as early as ≈8000 BP) for the appearance of domesticates in such Spanish sites as Cueva de La Dehesilla (11) and Cova Fosca (12) were obtained from samples collected in disturbed contexts. The dated material contained in variable proportions late Paleolithic, Mesolithic, and Neolithic bone and charcoal, and the Neolithic artifact assemblages found therein corresponded to Epicardial contexts intruded into the underlying late Pleistocene or early Holocene deposits (10).

A side issue of the Mesolithic-Neolithic transition as seen from these kinds of sites was the local domestication of goats, suggested for Cova Fosca (13), and the late Mesolithic acquisition of exotic domestic sheep through long distance exchange mechanisms, suggested for Abri Dourgne and Grotte Gazel, among others (14). This was a definitional issue, involving the identification as domesticates of juvenile ovicaprid bones recovered in high mountain sites that might in fact belong to young chamois or ibex. Such identifications created the impression that in these regions the Neolithic did not spread as a complete integrated package. Instead, local hunter-gatherers would have gone through a process of piecemeal independent invention, or adoption, of different elements. However, once the taxonomic status of bones attributed to sheep reported for those Languedoc sites was reevaluated, the evidence for domesticates in the Mesolithic vanished (15). This made it clear that the Cardial and related impressed ware cultures of west Mediterranean Europe represent the simultaneous appearance in the archaeological record of the whole package of features involved in the earliest agro-pastoral practices of the region: animal and plant domesticates, ceramic vessels, polished stone axes, and village dwelling. None

Abbreviations: AMS, accelerator mass spectrometer; BP, before present; Cal, calendar.

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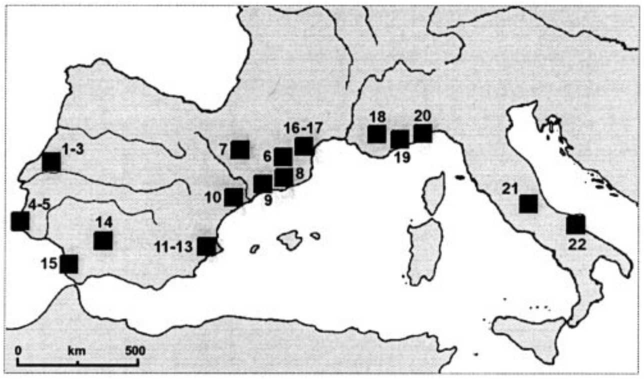

Fig. 1. Location of sites mentioned in the text. 1–3, Caldeirão, Pena d'Água, and Cisterna; 4–5, Cabranosa and Padrão; 6, Margineda; 7, Chaves; 8, La Draga; 9, Frare; 10, Fosca; 11–13, Cendres, Or, and La Falguera; 14, La Dehesilla; 15, El Retamar; 16–17, Dourgne and Gazel; 18, Baratin; 19, Pendimoun; 20, Arene Candide; 21, San Marco; 22, Coppa Nevigata.

of these have ever been found in secure, undisturbed Mesolithic contexts.

Since originally formulated (10), these conclusions have remained unchallenged. Their verification removed any empirical foundation for models describing the emergence of the Neolithic in west Mediterranean Europe as resulting from gradual east-west dispersal of economical and technical innovations. Such models dominated the literature for the last quarter of a century (16–18). They also are difficult to reconcile with the fact that there is no evidence for long distance exchange or trade networks through which indigenous hunter-gatherer groups could have acquired the Neolithic package (or any of its individual components) and transformed themselves into agro-pastoral societies. Moreover, no sound and testable ecological or social explanations have been offered for why local Mesolithic people would have been willing to undertake such a transformation.

