APPARENT ^{14}C AGES OF MARINE MOLLUSK SHELLS FROM A GREEK ISLAND: CALCULATION OF THE MARINE RESERVOIR EFFECT IN THE AEGEAN SEA

YORGOS FACORELLIS, YANNIS MANIATIS

Laboratory of Archaeometry, Institute of Materials Science, NCSR "Demokritos"
153 10 Aghia Paraskevi, Attiki, Greece

and

BERND KROMER

Heidelberg Academy of Sciences, Neuenheimer Feld 366, D-69120 Heidelberg, Germany

ABSTRACT. The excavation of the Cyclope cave, situated on the deserted island of Youra in the Northern Sporades (39°22′N, 24°10′E), revealed material of marine and terrestrial origin in undisturbed layers, suitable for radiocarbon dating. In some cases, material from different reservoirs was found together in the same archaeological layer. This research had two aims. The first was the dating of charcoal-seashell pairs in order to determine the marine reservoir effect in this region, based on samples with ages spanning from the end of the 8th millennium to the beginning of the 7th millennium BC. The second aim was dating the stratigraphy of this site, by using the calculated ΔR value in conjunction with the marine calibration curve. This enabled the accurate calibration of the ^{14}C ages of marine samples found in layers without charcoal pieces. The results show that this is the oldest human settlement ever found on an island in the Aegean Sea.

INTRODUCTION

The deserted island of Youra is located *ca.* 30 km northeast of the island Alonnessos (39°22′N, 24°10′E), which belongs to the group of Northern Sporades islands in the Aegean Sea. In the southern part of the island and at an elevation of 150 m from the present sea level the so-called Cyclope cave is found, the largest known cave in the Sporades (50 × 60 m, Fig. 1) (Sampson 1996).

During the excavation of this site three pilot trenches were opened, one in the center of the cave (Trench A) and the other two near the entrance (Trench B and C) (Fig. 1). From these trenches material of different types suitable for ^{14}C dating was unearthed. More specifically, charcoal pieces from fireplaces, food remains such as terrestrial and marine mollusk shells, and bones from mammals, birds and fish were collected. This site, therefore, provided an excellent opportunity to determine the reservoir effect in the Aegean Sea and the local deviation constant (ΔR value) from the global carbon-cycle model (Stuiver, Pearson and Braziunas 1986; Stuiver and Braziunas 1993), which has not yet been measured in this part of the world.

At the same time, the absence of charcoal and bones of terrestrial animals from several occupational layers made it necessary to obtain reliable calendar dates from marine samples. The goal of this paper is to determine the marine reservoir effect in this region by dating contemporaneous terrestrial-marine pairs of samples buried together in certain layers in the cave. A second aim is to apply this reservoir correction in order to obtain accurate calendar dates for all archaeological layers.

So far 26 samples have been dated from the Cyclope cave, originating from all three pilot trenches (Fig. 1). The description of the samples is presented in Table 1; additional information for each sample is given in the Appendix.

Proceedings of the 16th International ^{14}C Conference, edited by W. G. Mook and J. van der Plicht
RADIOCARBON, Vol. 40, No. 2, 1998, P. 963–973

https://doi.org/10.1017/S0033822200018932 Published online by Cambridge University Press

