population explosions that coincided exactly with the periods of maximum temperature differences between the two seas. We do not have sufficient information to reject this possibility but do not consider it very likely.

W. G. DEUSER
E. H. ROSS
L. S. WATERMAN
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

References and Notes

1. For example, see R. F. Flint, *Geol. Soc. Am. Bull.* **70**, 343 (1959); R. W. Fairbridge, *Geol. Rundsch.* **54**, 399 (1965); J. E. Damouth and R. W. Fairbridge, *Geol. Soc. Am. Bull.* **81**, 189 (1970); K. W. Butzer, G. L. Isaac, J. L. Richardson, C. Washbourn-Kamau, *Science* **175**, 1069 (1972); C. Parmenter and D. W. Folger, *ibid.* **185**, 695 (1974); R. E. Newell, G. F. Herman, S. Gould-Stewart, M. Tanaka, *Nature (London)* **253**, 33 (1975).
2. O. Krümmel, *Handbuch der Ozeanographie* (Engelhorn, Stuttgart, 1907), vol. 1, p. 332.
3. H. Craig, *Science* **154**, 1544 (1966).
4. C. Emiliani, *Am. J. Sci.* **252**, 149 (1954); N. J. Shackleton, J. D. H. Wiseman, H. A. Buckley, *Nature (London)* **242**, 177 (1973).
5. R. B. Whitmarsh *et al.*, *Initial Reports of the Deep-Sea Drilling Project* (Government Printing Office, Washington, D.C., 1974), vol. 23, p. 677; E. Vincent, W. E. Frerichs, M. E. Heiman, *ibid.*, vol. 24, p. 827. The correlation between the data for the two sites was improved considerably by expanding to 13.4 m the coring gap below core 1 at site 228 in the Red Sea, which in the *Initial Reports* is given the nominal length of 10 m.
6. The per mil enrichment in ^{18}O relative to the standard Pee Dee belemnite (PDB) carbonate is $\delta^{18}O = 1000[(R/R_{PDB}) - 1]$, where R is the ratio $^{18}O/^{16}O$.
7. W. S. Broecker and J. van Donk, *Rev. Geophys. Space Phys.* **8**, 169 (1970).
8. S. Epstein, R. Buchsbaum, H. A. Lowenstam, H. C. Urey, *Geol. Soc. Am. Bull.* **64**, 1315 (1953); C. Emiliani, *J. Geol.* **63**, 538 (1955).
9. J. L. Gevirtz and G. M. Friedman, *J. Sediment. Petrol.* **36**, 143 (1966); W. G. Deuser and E. T. Degens, in *Hot Brines and Recent Heavy Metal Deposits in the Red Sea*, E. T. Degens and D. A. Ross, Eds. (Springer, New York, 1969), p. 336; J. D. Milliman, D. A. Ross, T.-L. Ku, *J. Sediment. Petrol.* **39**, 724 (1969).
10. Naval Oceanographic Office, *Monthly Charts of Mean, Minimum and Maximum Sea Surface Temperature of the Indian Ocean* (Spec. Publ. SP-99, Naval Oceanographic Office, Washington, D.C., 1967).
11. Supported by NSF grant GA-38199. Sediment samples were supplied by the Deep-Sea Drilling Program, funded by the National Science Foundation. We thank R. L. Fleisher for help in questions of micropaleontology, especially during the initial stages of the work. Contribution No. 3670 from the Woods Hole Oceanographic Institution.

8 December 1975

Historical Dates for Neolithic Sites of Southeast Europe

Abstract. *Direct comparison of the radiocarbon contents of charcoal samples with those of bristlecone pine wood samples dated by tree rings shows that a full-fledged Neolithic with pottery and all the domesticated animals, except the horse, was present in southeast Europe as early as the 65th century B.C. The chronologies for the stratigraphic sequences of the settlements of Achilleion and Anza, based on a total of 37 La Jolla radiocarbon measurements, cover almost 1000 years.*