These facts suggest that the spread of farming in west Mediterranean Europe was associated with some sort of demic diffusion process such as the "wave of advance" model put forward by Ammerman and Cavalli-Sforza (19, 20). According to their analyses, the annual rate of population growth experienced by frontier farmers can hardly have been greater than 1%, and ethnographically observed rates of migratory activity in similar situations never exceed 2,000 km^2 per generation. This rate carries the implication that the model will not work if observed rates for the spread of farming are greater than 2 km/year. Ammerman and Cavalli-Sforza calculated that the average rate from Greece to the British Isles was close to 1 km/year, which is within the model's expectations. Although regional variations in this overall rate were noted, their causes were thought to lie in environmental specificities (as in the Alpine area) or lack of data (as in the eastern Linear Band Keramik area and Iberia), and it was not conceived that their order of magnitude could be such as to threaten the validity of the model.

As more results were obtained, however, it became clear that in some cases (such as the Linear Bandkeramik and Cardial spreads) these regional rates were more than just "somewhat faster" or "somewhat slower" (10, 21). For instance, because the data indicated an inception of the Neolithic ≈5800 calendar (cal) B.C. in Ligúria, ≈5600 cal B.C. in Valencia, and ≈5400 cal B.C. in central Portugal, the rate of spread across the 2,000 km separating the two ends of the geographic distribution of the Cardial had to have been in the range of 5 km/year. Moreover, the style of decoration in ceramics from undated sites in Portugal implies contemporaneity with the earliest Cardial sites of eastern Spain (10, 22) and hence an even faster spread. It was suggested, therefore, that the mechanism best explaining the west Mediterranean process was maritime pioneer colonization (10, 22), a hypothesis first entertained for southern Portugal by Arnaud (23) and for which the occupation of the Pacific islands (24, 25) provides an analogy.

Chronology of the Iberian Cardial

Evidence accumulated over the last few years in Iberia shows that eliminating disturbed sites and mixed levels is not sufficient to obtain an adequate evaluation of the rate of spread of the Cardial. There are problems also with the dating of bulk charcoal or wood samples from levels that are unquestionably *in situ* because of the old wood effect.

Most frequently, this effect is produced by organic material including charcoal, derived from erosion of the surrounding early Holocene soils that contributed to the formation of deposits accumulated in caves or rock shelters in early Neolithic times. In addition, vertically displaced charcoal from underlying Pleistocene levels may penetrate early Neolithic levels even when no signs of disturbance are visible macroscopically and, hence, go unnoticed during excavation. Finally, the use as timber or as fuel of the centuries-old oak trees that constituted the Mediterranean forest cleared by the first agro-pastoral groups may result in the presence in early Neolithic deposits of wood or charcoal material belonging to the inner rings of those trees, the carbon-14 content of which had begun decaying before they were felled or burned. Ages obtained from samples of such material or including such material may be significantly older than the archaeological events for which dating was sought.

On the basis of evidence from the Portuguese cave site of Caldeirão (9) and the underwater lakeside dwelling of La Draga in northern Catalonia (26), it already had been suggested that this problem affected the dating of the earliest Neolithic in west Mediterranean Europe (10). At Caldeirão, AMS dates on short lived samples of diagnostic Neolithic material (human and sheep bone) indicated an age of ≈5150 cal B.C. for the site's Cardial occupation (Table 1). A conventional date on wood charcoal, however, indicated an age of ≈5750 cal B.C., 600 years earlier. At La Draga, conventional dates on charred cereal seeds indicated an age of ≈4900 cal B.C., as did similar dates on wood charcoal from hearth features, but the wood of an oak pillar was dated to ≈5350 cal B.C., 450 years earlier.

A recently published dating experiment (36) demonstrated conclusively that the old wood effect was indeed a major factor to be considered when accounting for the variability in dates from early Neolithic Iberian sites. The first result to be obtained for the Cardial deposits in Cova de les Cendres (Valencia) is 7540 ± 140 BP. The sample was made up of bulk charcoal, and the result was much earlier than the ≈6700 BP that would have been expected based on the dating of the Cardial elsewhere in Spain and France. This result prompted an investigation of the plant species represented in the charcoal assemblage and the consequent identification of *Pinus nigra* and *Juniperus* sp., the most common taxa in the underlying Pleistocene levels. Individual pieces of *P. nigra* and *Quercus* sp. found in the Cardial deposits were then submitted to AMS dating, with results of 20430 ± 170 BP for the former and 8310 ± 80 BP for the latter.