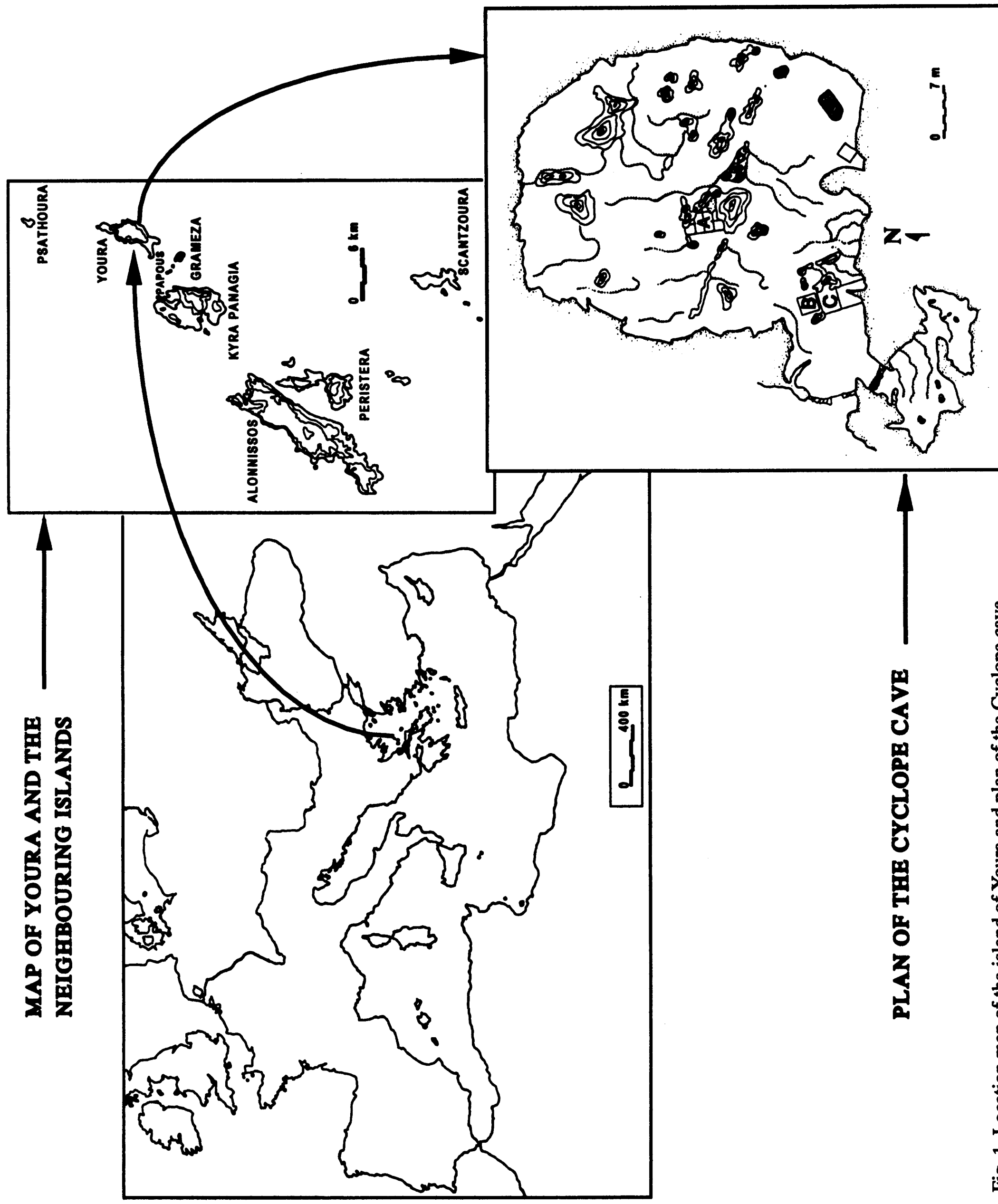

Fig. 1. Location map of the island of Youra and plan of the Cyclope cave

https://doi.org/10.1017/S0033822200018932 Published online by Cambridge University Press

TABLE 1. Description of Samples and Dating Results from the Cyclope Cave on the Island of Youra

Lab code	Trench	Date of unearthing	Material	$\delta^{13}C$ (‰)	^{14}C age (yr BP)	Calibrated date (cal AD/BC)	Corrected calibrated date (cal BC)
DEM-268	A, Layer 3, Square (1-2) Depth 0.37 m	3/7/1992	Charcoal	−25.00	1879 ± 51	79–225 AD (68.3%) 23–312 AD (95.4%)	
DEM-266	B, Layer 4, Square 4 Depth 0.70 m	3/7/1992	Charcoal	−25.00	6837 ± 40	5703–5630 BC (68.3%) 5732–5598 BC (95.4%)	
DEM-267	B, Layer 7, Square (1-4) Depth 1.18 m	3/7/1992	Charcoal	−25.00	5311 ± 36	4226–4044 BC (68.3%) 4241–4000 BC (95.4%)	
DEM-392	C/West, Layer 5, Square (1-4) Depth 0.80–0.90 m	7/7/1993	Charcoal	−25.00	34 ± 56	1703–1917 AD (68.3%) 1683–1934 AD (95.4%)	
DEM-345	C/West, Layer 5, Square (1-4) Depth 0.80–0.90 m	5/7/1993	*Patella ulyssiponensis* Gmelin	1.00	6730 ± 38	5290–5229 BC (68.3%) 5329–5203 BC (95.4%)	5196–5054 BC (68.3%) 5226–4997 BC (95.4%)
DEM-393	C/West, Layer 6, Square (1-4) Depth 1.20 m	7/7/1993	Charcoal	−25.00	7398 ± 64	6341–6170 BC (68.3%) 6377–6047 BC (95.4%)	
DEM-370	C/West, Layer 6, Square (1-4) Depth 1.20 m	7/7/1993	*Patella ulyssiponensis* Gmelin	1.00	7971 ± 41	6459–6389 BC (68.3%) 6520–6355 BC (95.4%)	6358–6210 BC (68.3%) 6394–6166 BC (95.4%)
DEM-369	C/West, Layer 7, Square (1-4) Depth 1.40–1.50 m	8/7/1993	*Patella ulyssiponensis* Gmelin	1.00	7803 ± 41	6338–6200 BC (68.3%) 6368–6165 BC (95.4%)	6164–6032 BC (68.3%) 6206–5991 BC (95.4%)
DEM-368	C/West, Layer 8, Square (3-4) Depth 1.70–1.85 m	13/7/1993	*Patella ulyssiponensis* Gmelin	1.00	8218 ± 43	6797–6608 BC (68.3%) 6935–6576 BC (95.4%)	6586–6455 BC (68.3%) 6645–6414 BC (95.4%)
DEM-431	C/West, Layer 9, Square 5 Depth 1.85–2.00 m	6-7/7/1994	*Patella ulyssiponensis* Gmelin	0.17*	8624 ± 20	7366–7261 BC (68.3%) 7403–7227 BC (95.4%)	7182–7023 BC (68.3%) 7246–6996 BC (95.4%)
DEM-430	C/West, Layer 9, Square 5 Depth 1.85–2.00 m	6-7/7/1994	*Helix cincta* (Müller)	−8.75*	8754 ± 20	7903–7700 BC (68.3%) 7925–7632 BC (68.3%)	
DEM-435	C/West, Layer 11, Square 4 Depth 2.20–2.40 m	11/7/1994	*Patella ulyssiponensis* Gmelin	1.02*	8776 ± 19	7483–7429 BC (68.3%) 7505–7410 BC (95.4%)	7385–7254 BC (68.3%) 7417–7199 BC (95.4%)
DEM-434	C/West, Layer 11, Square 4 Depth 2.20–2.40 m	11/7/1994	*Helix cincta* (Müller)	−7.93*	8855 ± 28	7974–7744 BC (68.3%) 8018–7728 BC (95.4%)	
DEM-597	C/West, Layer 14, Square 1 Depth 2.90–3.10 m	14-15/7/1994	Charcoal	−25.00	9274 ± 43	8388–8196 BC (68.3%) 8411–8098 BC (95.4%)	