Neolithic sites have been excavated in the Aegean area from the beginning of this century (*1*), but their chronological context was not clearly understood for decades. The steady increase of systematic investigations of stratified mounds and caves (*2*), coupled with the advent of radiocarbon dating, brought on drastic revisions for interpreting the true age of the southeast European Neolithic (*3–5*). It is now clear that a full-fledged Neolithic stage of animal and crop domestication, including hard-baked pottery, existed in southeast Europe as early as the middle part of the seventh millennium B.C. At this stage, emmer wheat, barley, peas, and lentils were cultivated and all animals were domesticated except the horse. Obsidian trade was known; fine stone carving and ceramic techniques attest a high level of development, as does the architecture of solidly built rectangular houses of pisé or mud-brick walls and plastered floors. This fully developed agricultural civilization of Europe was essentially contemporaneous with those of Anatolia and Mesopotamia.

Of the 20 systematically excavated mounds in Thessaly and Macedonia, the settlements of Achilleion and Anza are of exceptional value for chronological studies. The mound of Achilleion is located on the edge of the Karditsa Plain of Thessaly, Greece. It was excavated in 1973–74 (*4*). Anza is located in Ovče Polje, in the River Vardar basin, in eastern Macedonia, and was excavated in 1969–71 (*5*). Both locations are multiple-strata sites yielding stratigraphic evidence of millennial duration, which covers complete sequences of the Sesklo civilization in Greece (Achilleion) and Starčevo–Early Vinča in Yugoslavia (Anza).

The long-lived bristlecone pine (*Pinus aristata*) of California has made it possible to establish a continuous absolute tree-ring chronology going back to the sixth millennium B.C. Prior to 4000 B.C. the chronology is based on 28 individual wood specimens (*6*). Cross-dating of these specimens has now made it possible to continue the sequence to beyond 6200 B.C. From this early sequence a limited number of samples, each comprising ten annual tree rings, consisted of more than 18 g of wood and were suitable for carbon-14 determinations.

Recently, European workers have been able to extend their tree-ring chronology, essentially from European oaks, to about 300 B.C. (*7*). Comparisons of samples from these two tree-ring series showed that irrespective of their place of origin, samples of wood grown at the same time have essentially the same carbon-14 content. Effects from in situ production of carbon-14 and from the physiology of wood growth must be negligible (*8*).

The experimental errors encountered when the carbon-14 contents of two wood samples are compared arise not only from statistical counting errors, but also from uncertainties in the counter calibrations. These calibration errors are practically avoided if measurements of the two samples are carried out in the same laboratory, preferably at the same time. In this way the most accurate single radiocarbon dates are obtained. In principle, it is possible to obtain results of even greater accuracy if series of samples from so-called floating tree-ring sequences are available. Age determinations of this type have been carried out for Neolithic settlements of Swiss lake dwellers (*9*). Unfortunately, floating tree-

Table 1. Conventional radiocarbon ages (*12*) of three samples from Achilleion (Table 2) and of six tree ring–dated bristlecone pine (BCP) wood samples listed in sequence of measurement. Values in the last column are given with their 1 σ statistical counting error (*12*). Abbreviations: LJ, La Jolla; B.P., before present.

LJ number	Sample	Archeological field number	Tree-ring age (years B.C.)	Conventional radiocarbon age (years B.P.)
3306	BCP wood		6030–6020	7125 ± 55
3308	BCP wood		5960–5950	6958 ± 100
3325	Charcoal	B-5 L-21		7287 ± 52
3310	BCP wood		5990–5980	7124 ± 52
3328	Charcoal	B-1 L-19		7307 ± 52
3311	BCP wood		6000–5990	7194 ± 53
3312	BCP wood		6020–6010	7156 ± 52
3329	Charcoal	B-1 L-26		7368 ± 52
3314	BCP wood		6050–6040	7103 ± 51
3313	BCP wood		5980–5970	7053 ± 51
Average of seven BCP wood samples			5999	7100 ± 21
Average of LJ 3325 and LJ 3328 (IIa2)			6211	7297 ± 36

ring sequences of prehistoric significance are rarely available.