These results proved beyond a doubt that pieces of Pleistocene and early Holocene charcoal had made their way into the Cardial deposits. Dating a new series of bulk charcoal samples from which *P. nigra* and *Juniperus* sp. were excluded provided results closer to what might have been expected and that were accepted as good by the authors of the experiment: 6730 ± 80 BP and 6420 ± 80 BP. These samples included *Quercus* sp., however, and given the above-mentioned 8310 ± 80 BP result for an individual fleck of *Quercus* sp. charcoal from these

Table 1. Radiocarbon dates for the Cardial culture in Iberia (9, 10, 26–38)

Site name	Site type	Provenience	Sample	Lab number	Date BP	Cal B.C. 1σ	Cal B.C. 2σ
Caldeirão	Cave	Layer Eb	Wood charcoal	ICEN-296	6870 ± 210	5970–5570	6120–5370
		Horizon NA2	*Ovis aries* bone	OxA-1035	6330 ± 80	5348–5231	5480–5079
		Horizon NA2	*Ovis aries* bone	OxA-1034	6230 ± 80	5302–5072	5340–4940
		Horizon NA2	Human bone	OxA-1033	6130 ± 90	5226–4941	5296–4843
Pena d'Água	Rock-shelter	Layer Eb (base)	*Olea* sp. charcoal	Wk-9214	6775 ± 60	5724–5625	5766–5561
		Layer Eb (base)	Wood charcoal	ICEN-1146	6390 ± 150	5467–5215	5579–4993
Almonda	Cave	Cisterna-AMD2, level 1	Pierced *Cervus elaphus* canine	OxA-9287	6445 ± 45	5473–5369	5477–5321
		Cisterna-AMD2, level 1	Bone bead	OxA-9288	6445 ± 45	5473–5369	5477–5321
Cabranosa	Open air	Neolithic hearth	*Mytilus* sp. shells	Sac-1321*	6930 ± 60	5563–5389	5579–5325
Padrão	Open air	Hearth	*Tapes decussata* shells	ICEN-873*	6920 ± 60	5521–5386	5577–5318
		Hearth	*Cerastoderma edule* shells	ICEN-645*	6800 ± 50	5432–5278	5442–5255
Margineda	Cave	Level 3b base	Wood charcoal	Ly-2839	6670 ± 120	5627–5443	5725–5336
		Level 3b	Wood charcoal	Ly-3289	6850 ± 150	5839–5583	5977–5443
		Level 3a	Wood charcoal	Ly-3288	6640 ± 160	5633–5389	5773–5263
Chaves	Cave	Level I	Wood charcoal	GRN-12685	6770 ± 70	5680–5582	5726–5523
		Level I	Wood charcoal	GRN-12683	6650 ± 80	5593–5446	5662–5433
		Level I	Wood charcoal	CSIC-378	6460 ± 70	5440–5312	5521–5262
		Level I	Wood charcoal	GRN-12686	5210 ± 340†	Unacceptable, too young	
La Draga	Open air	Hearth E-6	Wood charcoal	GAK-1523†	5710 ± 170	4772–4357	4940–4175
		Hearth E-6	Wood charcoal	UBAR-245†	5920 ± 240	5194–4498	5366–4259
		Hearth E-40	Wood charcoal	UBAR-311†	5970 ± 110	4960–4718	5208–4552
		Hearth E-50	Wood charcoal	UBAR-312†	6570 ± 460	5929–5005	6360–4466
		Garbage disposal in H-30	Animal bone	UBAR-315†	6700 ± 710	6190–4854	7042–4046
		Post E-106	*Quercus* wood	UBAR-314	6410 ± 70	5432–5269	5444–5228
		Hearth E-56	Cereal seeds	UBAR-313	6010 ± 70	4951–4806	5065–4729
		Hearth E-3	Cereal seeds	Hd-15451	6060 ± 40	5031–4914	5061–4845
Frare	Cave	T22–23, level 5c	Wood charcoal	I-13030	6380 ± 310	5579–4946	5839–4594
Cendres	Cave	H19	Single *Pinus nigra* fleck	Beta-116625†	20430 ± 170	Unacceptable, too old	
		H19a	Single *Quercus* fleck	Beta-116624†	8310 ± 80	Unacceptable, too old	
		VIe	Wood charcoal, contaminants included	Ly-4302†	7540 ± 140	Unacceptable, too old	
		VII	Wood charcoal, contaminants excluded	Beta-75220	6730 ± 80	5662–5526	5712–5446
		H18	Wood charcoal, contaminants excluded	Beta-75219	6420 ± 80	5435–5269	5470–5225
		H17, fireplace	Wood charcoal	Beta-75218	6260 ± 80	5270–5076	5370–4990
		Estrato VII	*Hordeum vulgare*	Beta-142228	6340 ± 70	5457–5262	5474–5081
		VIIa	*Ovis aries* bone	Beta-107405	6280 ± 80	5280–5086	5416–5049
Or	Cave	J4, Levels 16–17	Wood charcoal	GANOP-C13	6720 ± 380	5956–5270	6356–4837
		J4, levels 14–15	Wood charcoal	GANOP-C12	6630 ± 290	5733–5270	6009–4938
		Basal Cardial (1955–58)	Cereal seeds	KN-51	6510 ± 160	5618–5318	5722–5079
		J4, level 17	*Triticum aestivum*	OxA-10192	6310 ± 70	5359–5153	5469–5067
		Upper Cardial (1955–58)	Cereal seeds	H-1754/1208	6265 ± 75	5316–5079	5459–5036
		J4, level 14	*Triticum aestivum*	OxA-10191	6275 ± 70	5317–5083	5459–5048
La Falguera	Rock shelter	EU 2051b	*Triticum monococcum*	Beta-142289	6510 ± 70	5512–5381	5616–5321
El Retamar	Open air		Marine shells	Beta-90122*	6780 ± 80	5434–5259	5470–5143