TABLE 1. Description of Samples and Dating Results from the Cyclope Cave on the Island of Youra *(Continued)*

Lab code	Trench	Date of unearthing	Material	$\delta^{13}C$ (‰)	^{14}C age (yr BP)	Calibrated date (cal AD/BC)	Corrected calibrated date (cal BC)
DEM-416	C/East, Layer 14, Square 1 Depth 1.95–2.20 m	20/7/1994	*Patella ulyssiponensis* Gmelin	0.91*	8864 ± 37	7553–7486 BC (68.3%) 7588–7455 BC (95.4%)	7461–7345 BC (68.3%) 7490–7277 BC (95.4%)
DEM-415	C/East, Layer 14, Square 1 Depth 1.95–2.20 m	20/7/1994	*Helix cincta* (Müller)	−8.94*	8834 ± 20	7958–7738 BC (68.3%) 8000–7709 BC (95.4%)	
DEM-521	C/East, Layer 14, Square 9 Depth 2.03–2.13 m	5/7/1995	Charcoal	−25.00	4814 ± 25	3643–3540 BC (68.3%) 3654–3525 BC (95.4%)	
DEM-525	C/East, Layer 14, Square 9 Depth 2.03–2.13 m	5/7/1995	*Patella ulyssiponensis* Gmelin	2.55*	6754 ± 34	5310–5250 BC (68.3%) 5346–5223 BC (95.4%)	5208–5078 BC (68.3%) 5238–5036 BC (95.4%)
DEM-547	C/East, Layer 15, Square 5 Depth 2.13–2.28 m	7/7/1995	*Patella ulyssiponensis* Gmelin	0.89*	8761 ± 29	7479–7417 BC (68.3%) 7503–7382 BC (95.4%)	7374–7236 BC (68.3%) 7413–7138 BC (95.4%)
DEM-580	C/East, Layer 17, Square 5 Depth 2.38–2.47 m	10/7/1995	Charcoal	−25.00	8283 ± 27	7418–7269 BC (68.3%) 7430–7103 BC (95.4%)	
DEM-545	C/East, Layer 17, Square 5 Depth 2.38–2.47 m	10/7/1995	*Patella ulyssiponensis* Gmelin	0.63*	8773 ± 24	7483–7425 BC (68.3%) 7507–7401 BC (95.4%)	7384–7250 BC (68.3%) 7418–7190 BC (95.4%)
DEM-522	C/East, Layer 19, Square 5 Depth 2. 80 m	11/7/1995	Charcoal	−25.00	8487 ± 22	7536–7493 BC (68.3%) 7547–7447 BC (95.4%)	
DEM-543	C/East, Layer 19, Square 5 Depth 2.80 m	11/7/1995	*Patella ulyssiponensis* Gmelin	1.13*	9011 ± 22	7724–7593 BC (68.3%) 7833–7568 BC (95.4%)	7552–7485 BC (68.3%) 7587–7452 BC (95.4%)
DEM-544	C/East, Layer 19, Square 5 Depth 2.80 m	11/7/1995	*Helix cincta* (Müller)	−8.00	9042 ± 24	8081–8029 BC (68.3%) 8089–8007 BC (95.4%)	
DEM-524	C/East, Layer 20, Square 5 Depth 3.02 m	18/7/1995	Charcoal	−25.00	8791 ± 23	7925–7710 BC (68.3%) 7949–7700 BC (95.4%)	
DEM-573	C/East, Layer 20, Square 5 Depth 3.02 m	18/7/1995	*Patella ulyssiponensis* Gmelin	1.00	9056 ± 28	7851–7681 BC (68.3%) 7883–7607 BC (95.4%)	7601–7503 BC (68.3%) 7678–7480 BC (95.4%)

*$\delta^{13}C$ measurements at the Institute of Environmental Physics, University of Heidelberg

Methods

The charcoal samples were thoroughly examined under a stereoscope and the rootlets, if any, were removed by hand picking. They were treated chemically with solutions of 4% HCl and 4% NaOH, successively, to remove all carbon contaminants. Next, they were combusted to CO_2 using a de Vries–type combustion system (de Vries and Barendsen 1953; Münnich 1957).

The shells of the terrestrial and marine mollusks were washed with deionized water in an ultrasonic bath and the depositions on the surface were removed with a dentist's drill. Next, 35% of their remaining weight was removed with a solution of 2% HCl to eliminate the carbonate that recrystallized during the time of burial. After grinding to a fine powder they were converted to CO_2 with a solution of HCl 3N.

