PRE-BOMB MARINE RESERVOIR AGES IN THE WESTERN PACIFIC

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ABSTRACT. In this study, molluscan shells housed at the University Museum, the University of Tokyo, provided a new set of region-specific correction values (ΔR) for the western Pacific, in particular for the central part of the main islands in the Japanese Archipelago and the southwest islands of Japan. The values of 40 total samples were calculated from 11 regions. North of the main islands and in the Ryukyu Islands, the mean ΔR values showed comparatively small values, 5–40 ^{14}C yr; in the central part of the main islands, these values were 60–90 ^{14}C yr.

INTRODUCTION

There are many shellmound remains in the Japanese Islands, and although an exact number is not known, it has been estimated at 2000–3000 (Sanseido Publishing Company 2002), with more than half from shell middens of the Jomon period. For a hunter-gatherer living near the sea, marine products and resources held an important role. Shell middens from the Incipient stage of the Jomon period were not found; instead, shell middens appeared in the first half of the Earliest stage, more than 10,000 yr ago. Radiocarbon dating of the samples excavated from the Natsushima shellmound in Kanagawa Prefecture was carried out 50 yr ago. It gave a surprisingly old date of >9000 BP (9450 ± 400 BP for oyster shell and 9240 ± 500 BP for charcoal; Crane and Griffin 1960). Shellmounds of this time were small middens. The surface of the sea rose along with global warming (during the Jomon transgression), with sea levels rising the most in the Early stage of the Jomon period, before about 7000–6000 yr ago, some 2~3 m higher than the present mean sea level. Sea levels then decreased, and huge circular and horseshoe-shaped middens were formed in the Middle and Late stages of the Jomon.

The Kasori shellmound in Chiba Prefecture is one of the biggest shell middens in Japan, and 2 circular middens (160 × 140 m) are connected. Charcoal samples dated to 4790 ± 80 BP for the lower layer and 3630 ± 90 BP for the upper layer (Kigoshi 1967). Because it is thought that occupation and residence habits were altered due to environmental changes, a detailed chronological investigation is necessary. To study the Kasori shellmound site, a large-scale investigating committee was organized, and charcoal samples were obtained in order to determine the age of remains and archaeological features. In addition to pottery and stone implements and other artifacts, shell and bone samples were collected and dated at the same time. In general, sample ages were estimated based on the chronological order and typology of the earthenware vessels collected. However, pillar materials, charcoal, and carbonized materials were not collected, and it is rare that they were saved even if collected. Therefore, from the middens excavated in the past, only shells have been preserved, so it is necessary to date shell samples to determine the age of the midden. Fortunately, when charred material adheres to a potsherd, it can be used for dating.

It is necessary to calibrate a conventional ^{14}C age of shell samples by using the marine calibration curve Marine04 (Hughen et al. 2004). The average of apparent ^{14}C ages in the world oceans was shown to be 405 ^{14}C yr older than the terrestrial products. This value comes from the model ocean

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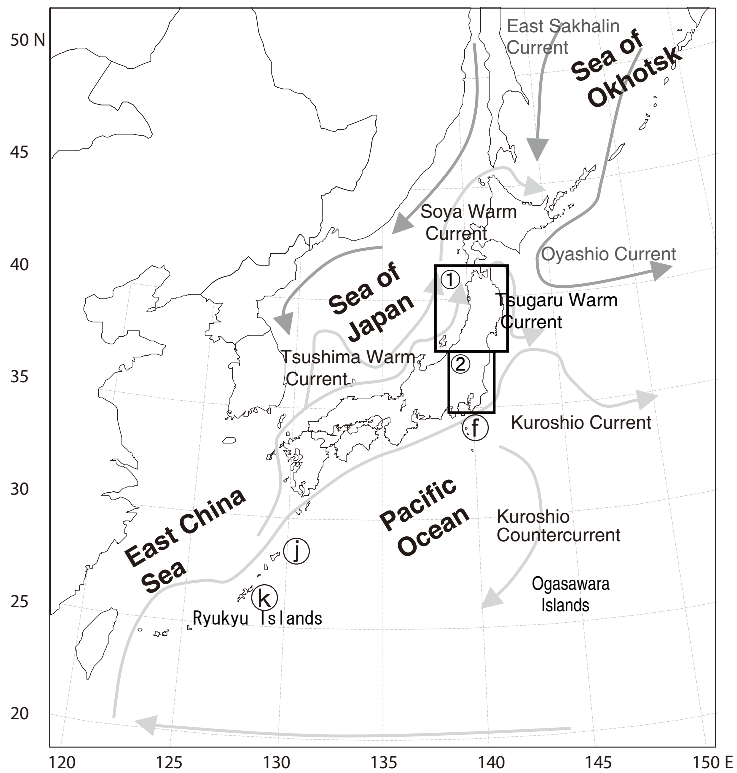