*Calibrated after subtraction of 380 ± 30 years for correction of the reservoir effect (1, 2).

†Not included in Fig. 4 because the result is unacceptable, or the large standard deviation makes its representation redundant or irrelevant in regard to other samples from the same site.

levels, in all probability these new determinations are skewed also by the old wood effect. This interpretation receives considerable support from the date for another individual fleck of *Quercus* sp. collected from the uppermost preceramic level of the site: 6670 ± 80 BP (39).

A sample of sheep bone, a short lived diagnostic Neolithic item, was dated to 6280 ± 80 BP. An almost identical result was obtained from charcoal collected in a hearth feature: 6260 ± 80 BP. Both are indistinguishable statistically from a new AMS date of 6340 ± 70 BP for a sample of barley, *Hordeum vulgare* (39). Together, these three dates show that the 2σ calibrated age of the earliest Neolithic occupation of Cendres lies in the interval between 5000 and 5500 cal B.C.

The major early Neolithic site in Mediterranean Spain undoubtedly is the Cova de l'Or, with its wealth of baroquely decorated ceramic vessels, sophisticated bone tools, personal ornaments, and abundance of cereal and sheep remains (37). These assemblages have been thought to date to ≈5600 cal B.C. on the basis of conventional carbon-14 results on well provenienced bulk charcoal samples from Bernat Martí's 1970s exca-