In both cases the CO_2 produced was purified (Münnich 1957). Finally the samples were measured in the proportional counters of our laboratory (Facorellis 1996; Facorellis, Maniatis and Kromer 1997). Some samples were measured for >20 d in order to minimize the statistical error to *ca.* 0.25% (Table 1).

A small portion of the homogenized powder of some terrestrial and marine mollusk shells was sent to the University of Heidelberg for the determination of the $\delta^{13}C$ values (denoted with * in Table 1). ^{14}C ages for the rest of the samples were calculated using $\delta^{13}C$ values of –25‰ for charcoal, –8‰ for terrestrial mollusk shells and 1‰ for marine mollusk shells, which are in agreement with the measured $\delta^{13}C$ values of the corresponding material.

Results and discussion

The material from the excavation of the Cyclope cave is suitable for the calculation of the marine reservoir effect ΔR for the following reasons:

1. A large variety and quantity of marine and terrestrial species, short-lived (*ca.* 10 yr) and suitable for ^{14}C dating, were available.
2. The extended duration of use of the cave (from the Mesolithic to the Neolithic period, as well as during the Roman period) enables the dating of atmospheric-marine pairs of samples from different time periods.

Calculation of the Marine Reservoir Effect ΔR

In order to calculate the marine reservoir effect in the region of the island of Youra in the Aegean Sea, we can use atmospheric-marine pairs of samples originating from the same location and layer of the cave. At present, 8 such pairs have been dated; these can be subdivided as follows: 1) 4 pairs of terrestrial-marine mollusk shells (DEM-430 and -431, DEM-434 and -435, DEM-415 and -416, DEM-544 and -543) and 2) 4 pairs of charcoal-marine mollusk shells (DEM-393 and -370, DEM-580 and -545, DEM-522 and -543, DEM-524 and -573).

Table 2 shows the ^{14}C ages of the terrestrial and the marine mollusk shells. By comparing the ages of each pair, one can see that the latter are either younger than the corresponding terrestrial mollusk shells or within 1σ of their age. The values of the age differences between different pairs show large scattering, having an arithmetic mean of *ca.* 50 yr.

As is understood from the global carbon cycle (Oeschger *et al.* 1975; Stuiver, Pearson and Braziunas 1986; Stuiver and Braziunas 1993), the apparent ages of the marine mollusk shells are older than their actual ages. The ages of the terrestrial mollusk shells also appear to be older than the real ones

TABLE 2. ^{14}C Ages of Contemporaneous Terrestrial-Marine Mollusk Shell Pairs of Samples Buried in the Same Human Occupational Layer of the Cyclope Cave

Lab code	Material	^{14}C age (yr BP)	R (yr)*
DEM-430	*Helix cincta* (Müller)	8754 ± 20	
DEM-431	*Patella ulyssiponensis* Gmelin	8624 ± 20	130 ± 28
DEM-434	*Helix cincta* (Müller)	8855 ± 28	
DEM-435	*Patella ulyssiponensis* Gmelin	8776 ± 19	79 ± 34
DEM-415	*Helix cincta* (Müller)	8834 ± 20	
DEM-416	*Patella ulyssiponensis* Gmelin	8864 ± 37	–30 ± 42
DEM-544	*Helix cincta* (Müller)	9042 ± 24	
DEM-543	*Patella ulyssiponensis* Gmelin	9011 ± 22	31 ± 33
Mean R			**53 ± 68**

*R = the age difference between the samples of each pair.

(Evin *et al.* 1980, Goodfriend and Stipp 1983; Goslar and Pazdur 1985; Yates 1986). This may be due to the dietary habits of the terrestrial mollusks, which metabolize geological-age carbon from the limestone of the region where they live for the formation of their shell (Goodfriend and Hood 1983). Therefore, the terrestrial-marine mollusk shell pairs are not suitable for the calculation of ΔR.

From the above it is clear that the calculation of the ΔR value must be based on the pairs of the second group of samples (charcoal-marine shells) (DEM-524 and -573, DEM-522 and -543, DEM-580 and -545, DEM-393 and -370). By comparing the ages of each pair, one can see that the ages of the marine shells produce systematically older ages than the ages of charcoal samples, as expected. Table 3 shows the ^{14}C ages of these samples, as well as the R value of each pair: 265 ± 36, 524 ± 31, 490 ± 36 and 573 ± 76 yr, respectively. The R values of the three last pairs overlap within 1σ, while that of the first one, which belongs to the deeper and hence the older occupational layer, is considerably lower. This is either due to some sample or pair peculiarity or it may imply a change in the marine reservoir effect in this region after the 8th millennium BC that needs to be checked with more samples in the near future. For these reasons we decided not to consider it in the determination of the mean value for the local marine reservoir effect. Accordingly, the resulting mean R value of the last three charcoal-marine shell pairs is 515 ± 22 yr. This is higher than the mean value of the 373 yr that

TABLE 3. ^{14}C Ages of Contemporaneous Charcoal-Marine Mollusk Shell Pairs of Samples Buried in the Same Human Occupational Layer of the Cyclope Cave