We have measured the radiocarbon contents of three charcoal samples from the mound of Achilleion, alternating them with samples of bristlecone pine wood dated by tree rings as from the 61st and 60th centuries B.C. (Table 1). This direct comparison ascertains the exact century of the respective horizons and allows a reliable extrapolation to other archeological phases for which radiocarbon dates have been determined. The measurements were carried out by counting the samples as acetylene gas in two independent sets of instruments ("M & B" and "Tim") for 2 days each.

The age range of the bristlecone pine samples was too small to recognize any changes in the radiocarbon level of the atmospheric carbon dioxide during the period in question. Comparison with bristlecone pine wood measured previously in the 5400 B.C. time range shows that during the first half of the sixth millennium B.C. $\Delta^{14}C$ rose by approximately 1 percent. The measurements on bristlecone pine wood so far carried out do not allow one to recognize any "wiggles" during that period of time. If the assumption is made that there was no change in the carbon-14 content of the atmospheric carbon dioxide during the period under consideration, then the average conventional radiocarbon age of all the bristlecone pine samples measured corresponds to an average true age of the bristlecone pine samples as determined from tree rings. Likewise, with this assumption, the statistical standard error of the average age can be calculated from the errors of the individual measurements. The averages of the values are given in Table 1. Also given in Table 1 is the average of the results for two archeological samples that, according to their stratigraphic position, belong to the same archeological horizon.

The La Jolla laboratory used two different pairs of counters, one (M & B) for samples for which sufficient material was available, and the second (Tim) for cases where relatively small samples were at our disposal. With very few exceptions, all samples, including those measured by the two other laboratories [at the University of California at Los Angeles (UCLA) and the University of Pennsylvania], are in agreement within the expected accuracy of the measurements. It should be noted that comparison of results, as listed in Table 1, does not improve the values for the absolute dates because of the slight uncertainties in background and standard values.

Investigators at Achilleion have identified four periods of Sesklo development with 12 clearly defined subphases, beginning with an early ceramic phase and culminating in the final Sesklo stages. Table 2 lists the results of radiocarbon measurements for charcoal samples from these 12 stages in sequence of their stratigraphic position.

With the assumption made above, that the ^{14}C content of atmospheric carbon

Table 2. Conventional radiocarbon ages (*12*) and 1σ statistical counting errors (*12*) of charcoal samples from Achilleion, Greece, and their most probable historical ages derived by direct comparison with dendrochronologically dated bristlecone pine wood with a similar radiocarbon content (Table 1).

Archeological stratum	Field number	Laboratory number	Conventional radiocarbon age (years B.P.)					Most probable historical date (years B.C.)
			La Jolla		UCLA (*10*)	Pennsylvania	Average	
			M & B counters	Tim counters				
IVb	D-4 L-2	1882A			6930 ± 155			
IVa	C-4 L-9	3202		6986 ± 100				
	D-2 L-7	2130				7084 ± 91	7035 ± 80	
IIIc	B-4 L-10	2941	6950 ± 51					
	B-4 L-13	2125				6964 ± 87		
	A-1 L-10	2943		6963 ± 80				
	D-2 L-11	3200		7014 ± 80			6981 ± 50	5900
IIIb	A-1 L-13	1896B			7180 ± 155			
	A-2 L-14	2124				7086 ± 85		
	A-3 L-14	1896E			7280 ± 100			
	A-3 L-14	2123				7454 ± 78		
IIIa2	A-2,3 L-15,16	2942	7180 ± 51					
	B-2 L-16	2122				7107 ± 86		
	B-2 L-17	2121				7181 ± 85	7160 ± 50	
IIIa1	B-4 L-15–18	2940		6588 ± 80				
	B-4 L-18	2944	7018 ± 50					
	C-1 L-21	3182	6922 ± 52					
	A-1 L-18	2120				7342 ± 68		
	A-4 L-21	3327		7120 ± 60			7066 ± 40	6000
IIb	D-2 L-18	1896C			7330 ± 100			
	D-2 L-19	3201		7212 ± 80				
	A-2 L-22	3326		7286 ± 80			7270 ± 50	
IIa2	D-2 L-22	3181	7246 ± 53					
	B-1 L-19	3328	7307 ± 50					
	B-5 L-21	3325	7287 ± 50				7280 ± 30	6200
IIa1	A-1 L-26	2117				7273 ± 76		
Ic	B-5 L-24	3186	7296 ± 50					
Ib	B-1 L-31	1882B			7260 ± 155			
	B-2 L-27	3184	7322 ± 53					
	B-1 L-26	3328	7368 ± 52				7345 ± 40	6300
Ia	B-2 L-26	2118				7471 ± 77		
	T-7 L-11,12	1896A			7460 ± 175		7470 ± 70	6450