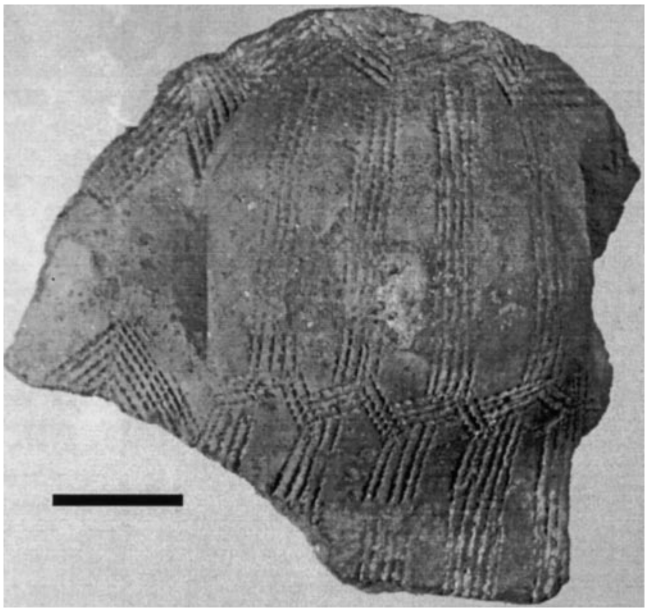

Fig. 2. Baroquely decorated Cardial sherd from Galeria da Cisterna (Vessel 1, zone AMD2). (Scale bar, 2 cm.)

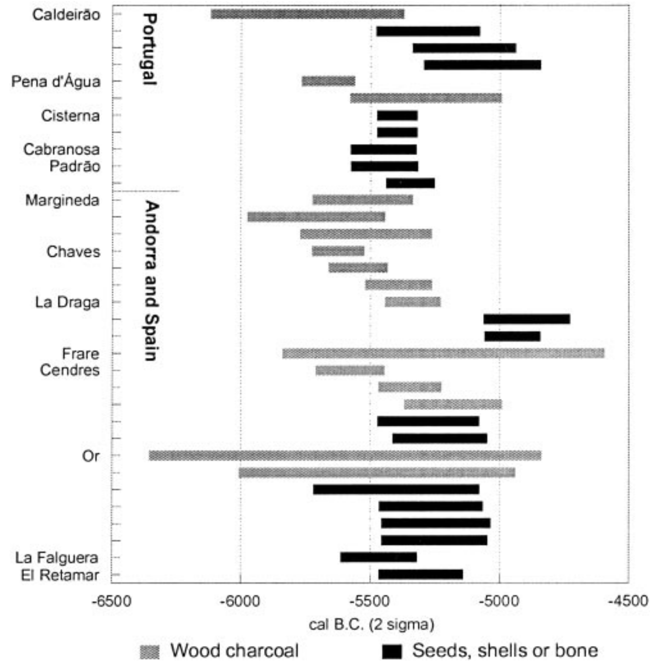

Fig. 4. 2σ calibrated dates for all dated Iberian Cardial sites.

vations. Despite their large standard deviations, these results might be taken to suggest that the earliest agro-pastoral economies of the region were only slightly later than those of Provence and Ligúria.

Zone AMD2, a burial chamber in the multicomponent Portuguese site of Galeria da Cisterna (Almonda karstic system) excavated in 1988-89 (40), features baroquely decorated Cardial ceramics (Fig. 2), stylistically similar to those from the basal levels of Or, and the same range of ornaments found throughout the latter's early Neolithic sequence. This suggests that the ceramics were deposited in the cave during funerary rituals by the earliest agro-pastoral settlers of littoral-central Portugal and that at least some of the ornaments might belong also to that early Cardial context. In fact, two particular kinds of pendants that are well represented in the Cisterna assemblage, pierced red deer canines and bone beads imitating their shape (Fig. 3), also are absent completely from both the previous Mesolithic and later post-Cardial periods of Portuguese prehistory.