Lab code	Material	^{14}C age (yr BP)	R (yr)*	ΔR (yr)†
DEM-524	Charcoal	8791 ± 23		
DEM-573	*Patella ulyssiponensis* Gmelin	9056 ± 28	265 ± 36	–63 ± 82
DEM-522	Charcoal	8487 ± 22		
DEM-543	*Patella ulyssiponensis* Gmelin	9011 ± 22	524 ± 31	151 ± 37
DEM-580	Charcoal	8283 ± 27		
DEM-545	*Patella ulyssiponensis* Gmelin	8773 ± 24	490 ± 36	120 ± 63
DEM-393	Charcoal	7398 ± 64		
DEM-370	*Patella ulyssiponensis* Gmelin	7971 ± 41	573 ± 76	183 ± 79
Mean R			**515 ± 22**	
Mean ΔR				**149 ± 30**

*R = the age difference between the samples of each pair.
†ΔR = the regional marine reservoir effect calculated for each pair.

is derived from the mixed layer (75–100 m) of the global carbon-cycle model proposed by Stuiver, Pearson and Braziunas (1986) and Stuiver and Braziunas (1993). This phenomenon is related to the circulation and mixing of the seawater from the 8th to the 6th millennia BC in the Aegean Sea, and its investigation is out of the scope of this work, as it demands far more data than available at present.

By taking into account the mean R value between the terrestrial and the marine mollusk shells, as well as between the charcoal and the marine mollusks, the mean apparent age of the terrestrial mollusks from the island of Youra appears to be 568 ± 71 yr older than the charcoal samples.

In order to determine ΔR, we use the three pairs of charcoal-marine shells DEM-522 and -543, DEM-580 and -545, DEM-393 and -370 (Table 3) and the following procedure: For each pair, using the marine calibration curve we find the marine ^{14}C ages corresponding to the calendar dates derived from the terrestrial ages (see Fig. 2). The difference between these calculated marine ages and the measured ages for the marine samples gives a ΔR value for each pair of samples (Southon, Rodman and True 1995). The calculated ΔR values are shown in Table 3. The large ΔR errors are due to the plateaus in the terrestrial calibration curve, which increase the calibrated age range associated with a terrestrial ^{14}C date; this increase is carried through the date calculations of the marine samples. The resulting mean ΔR value for this region is 149 ± 30 yr. This is valid for a time period spanning *ca.* 2000 yr, from the end of the 8th millennium to the beginning of the 7th millennium BC.

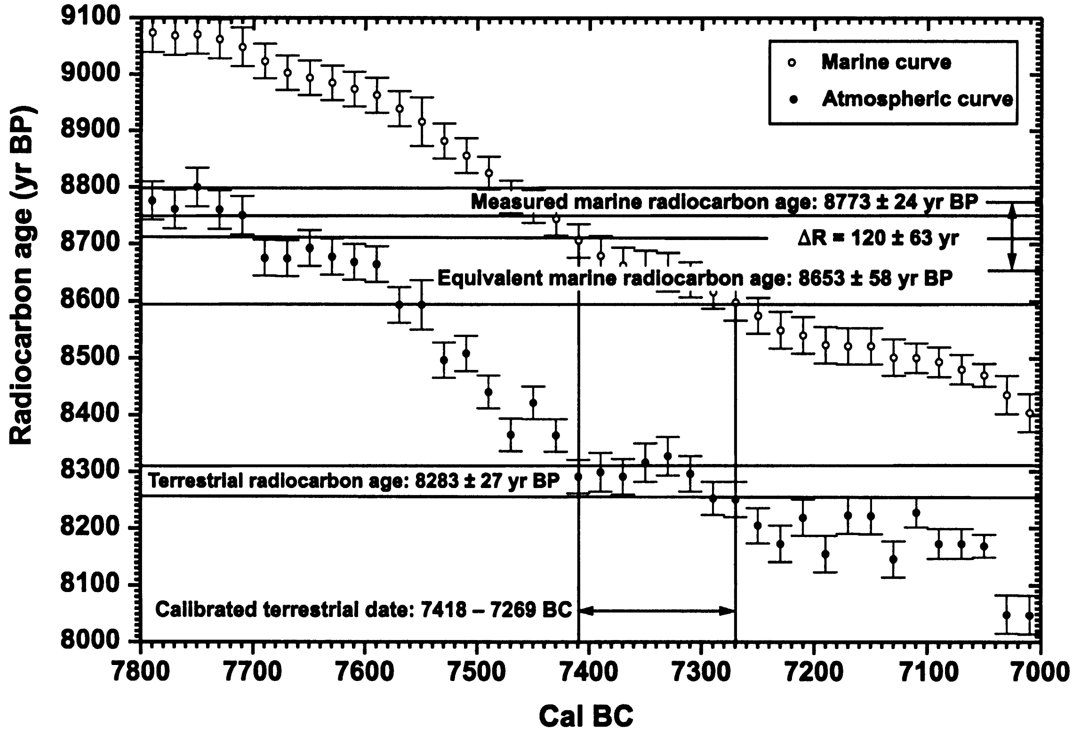

Fig. 2. Example of calculation of ΔR from the second pair of terrestrial-marine samples in Table 2 (DEM-580 and DEM-545). The measured ^{14}C age 8283 ± 27 BP of the terrestrial sample calibrates to 7418–7269 BC. Based on this calendar date, the marine calibration curve gives the ^{14}C age of 8653 ± 58 BP. ΔR is the difference between this calculated marine date and the measured ^{14}C age of 8773 ± 24 yr BP for the marine sample.