Figure 1 Location of sample collection and oceanographic conditions in the western Pacific. Letters in circles indicate the region where shells were collected. Arrows show currents: dark lines = cold currents; light lines = warm currents.

reservoir age calculated by an ocean-atmosphere box diffusion model. However, depending on the location, marine reservoir ages can show various regional fluctuations, which are affected by upwelling of ^{14}C-depleted deep-sea water or the inflow of river water, etc. The difference between the regional reservoir age and the mixed-layer reservoir age is the region-specific collection value, ΔR. This value may change depending on the place and time. If the value is not understood, the age of the shell sample therefore cannot be determined precisely.

Recently, marine reservoir ages around the Japanese Archipelago were reported, especially around the northern and southern islands. The surface layer of the North Pacific is affected by upwelling water aged 2000 BP or less (Broecker 2002). In the western part of the region, the mean ΔR for Sakhalin and Hokkaido was estimated as 393 ± 32 ^{14}C yr (Kuzmin et al. 2001; Yoneda et al. 2007). Faunal remains of terrestrial and marine mammals excavated from 5 shell middens in Hokkaido Island, with ages ranging from the Jomon period (4900 BP) to the Ainu cultural period (800 BP), were dated and compared to the apparent ages. The difference in the ^{14}C age of northern fur seal and Japanese deer is ~800 ^{14}C yr with estimated ΔR values of ~380 ^{14}C yr (Yoneda et al. 2001). The ΔR values agreed well with pre-bomb shell results showing that the thermohaline circulation system does not show a big change after the hypsithermal interval.

On the other hand, in the Ryukyu Islands, the ΔR values are smaller. Typical ΔR values for water belonging to the Kuroshio Current in the south (northern Taiwan and Ishigaki Island) have a mean ΔR value of 73 ± 17 ^{14}C yr (n = 14) (Hideshima et al. 2001; Yoneda et al. 2007). For the Okinawa

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and Amami regions, the mean ΔR value of 29 ± 18 ^{14}C yr (n = 5) is slightly smaller (Yoneda et al. 2007).

There are few data for the central part of the main islands in the Japanese Archipelago. The ΔR values at Miura Peninsula (region h in Figure 3) were estimated at 82 ± 33 and 77 ± 32 ^{14}C yr from marine shells uplifted by earthquakes (Shishikura et al. 2007). In addition, 3 values are reported: 109 ^{14}C yr for Shimoda (region i in Figure 3), 393 ^{14}C yr for Kashima-nada (near region c in Figure 2), and –7 ^{14}C yr for the Kii Peninsula (Yoneda et al. 2000). The local reservoir collections are estimated by paired shell and charcoal samples excavated in shellmounds in Aichi Prefecture, –11 ± 23 ^{14}C yr (n = 4) for the Yoshigo shellmound (2910~2800 BP) and 206 ± 30 ^{14}C yr (n = 2) for the Kusubasama shellmound (6810~6730 BP) (Nakamura et al. 2007).