Table 3. Conventional radiocarbon ages, with 1 σ statistical counting errors (*12*) and most probable historical ages of charcoal samples from Anza, Yugoslavia, derived in the same manner as for the samples listed in Table 2.

Archeological stratum	Field number	Laboratory number	Conventional radiocarbon age (years B.P.)				Most probable historical date (years B.C.)
			La Jolla		UCLA	Average	
			M & B counters	Tim counters or one counter			
IV	VIII 55	2411		6070 ± 190			
	XX 190	2329	6210 ± 60			6200 ± 60	5200
III	V 62	2185		6510 ± 110			
	L 19	1705B			6540 ± 120		
	VII 191	2345		6540 ± 120			
	L 20	1705C			6700 ± 80	6600 ± 50	5500
II	VII 117	2344		7000 ± 270			
	VII 121	2343		7000 ± 280			
	VII 177	2338		6800 ± 140			
	VII 122	2337		7080 ± 60			
	VII 213,215	2405		6940 ± 80			
	VII 124	2351		7040 ± 90			
	VII 156	2409	6850 ± 50			6900 ± 35	
Ib	VII 251	2342		7100 ± 80			
	VII 240	2339		7110 ± 80			
	VII 253	2333		6840 ± 120			
	VII 188	2341		7230 ± 170			
	VII 256	2332		7110 ± 120		7100 ± 40	6000
Ia	V 90–110	3183	7150 ± 50				
	V 76–86	3186	7140 ± 70				
	V 103–120	3032	7210 ± 50				
	VII 257	233011	7170 ± 60				
	V 111	2181		7270 ± 140		7190 ± 30	6100

dioxide did not change noticeably between 6400 and 5800 B.C., the absolute historical dates listed in the last column in Table 2 are obtained. It appears that the earliest stratum (Ia) dates from the 65th century B.C. Unfortunately, no datable material from this stratum was available for measurements at La Jolla, but the four determinations [two from the Pennsylvania (*10*) and two from the UCLA (*11*) laboratories] indicate that it is close to 200 years older than the next stage (Ib), which is dated by direct comparison with bristlecone pine wood.

The next younger stages follow in unusually rapid succession, differing in age by hardly more than the counting errors. This could be due to rapid development, or to a drop in $\Delta^{14}C$ during this period. Such a drop would let the older samples appear too young by up to 200 years relative to the younger ones. Therefore, the possibility cannot be entirely excluded that the earliest stages of Achilleion could date from the 66th or even 67th century B.C. Nothing final, however, can be said as long as no wood from this period that has been dated by tree rings is available for ^{14}C determinations.

The upper strata of the archeological sequence of Achilleion have ages close to those of the bristlecone pine samples, and therefore $\Delta^{14}C$ changes cannot affect the results. The four stages of period three, IIIa1, IIIa2, IIIb, and IIIc almost certainly belong to the 61st and 60th centuries B.C.

The earliest dates from the Anza settlement (Table 3) are synchronous with the end of Achilleion II or the beginning of Achilleion III. As the cultural and physical characteristics of Anza are closely related to those of Achilleion, it can be deduced that a lapse of about 300 years took place as the Thessalian culture spread northward into the central Balkans. The 12 radiocarbon dates from Anza position its four major periods within a chronology of almost 1000 years. In this way, stratigraphic data combined with radiocarbon dates provide an indispensable yardstick for determining the chronology of the inland portion of the Balkan Peninsula—the formation and duration of the Starčevo and Early Vinča cultures.