This ΔR value is the first ever calculated in the Aegean and the second in the Mediterranean Sea. The first published value corresponds to a recent marine shell sample collected in 1954 at the Kouali Point of Tipasa in Algeria (36°40′N, 2°30′E) (Broecker and Olson 1959, 1961), which produced a ΔR value of −133 ± 83 yr (Stuiver, Pearson and Braziunas 1986). This difference implies either a different local marine reservoir effect between the two regions or a variation in the reservoir effect through the time in the Mediterranean. However, more work is needed to interpret this difference clearly.

Chronology of the Cave Stratigraphy

Table 1 shows the results of all the ^{14}C-dated samples from the Cyclope cave. They are sorted according to trench and sampling depth. The ^{14}C ages were calibrated using the computer program CALIB 3.0.3c (Stuiver and Reimer 1993). The calibration of the ages of the terrestrial samples is based on Stuiver and Pearson (1993), Pearson, Becker and Qua (1993), Linick *et al.* (1986) and Kromer and Becker (1993) and that of the marine samples on Stuiver and Braziunas (1993). The calendar dates are given with one and two standard deviations (probability 68.3% and 95.4%, respectively). The same table presents the calendar dates of the marine mollusks, corrected for the marine reservoir effect. These dates are produced by using the calculated value ΔR = 149 ± 30 yr, together with the marine calibration curve. The calendar dates of the marine samples calculated using the marine calibration curve, neglecting any local marine reservoir effect (ΔR = 0), are also presented for comparison. The corrected dates are younger, as expected.

Figure 3 shows the calibrated age ranges of the charcoal samples (black bars), as well as those of the marine shells corrected for the marine reservoir effect (gray bars), displayed in stratigraphic order. The length of each bar represents the age range and the height represents the percent probability that the sample is in the specific range. The present results show that the Cyclope cave was used by man from 8400 to 3500 BC (trench B and C), as well as during the first centuries AD (trench A). It is important to note that this is the oldest human settlement ever found on an island in the Aegean Sea, extending the navigational skills of prehistoric man several millennia in the past.

Conclusion

The material unearthed during the excavation of the Cyclope cave at the island of Youra enabled the determination of the marine reservoir effect ΔR for the first time in this region of the Aegean Sea. The value of this constant was found to be *ca.* 150 yr in a period from the end of the 8th millennium to the beginning of the 7th millennium BC. However, the oldest pair showed a considerable difference from the above value.

The mean apparent age of the marine shells was found to be *ca.* 520 yr older than the charcoal, although the oldest pair showed a difference of 265 yr. The determination of this constant enabled the calibration of the ^{14}C ages of other marine samples found in archaeological layers without charcoal pieces. The results show that the Cyclope cave was used from the Mesolithic to the Final Neolithic period (8400–3500 BC), as well as during the first centuries AD.

The ^{14}C ages of the terrestrial shells compared to those of the marine shells originating from the same layer proved to be older by *ca.* 50 yr. Therefore, if we take into account the mean age difference of the marine shells, the apparent age of the land snails is *ca.* 570 yr older than the charcoal.