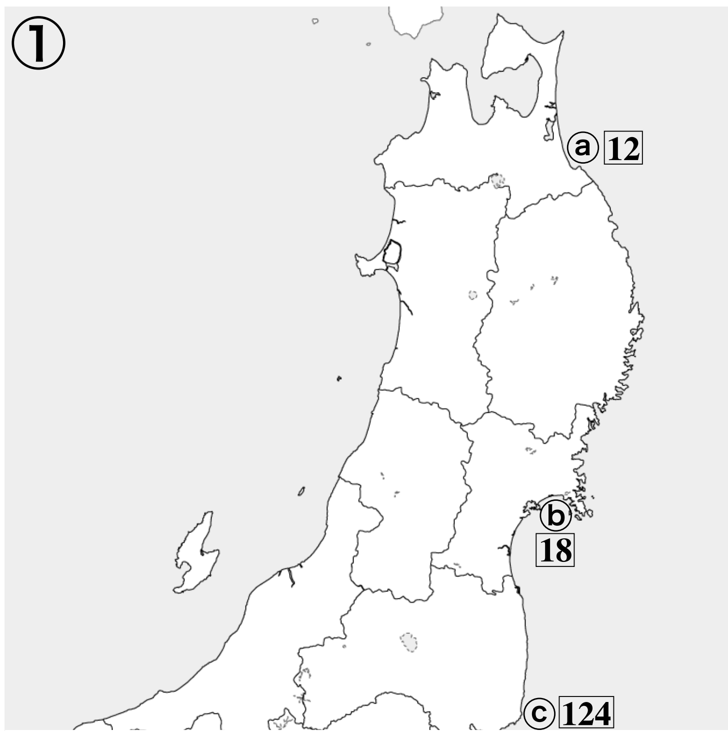

Figure 2. Location of sample collection in the Tohoku region and the mean ΔR values

The Kuroshio Current flows east of the Japanese Islands from the south, and the Oyashio Current of the cold current flows from the north. With warming, the subtropical Kuroshio front advanced northward and reached Kashima in central Japan (36°N) about 7000 yr ago, and around 5500 yr ago it retreated to the south (Chinzei et al. 1987). Also, from analysis of a piston core collected in the northwestern part of the Pacific Ocean in central Japan, it is presumed there was a big change in the marine environment not seen after the Early stage of the Jomon period (Niimura et al. 2006).

In this study, the apparent ^{14}C ages of shell samples collected from the 1880s to 1920s are measured to obtain the local reservoir collection values. There were 40 samples collected from 11 areas. Among those, 19 samples were collected in the Kanto District. Since many shellmounds exist in the Kanto area, the data of this area are important.

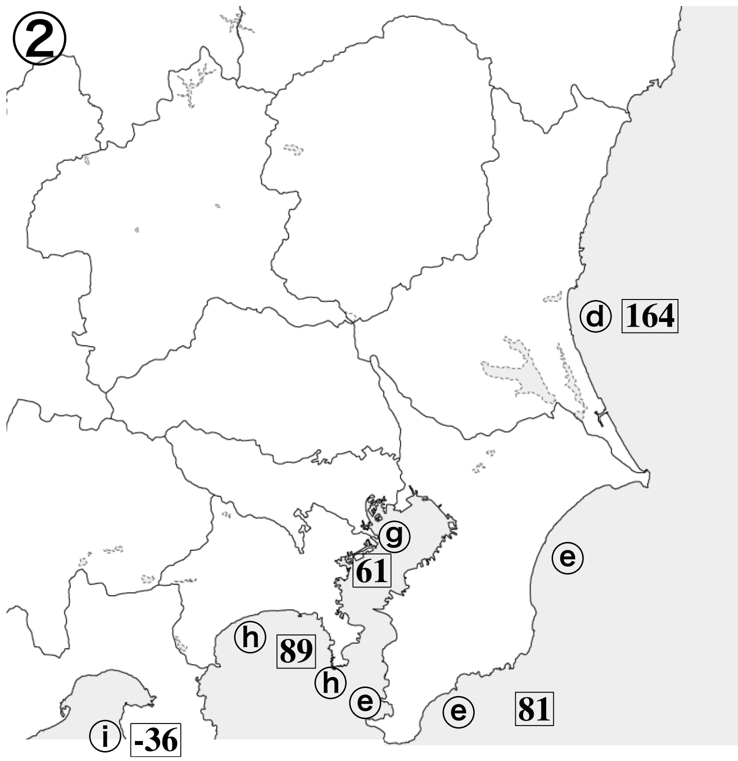

Figure 3 Location of sample collection in the Kanto region and the mean ΔR values

MATERIALS AND METHODS

As in Yoneda et al. (2007), the shell materials used in this study have been stored at the Department of Paleontology of the University Museum, the University of Tokyo. The 2 sets of materials are grouped together in the same collection. The specimens were collected before World War II and have labels recording the collected localities and year as well as the collector's name. In this research, ^{14}C dating was performed on the samples collected on the main islands of Japan, especially the Kanto region (Figure 3) as well as the Izu Islands and the Ryukyu Islands. Most of the samples had evidence of live collection. Articulated bivalves and shells with organic tissues of ligament and other regions on their surface were selected.