Because the stylistically early Cardial ceramics from Cisterna were part of a palimpsest accumulated over time in thin Holocene deposits that included later Epicardial, Copper Age, Bronze Age, and Iron Age pottery, no faunal or human bone material could be associated securely with the early Cardial component. Thus, the Cisterna Cardial remained undated until recent publication of the ornaments from Or (41, 42) revealed that the two kinds of pendants mentioned above, pierced red deer canines and bone beads imitating them, are characteristic of the earliest part of that site's Neolithic sequence. This strengthens the hypothesis that such artifacts indeed were associated with the baroquely decorated Cardial pottery from Cisterna and that the Valencian Cardial (as at Or) represents the original cultural background of the first farming societies in littoral-central Portugal. The hypothesis was tested through AMS dating of one specimen of each ornament type, which provided the same result for both samples: 6445 $\pm$ 45 BP, that is, $\approx$5400 cal B.C.

These results are some 200-radiocarbon years younger than current estimates for the age of the lowermost Cardial levels from Or. Because the latter could be skewed by an old wood effect, as suggested by the Cendres experiment, two samples from the same levels, each made up of two charred wheat seeds, were submitted for AMS dating with the following results: 6275 $\pm$ 70 BP for level 14 (upper Cardial) and 6310 $\pm$ 70 BP for level 17 (basal Cardial). These results are identical statistically to previously available conventional dates on poorly provenienced seed samples from the 1950s excavations. At 2σ, the dates for Cisterna fall within the lower part of the time range represented by the new Or results, which therefore represent a second positive test of the hypothesis of contemporaneity and very close cultural connection between the earliest Neolithic occupations of the two sites.

Cova de l'Or also represents a fourth demonstration, with Caldeirão, La Draga, and Cendres, that the use of bulk charcoal samples blurs what in fact is a very clear picture (Fig. 4). When only results obtained on short lived samples of diagnostic Neolithic items are considered (including those on marine shells collected in Neolithic hearth features excavated at open air sites), all dates for the earliest Cardial, from Valencia to Portugal, are identical statistically. This conclusion receives further support from the new AMS date of 6510 $\pm$ 70 BP for wheat seeds from the Cardial levels of the La Falguera rock shelter (39). Such contemporaneity implies a very rapid spread,

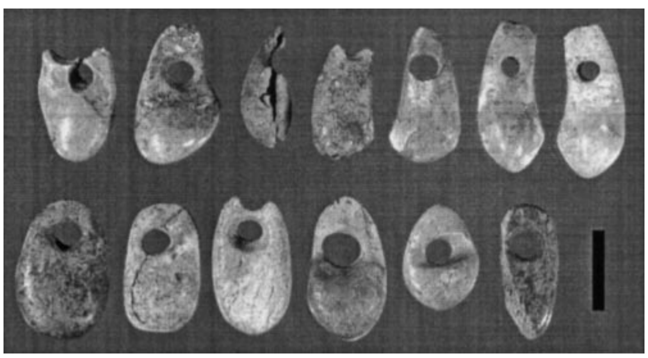

Fig. 3. Pierced red deer canines and bone beads imitating their shape from Galeria da Cisterna, zone AMD2. (Scale bar, 1 cm.)

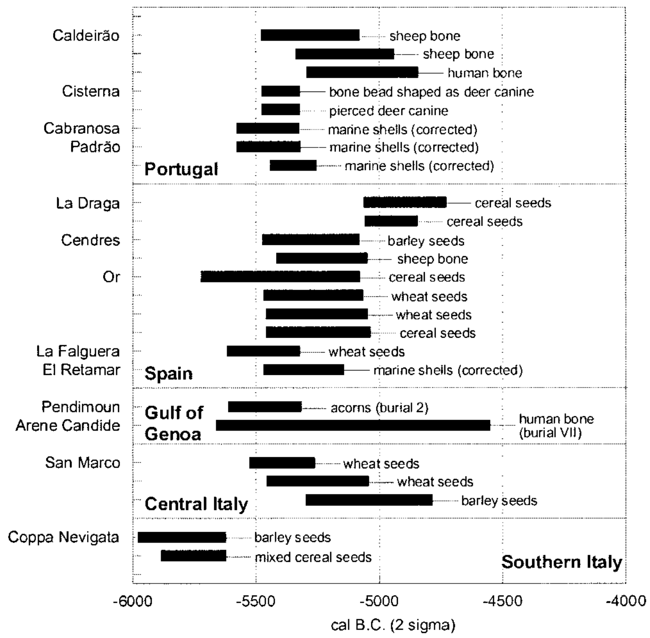

Fig. 5. 2σ calibrated dates on short lived diagnostic samples for the earliest Neolithic of west Mediterranean Europe.

within a maximum of four or five generations, of the Iberian Cardial.