C. Wesley Ferguson

Laboratory for Tree-Ring Research, University of Arizona, Tucson 85721

Marija Gimbutas

Institute for Archaeology, University of California, Los Angeles 90024

Hans E. Suess

Department of Chemistry, University of California, San Diego, La Jolla 92093

References and Notes

1. C. Tsountas, *Ai oroistorikai akropoleis Diminou neai Sesklo* (Athens, Greece, 1908); A. J. B. Wace and M. S. Thompson, *Prehistoric Thessaly* (Cambridge Univ. Press, Cambridge, England, 1912).
2. V. Milojčič, J. Boessneck, M. Hopf, *Die Deutschen Ausgrabungen auf der Argissa Magula in Thessalien: Beiträge zur ur-und frühgeschichtlichen Archäologie des Mittelmeer-Kulturraumes* (Habelt, Bonn, 1962); J. Milojčič von Zumbusch and V. Milojčič, *Die Deutschen Ausgrabungen auf der Otzaki-Magula in Thessalien I. Das frühe Neolithikum: Beiträge zur ur-und frühgeschichtlichen Archäologie des Mittelmeer-Kulturraumes* (Habelt, Bonn, 1971).
3. S. Weinberg, *Hesperia* **31**, 158 (1962); R. J. Rodden, *Sci. Am.* **212**, 82 (April 1965); T. W. Jacobsen, *Hesperia* **42**, 45 (1973).
4. M. Gimbutas, *J. Field Archaeol.* **1**, 277 (1974).
5. ———, *ibid*, p. 26.
6. C. W. Ferguson, *Science* **159**, 839 (1968); *Tree-Ring Bull.* **29**, 3 (1969); in *Radiocarbon Variations and Absolute Chronology*, I. U. Olsson, Ed. (Wiley, New York, 1970), p. 237; in *Proceedings of the Eighth International Radiocarbon Dating Conference*, T. A. Rafter and T. Grant-Taylor, Eds. (Lower Hutt, New Zealand, 1972), vol. 1, p. P. E. Damon, *et al.*, *Am. Antiq.* **39**, 350 (1974).
7. H. Becker, private communication.
8. W. F. Cain and H. E. Suess, *J. Geophys. Res.*, in press.
9. C. W. Ferguson, B. Huber, H. E. Suess, *Z. Naturforsch. Teil A* **21**, 1173 (1966); H. E. Suess and C. Strahm, *Antiquity* **44**, 91 (1970).
10. B. Lawn, *Radiocarbon* **17**, 200 (1975).
11. R. Berger and W. F. Libby, *ibid.*, in press.
12. Conventional radiocarbon ages, or "Libby ages," are by definition calculated with a radiocarbon half-life of 5568 years and normalized to a zero age in A.D. 1950. The definition of statistical counting error can be found in most textbooks on statistics or radioactivity.
13. Thanks are due to T. Linick for supervising and to C. Hutto for carrying out the technical operations of radiocarbon determinations. These determinations were financed by NSF grant DES74-22864. Archeological fieldwork was supported by NSF grant Soc. Sci. 73-09168 and dendrochronological research by NSF grant GP-4892.

17 November 1975; revised 5 January 1976

X-ray Microscopy of Biological Objects with Carbon Kα and with Synchrotron Radiation

Abstract. *X-ray micrographs of biological objects have been obtained with a resolution better than 1000 angstroms by using poly(methyl methacrylate) x-ray resist and carbon Kα or synchrotron radiation. Synchrotron radiation allows short exposure times; storage rings especially designed as radiation sources and improved x-ray resists would make exposure times under 1 second possible.*

The last few years have seen considerable effort in lithography to fabricate devices of smaller and smaller dimensions. Scanning electron beam systems (*1*) can generate patterns with line widths of less than 0.1 μm. X-ray lithography (*2–4*) promises a cheap replication technique for such high-resolution patterns. The well-