The surface of the outer growing edge of the shell was manually cleaned, and a small piece of about 100 mg was cut with a metal drill. The sample was then leached by 1M HCl to remove secondarily recrystallized carbonate until ~30% of the weight decreased. Each sample was reacted with 85% phosphoric acid within an evacuated glass vessel, and the carbon dioxide produced was purified cryogenically. Graphite samples of 1 mg were reduced by hydrogen gas under iron powder catalyst at 650 °C (Yoshida et al. 2004). The $^{14}C/^{12}C$ ratio was measured by accelerator mass spectrometry (AMS) at the MALT facility, School of Engineering, the University of Tokyo (Yoshida and Miyazaki 2001).

The stable isotopic ratios of carbon and oxygen ($\delta^{13}C$ and $\delta^{18}O$) were measured using a Finnigan MAT 252 isotopic ratio mass spectrometer attached to an automated carbonate device at the Department of Earth and Planetary Science, the University of Tokyo.

^{14}C reservoir ages were calculated as the difference between the conventional ^{14}C age (apparent shell ^{14}C age) and the ^{14}C age of atmospheric CO_2 at the year of collection (Stuiver and Braziunas 1993). The model ^{14}C ages in the atmosphere are based on the IntCal04 data set (Reimer et al. 2004). The regional correction value, ΔR, was estimated by the same procedure between the apparent shell ^{14}C age and surface ocean ^{14}C age at the year of collection using the marine model ^{14}C ages in the Marine04 data set (Hughen et al. 2004). Uncertainties for regional ΔR values are estimated by the standard error of the mean (see Table 1).

RESULTS AND DISCUSSION

Table 1 lists the results on sample isotopic values and ages. Stable isotopic data show reasonable values for marine carbonate, suggesting samples did not grow in estuarine conditions. The regions, from the Tohoku District through the Kanto region to the southwest, are affected by the Kuroshio Current and/or the Oyashio Current (and/or the Tsugaru Warm Current).

Northeast Region of the Main Islands

The ΔR value is large, 393 ± 32 ^{14}C yr, at the northeast shore in Hokkaido Island, as previously mentioned. On the other hand, in Hakodate, southwestern Hokkaido Island, the value of ΔR was much smaller (34 ± 42 ^{14}C yr) due to the influence of the Tsugaru Warm Current originating from the Tsushima Warm Current in the Sea of Japan (Yoneda et al. 2007). Two samples from Hachinohe (a in Figure 2) in Aomori Prefecture, northern end of the main islands, show similar reservoir ages (12 ± 24 ^{14}C yr) to previous values for Hakodate, located on the opposite shore across the Tsugaru Strait on Hokkaido Island. Furthermore, the value is 18 ± 35 ^{14}C yr in Shiogama (b in Figure 2) located ~300 km south. A similar ΔR value of 44 ± 24 ^{14}C yr (n = 2; Kuzmin et al. 2001) for the North Korean Current strongly suggests the Tsushima Warm Current has higher ^{14}C content, and it is estimated that the area containing "a" and "b" in Figure 2 is affected by these water masses.

In contrast, much higher ΔR values of 124 ± 36 ^{14}C yr for Soma, Fukushima Prefecture (c in Figure 2), and 164 ± 35 ^{14}C yr for Oharai, Ibaraki Prefecture (d in Figure 3), were obtained. The location of the latter is near Kashima-nada, where a large ΔR value of 393 ^{14}C yr is reported (Yoneda et al. 2000). It appears that the area is under the influence of the Kuroshio Warm Current, but the reason for these high values is unclear. Since there are only a few data for this area, it will be necessary to increase the number of samples and to further examine the issue in the future.

Kanto and Chubu Regions

Mean values for the central Kanto District range from 60 to 90 ^{14}C yr (Figure 3). Samples of region e (Figure 3; Boso Peninsula, Chiba) show a big distribution of ΔR values from –38 ± 36 to 219 ± 46 ^{14}C yr (n = 7). Two samples were collected on the open sea coast (in Kujukuri and Kominato) and 5 samples in the Bay of Tokyo (Uraga Channel). Four of these samples collected in Heigun, Chiba (Table 1), show the same distribution though collected in the same place on the same day. The average of the ΔR values is 38 ± 20 ^{14}C yr (n = 4), and the standard deviation is 86 ^{14}C yr. The mean ΔR value of the Boso Peninsula (region e in Figure 3) is 81 ± 15 ^{14}C yr (n = 7). Furthermore, in the inner part of Tokyo Bay (region g in Figure 3), the mean ΔR value is 61 ± 22 ^{14}C yr (n = 3). There is a substantial input of terrestrial runoff to this area, which might cause contributions from both the hard-water effect or the effect of precipitation. Since the flux of a river is 1/7 or less of the capacity of 62,100 million tons of Tokyo Bay (River Bureau 2004), judging from recent averages, it is presumed that the influence is small. Another problem is that the ΔR values estimated by archaeological samples in the coast of Tokyo Bay changed depending on the type of shellfish (Yoshida et al. 2008). For

Table 1 Apparent ^{14}C ages and reservoir ages on molluscan shells.