Chronology of the Earliest Neolithic in France and Italy

The Iberian pattern suggests that radiometric chronology for the earliest Neolithic in neighboring regions to the east also may be skewed significantly by the old wood effect. Unfortunately, this hypothesis is difficult to test, because there are very few direct dates on diagnostic material. Those data that are available (refs. 43–46 and BANADORA database, http://carbon14.univ-lyon1.fr/banadora.htm), however, indicate the same problem for those regions.

At the open air site of Baratin (ref. 43 and BANADORA database) in Provence, AMS dates on individual pieces of charcoal from three different features provided ages between 6125 ± 80 BP (Lyon-100/OxA) and 6290 ± 70 BP (Lyon-252/OxA), several centuries younger than the previously available conventional date of 6600 ± 140 BP (Gif-1855). At the Arene Candide cave (44), AMS dating of identified charcoal showed that level 27 yielded both 6150 ± 70 BP (Beta-66552) remains of *Phillyrea* sp. and 6880 ± 60 BP (Beta-66553) remains of *Pistacia terebintus*. At Coppa Nevigata (3, 45), two dates on cereal seeds provided virtually identical ages of 6850 ± 80 BP (OxA-1474) and 6880 ± 90 BP (OxA-1475), yet the site was dated previously on conventional bulk charcoal to 7780 ± 320 BP (BM-2557).

The only other site in these regions for which AMS direct dates on diagnostic Neolithic material are available is that of San Marco in Umbria, central Italy (45–46), where three samples of *Triticum aestivum*, *Triticum compactum*, and *H. vulgare* seeds provided results of 6430 ± 80 BP (OxA-1853), 6270 ± 70 BP (OxA-1851), and 6120 ± 90 BP (OxA-1854), respectively. Two other conventional results can be considered also as unmistakably related to the early Neolithic use of the sites in question: the 6490 ± 75 BP (Ly-5340) date on acorns collected inside a burial feature at the Abri Pendimoun (43 and BANADORA database) and the 6255 ± 255 BP (GX-16963G) date on human bone from the burial VII of Arene Candide (44).

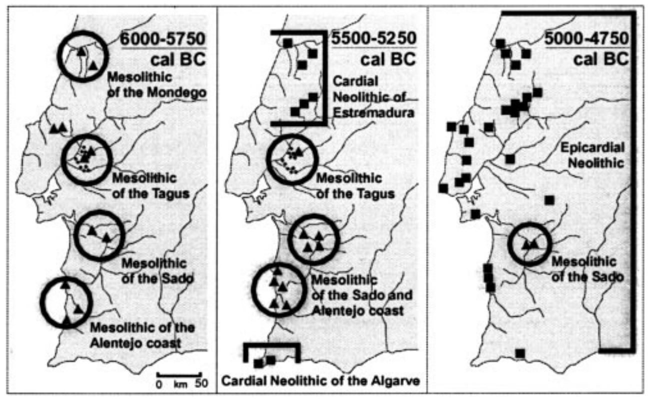

Fig. 6. Geographic distribution of late Mesolithic (▲) and early Neolithic (■) settlements in south-central Portugal between 6000 and 4750 cal B.C.