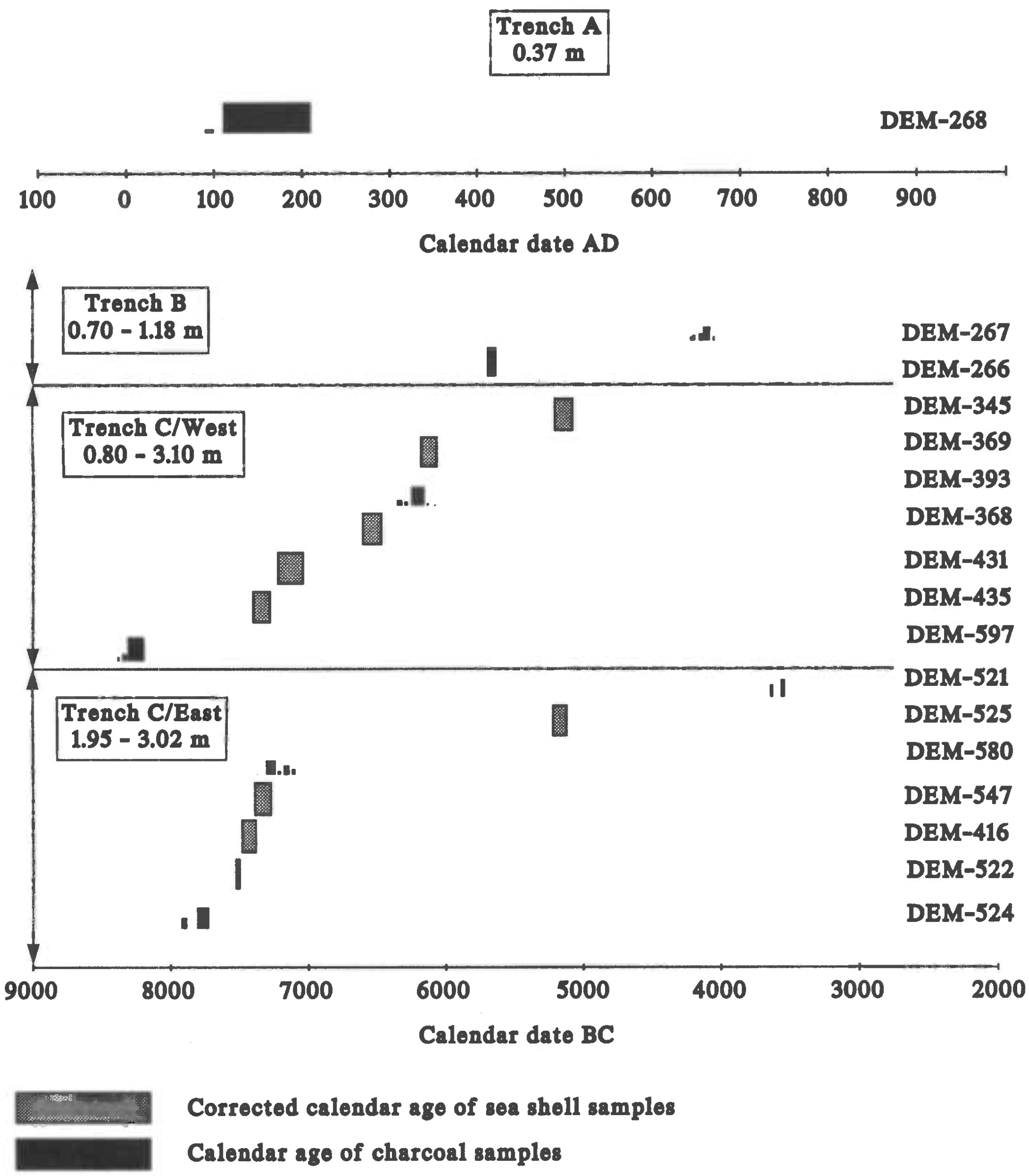

Fig. 3. Calendar dates of samples from the Cyclope cave sorted by trench and stratigraphic order. The length of each bar represents the age range and the height represents the percent probability that the sample is in the specific range.

Acknowledgments

The authors would like to thank the archaeologists Dr. Adamantios Sampson, director of the 21st Ephorate of Prehistorical and Classical Antiquities of the Cyclades, and Ms. Stella Katsarou who entrusted us with the material, as well as with the information from the field notebook of the excavation of the Cyclope cave.

Many thanks are also due to Ms. Evi Vardala-Theodorou, research biologist, in charge of the Malacological Department of the Natural History Museum, Goulandri and to Dr. Yannis Botsaris, biologist, for the identification of the species of the marine and the terrestrial mollusks, respectively, used in this study.

References

Broecker, W. S. and Olson, E. A. 1959 Lamont radiocarbon measurements VI. *American Journal of Science Radiocarbon Supplement* 1: 111–132.

Broecker, W. S. and Olson, E. A. 1961 Lamont radiocarbon measurements VII. *Radiocarbon* 3: 176–204.

Evin, J., Marechal, J., Pachiaudi, C. and Puissegur, J. J. 1980 Conditions involved in dating terrestrial shells. *Radiocarbon* 22(2): 545–555.

Facorellis, Y. (ms.) 1996 Study of the conditions and parameters for high precision dating with ^{14}C. Ph.D. thesis, Department of Physics, University of Patras, Greece. ISBN: 960-90526-0-X

Facorellis, Y., Maniatis, Y. and Kromer, B. 1997 Study of the parameters affecting the correlation of background *versus* cosmic radiation in CO_2 counters: Reliability of dating results. *Radiocarbon* 39(3): 225–238.

Goodfriend, G. A. and Hood, D. G. 1983 Carbon isotope analysis of land snail shells: Implications for carbon sources and radiocarbon dating. *Radiocarbon* 25(3): 810–830.

Goodfriend, G. A. and Stipp, J. J. 1983 Limestone and the problem of radiocarbon dating of land-snail shell carbonate. *Geology* 11: 575–577.

Goslar, T. and Pazdur, M. F. 1985 Contamination studies on mollusk shell samples. *Radiocarbon* 27(1): 33–42.

Kromer, B. and Becker, B. 1993 German oak and pine ^{14}C calibration, 7200–9439 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 125–135.

Linick, T. W., Long, A., Damon, P. E. and Ferguson, C. W. 1986 High-precision radiocarbon dating of bristlecone pine from 6554 to 5350 BC. *In* Stuiver, M. and Kra, R., eds., Calibration Issue. *Radiocarbon* 28(2B): 943–953.

Münnich, K. O. (ms.) 1957 Messung natürlichen radiokohlenstoffs mit einem CO_2 Proportional-Zahlrohr. Einige Anwendungen der Methode. Ph.D. dissertation, University of Heidelberg, Germany.

Oeschger, H., Siegenthaler, U., Schotterer and Gugelman, A. 1975 A box diffusion model to study the carbon dioxide exchange in nature. *Tellus* 27(2): 168–192.

Pearson, G. W., Becker, B. and Qua, F. 1993 High-precision ^{14}C measurements of German and Irish oaks to show the natural ^{14}C variations from 7890 to 5000 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 93–104.