Region	Sample nr		Species[a]		Location	Year collected	^{14}C age BP (1 σ)	Lab nr (TKa-)	δ^{13}C PDB	δ^{18}O PDB	Reservoir age	ΔR value
Tohoku	25		*Patinopecten yessoensis* (Jay)	a	Hachinohe, Aomori	1900	464 ± 24	13863	–0.4	2.6	394	10 ± 34
	58		*Modiolus kurilensis* (Bernard)		Hachinohe, Aomori	1910	461 ± 23	13862	1.5	4.0	362	13 ± 33
	294		*Cellana nigrolineata* (Reeve)	b	Shiogama, Miyagi	1891	482 ± 26	13865	2.2	1.6	388	18 ± 35
	236		*Megangulus venulosa* (Schrenck)	c	Soma, Fukushima	1904	574 ± 27	13866	–0.2	2.0	493	124 ± 36
Kanto	134		*Pseudocardium sachalinensis* (Schrenck)	d	Oharai, Ibaraki	1929	617 ± 25	14738	0.4	2.0	469	164 ± 35
	149		*Pseudocardium sachalinensis* (Schrenck)	e	Kujukuri, Chiba	1897	656 ± 38	14002	0.1	1.0	581	198 ± 45
	188	*	*Cellana toreuma* (Reeve)		Kominato, Chiba	1885	510 ± 26	13999	1.5	2.1	408	41 ± 35
	246	*	*Serpulorbis imbricatus* (Dunker)		Tateyama, Chiba	1906	668 ± 39	13997	2.3	1.4	581	219 ± 46
	193		*Lottia kogamogai* Sasaki & Okutani		Heigun, Chiba	1882	433 ± 27	14001	1.8	–0.6	330	–38 ± 36
	194	*	*Cellana toreuma* (Reeve)		Heigun, Chiba	1882	479 ± 25	14000	0.2	–2.0	376	8 ± 35
	232	*	*Montfortula picta* (Dunker)		Heigun, Chiba	1882	632 ± 29	13998	3.1	–1.0	529	161 ± 38
	287	*	*Patelloida saccharina* form *lanx* (Reeve)		Heigun, Chiba	1882	493 ± 46	13996	2.2	–0.2	390	22 ± 52
	60		*Septifer bilocularis* (Linnaeus)	f	Izu-Niijima, Tokyo	1887	444 ± 28	14016	2.8	–0.3	344	–23 ± 37
	270	*	*Monodonta labio* form *confusa* Tapparone-Canefri		Izu-Niijima, Tokyo	1887	475 ± 29	14737	1.9	1.7	375	8 ± 38
	292	*	*Cellana nigrolineata* (Reeve)		Izu-Niijima, Tokyo	1895	536 ± 26	14014	0.5	0.2	458	76 ± 35
	125		*Mactra veneriformis* Deshayes in Reeve	g	Tokyo	1882	534 ± 36	14010	0.5	–1.4	431	63 ± 43
	169		*Solecurtus divaricatus* (Lischke)		Yokohama, Kanagawa	1929	453 ± 28	14007	0.7	1.0	305	0 ± 37
	174		*Solecurtus divaricatus* (Lischke)		Yokohama, Kanagawa	1929	571 ± 27	14006	–0.2	0.3	423	118 ± 36
	34		*Atrina (Servatrina) pectinata* (Linnaeus)	h	Misaki, Kanagawa	1900	619 ± 61	14009	1.6	1.4	549	165 ± 66
	243		*Serpulorbis imbricatus* (Dunker)		Misaki, Kanagawa	1900	516 ± 27	14005	0.9	0.6	446	62 ± 36
	275		*Batillaria cumingii* (Crosse)		Misaki, Kanagawa	1881	536 ± 33	14003	1.0	–1.0	432	63 ± 41
	35		*Atrina (Servatrina) lamellata* Habe		Ninomiya, Kanagawa	1899	566 ± 49	14008	2.0	1.4	494	110 ± 55
	245	*	*Patelloida saccharina* form *lanx* (Reeve)		Yugawara, Kanagawa	1891	544 ± 43	14004	3.1	0.9	450	80 ± 49
Chubu	20		*Lithophaga (Leiosolenus) curta* (Lischke)	i	Numazu, Shizuoka	1884	497 ± 27	14013	–2.1	0.4	395	28 ± 36
	211	*	*Nipponacmea concinna* (Lischke)		Shimoda, Shizuoka	1896	370 ± 36	14012	–0.1	0.7	294	–88 ± 43
	231	*	*Nipponacmea concinna* (Lischke)		Shimoda, Shizuoka	1896	397 ± 38	14011	0.2	–0.2	321	–61 ± 45