When calibrated, these results indicate that the Neolithic begins significantly earlier in southern Italy, perhaps as early as 6000 cal B.C. but that northward and westward all available dates on short lived diagnostic samples are identical to those for Iberia (Fig. 5). The 2σ range for the Cisterna dates (5477–5321 cal B.C.), for instance, falls inside that for the Pendimoun burial (5613–5316 cal B.C.), which is in turn virtually identical to that for La Falguera (5616–5321 cal B.C.). Therefore, the rapidity of spread mentioned above for Iberia applies to the dispersal of the Cardial and related cultures as a whole: 2,000 km from the gulf of Genoa to the estuary of the Mondego in probably no more than 100–200 years at most, that is, at a rate of at least 10–20 km/year. It should be stressed that this conclusion holds even if the French chronology based on conventional bulk charcoal samples is retained, because identical results on the same kinds of samples from *in situ* Cardial deposits are known in Portugal, not only at Caldeirão but also at Pena d'Água, where a sample of *Olea* charcoal recently has been dated to 6775 ± 60 BP (28). In any case, these data make it clear that the chronology of the early Neolithic in France and Italy must be revised entirely on the basis of more direct dates of domesticates or on other diagnostic short lived Neolithic materials such as bone artifacts or human bone from burials.

Conclusions

By using Ammerman and Cavalli-Sforza's equations (20) and an annual rate of population growth of 1%, one can calculate a rate of spread of 10 km/year, implying a rate of migratory activity of 60,000 km^2 per generation, 30 times greater than the maximum observed ethnographically. Demic diffusion therefore cannot have proceeded through a wave of advance mechanism of short distance settlement expansion wherein population growth was accommodated through gradual and slow incorporation of adjacent land.

The area covered by the 40–50-km-wide coastal strip between the Mondego river in Portugal and the cape of Nao, the southern limit of the gulf of Valencia, is precisely 60,000 km^2. In the framework of maritime pioneer colonization, the similarities in ornaments and pottery decoration observed between the two extremes of this range can be taken as evidence for a swift expansion with maintenance of cultural traditions, and the littoral placement of settlements is evidence for diffusion through sea routes. In fact, under reasonable estimates of annual population growth, the observed rate of spread across such a large area requires the operation of long distance relocation episodes. It also implies such low population densities across the whole of the settled range that large voids must be postulated between nodes of the farmers' settlement network.

This prediction is met in the archaeological record by the "enclave" nature of early Neolithic territories in littoral-central Portugal, which occupy areas previously uninhabited by late Mesolithic hunter-gatherers. The latter continue to thrive in their own territories for some 500 years after initial Neolithic settlement (refs. 10 and 22; Fig. 6), but contrasts in material culture, economy, nutrition, and mortuary behavior remain unchanged throughout this period. Neolithic sites feature pottery, polished hand axes, and heat pretreatment of flint, which are absent altogether from the Mesolithic, as are domesticates. Neolithic skeletons feature isotopic signatures of a fully terrestrial diet, whereas Mesolithic ones indicate a 50% marine component. Neolithic people are buried in special-purpose collective funerary sites, whereas Mesolithic people are buried individually in habitation sites and have never been found carrying exclusively Neolithic body ornaments (tear-shaped *Glycymeris* beads, pierced red deer canines, and bone beads imitating them).

The rapidity of the spread also indicates that long distance colonization events took place well before saturation levels were attained at the point of origin, suggesting that purely historical causes were in operation and that ultimate explanations for the phenomenon must lie within the specific features of antecedent processes triggering the expansion of agro-pastoral economies from their Middle Eastern core areas. One possibility is that after the collapse of the levantine pre-pottery Neolithic B, for which there is significant evidence of social stratification and strongly developed cult practices, the succeeding westward-spreading Neolithic societies, which lack any archaeological evidence of specially built temples and of ranking in settlement or in burial, fissioned before groups became too large and severe conflict or social inequality developed (22, 47, 48). Along the north Mediterranean shores, this tendency to fission and move on would have been reinforced further because opportunities for settlement and expansion around initial enclaves were limited by physical geography and the presence of local hunter-gatherer groups.

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