Sampson, A. 1996 Excavation at the cave of Cyclope on Youra, Alonnessos. *In* Alram-Stern, E., ed., *Das Neolithikum in Griechenland mit Ausnahme von Kreta und Zypern.* Die Ägäische Frühzeit, Series 2, Volume 1. Vienna, Verlag der Österreichischen Akademie der Wissenschaften: 507–520.

Southon, J. R., Rodman, A. O. and True, D. 1995 A comparison of marine and terrestrial radiocarbon ages from northern Chile. *In* Cook, G. T., Harkness, D. D., Miller, B. F. and Scott, E. M., eds., Proceedings of the 15th International ^{14}C Conference. *Radiocarbon* 37 (2): 389–393.

Stuiver, M. and Braziunas, T. F. 1993 Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 137–189.

Stuiver, M., Pearson, G. W. and Braziunas, T. 1986 Radiocarbon age calibration of marine samples back to 9,000 cal yr BP. *In* Stuiver, M. and Kra, R., eds., Calibration Issue. *Radiocarbon* 28(2B): 980–1021.

Stuiver, M. and Pearson, G. W. 1993 High-precision bidecadal calibration of the radiocarbon time scale, AD 1950–500 BC and 2500–6000 BC. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 1–23.

Stuiver, M. and Reimer, P. J. 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. *In* Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 215–230.

de Vries, Hl. and Barendsen, G. W. 1953 Radio-carbon dating by a proportional counter filled with carbon dioxide. *Physica* 19: 987–1003.

Yates, T. 1986 Studies of non-marine mollusks for the selection of shell samples for radiocarbon dating. *In* Stuiver, M. and Kra, R., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2A): 457–463.

Appendix: Descriptions of Cyclope Cave Samples

DEM-268. Small charcoal pieces originating in a fireplace. The soil was very wet due to intense dripping. The fireplace abounded in ceramic sherds belonging to the Roman period.

DEM-266. Small charcoal pieces originating from a very thick horizon containing ashes. In the ash ceramic sherds belonging to the Middle Neolithic period were found.

DEM-267. Small charcoal pieces originating from the same horizon as the previous sample (DEM-266). At this depth inside and around the fireplace, numerous shells of marine and terrestrial mollusks, as well as terrestrial animals and fish bones, were found. There were no associated ceramic sherds.

DEM-392 and -345. Small charcoal pieces and shells of marine mollusks, respectively. The soil of this layer was loose and contained many roots. At this locality numerous shells of marine and terrestrial mollusks, terrestrial animals and fish bones, as well as neolithic sherds, obsidian blades and a few flint tools were found.

DEM-393 and -370. Small charcoal pieces originating in a fireplace and shells of marine mollusks, respectively. The soil of this layer was fine and sandy. In this layer numerous shells of marine and terrestrial mollusks and fish bones, as well as few neolithic sherds, obsidian blades and flint tools were found.

DEM-369. Shells of marine mollusks. The soil of this layer was loose and contained numerous shells of marine and terrestrial mollusks, as well as terrestrial animals and fish bones.

DEM-368. Shells of marine mollusks. The soil of this layer was loose and contained numerous shells of marine and terrestrial mollusks, as well as fish bones. There are no associated ceramic sherds.

DEM-431 and -430. Shells of marine and terrestrial mollusks, respectively. The soil of this layer was loose and contained a great amount of food remains (shells and bones), as well as a few obsidian blades and flint tools. There are no associated ceramic sherds.

DEM-435 and -434. Shells of marine and terrestrial mollusks, respectively. In this layer numerous shells of marine and terrestrial mollusks were found on a hard and compact floor. There are no associated ceramic sherds.

DEM-597. Small charcoal pieces originating in a fireplace. It represents the last layer on top of the natural rock of the cave. This layer contained reddish limestone debris and numerous shells of marine and terrestrial mollusks. There are no associated ceramic sherds.

DEM-416 and -415. Shells of marine and terrestrial mollusks, respectively. This layer contained a great amount of food remains (shells and bones). There are no associated ceramic sherds.

DEM-521 and -525. Small charcoal pieces and shells of marine mollusks, respectively, originating from a fireplace located in square 9 of layer 14. This square is located near a stalagmite and the layers exhibit a slope. The soil of this layer was loose and contained many stones and food remains (shells and bones). There are no associated ceramic sherds.

DEM-547. Shells of marine mollusks. The soil of this layer was loose and contained mainly large amounts of crushed shells of terrestrial mollusks, but also numerous shells of marine as well as terrestrial animals and fish bones. This layer probably represents a transition from the Mesolithic to the Neolithic period, as Neolithic ceramic sherds were found.

DEM-580 and -545. Small charcoal pieces and shells of marine mollusks, respectively. The soil of this layer was loose and contained food remains (shells and bones), as well as intact bone tools. There are no associated ceramic sherds.

DEM-522 -543 and -544. Small charcoal pieces originating in a fireplace and shells of marine and terrestrial mollusks, respectively. The soil of this layer was loose and contained a great amount of food remains (shells and bones), as well as a few flint tools. There are no associated ceramic sherds.

DEM-524 and -573. Small charcoal pieces originating in square 5 of layer 20 and shells of marine mollusks. A large part of this square is occupied by a stalagmite. The soil of this layer was loose, relatively wet and contained numerous shells of marine and terrestrial mollusks, as well as a few flint tools. There are no associated ceramic sherds.