Table 1 Apparent ^{14}C ages and reservoir ages on molluscan shells. *(Continued)*

Region	Sample nr		Species[a]		Location	Year collected	^{14}C age BP (1 σ)	Lab nr (TKa-)	$\delta^{13}C$ PDB	$\delta^{18}O$ PDB	Reservoir age	ΔR value
Ryukyu Island	17		*Anadara antiquata* (Linnaeus)	j	Amami-Oshima, Kagoshima	1901	419 ± 26	14741	1.3	0.4	346	–34 ± 35
	165		*Periglypta reticulata* (Linnaeus)		Amami-Oshima, Kagoshima	1901	441 ± 25	14740	1.6	–1.3	368	–12 ± 35
	357		*Strombus (Conomurex) luhuanus* Linnaeus		Amami-Oshima, Kagoshima	1901	425 ± 25	14739	2.2	–0.3	352	–28 ± 35
	107		*Atactodea striata* (Gmelin)	k	Okinawa, Ryukyus	1900	411 ± 24	14753	2.2	0.8	341	–43 ± 34
	112		*Acanthocardia nigropunctatum* (Habe & Ko-suge)		Okinawa, Ryukyus	1900	466 ± 24	14752	2.6	–1.6	396	12 ± 34
	128		*Tridacna maxima* (Roding)		Okinawa, Ryukyus	1900	435 ± 24	14751	2.2	0.1	365	–19 ± 34
	140		*Scutarcopagia scobinata* (Linnaeus)		Okinawa, Ryukyus	1899	520 ± 25	14750	2.3	–2.1	448	64 ± 35
	172		*Asaphis violascens* (Forscal)		Okinawa, Ryukyus	1900	437 ± 24	14749	2.3	0.0	367	–17 ± 34
	263	*	*Cellana grata* (Gould)		Okinawa, Ryukyus	1903	461 ± 27	14747	–0.5	0.8	383	10 ± 36
	295	*	*Trochus macuratus* Linnaeus		Okinawa, Ryukyus	1901	454 ± 29	14746	1.4	0.5	381	1 ± 38
	324	*	*Batillaria flectosiphonata* Ozawa		Okinawa, Ryukyus	1898	629 ± 26	14745	1.4	–1.6	556	173 ± 35
	327	*	*Clypeomorus petrosa chemnitziana* (Pilsbry)		Okinawa, Ryukyus	1898	523 ± 25	14744	3.8	–0.8	450	67 ± 35
	361	*	*Strombus (Canarium) mutabilis* Swainson		Okinawa, Ryukyus	1900	724 ± 26	14743	2.2	–0.8	654	270 ± 35
	369	*	*Strombus (Conomurex) luhuanus* Linnaeus		Okinawa, Ryukyus	1900	401 ± 28	14742	2.5	–0.4	331	–53 ± 37

[a]Asterisks (*) indicate Gastropoda; the others are Bivalvia.

clams from 5500~3200 BP, the mean ΔR value is –65 ± 20 ^{14}C yr (n = 3), and another species from the same family (*Cyclina orlentalis* Sowerby) from 7350~3200 BP shows 121 ± 33 ^{14}C yr (n = 2). Furthermore, 2 samples collected at Yokohama (samples 169 and 174 in Table 1) in region g, which are the same species (plankton feeder) and collected at the same time, show values of 0 ± 37 and 118 ± 36 ^{14}C yr, respectively.

In region h (Figure 3), the average ΔR value is estimated as 89 ± 22 ^{14}C yr (n = 5), which is extremely close to the previously reported values of 77 ± 32 ^{14}C yr (n = 4) for AD 1703 and 82 ± 33 ^{14}C yr (n = 5) for AD 1923 in the Miura Peninsula (Shishikura et al. 2007). Misaki (see Table 1) is located near the same site where Shishikura extracted the samples. Sagami Bay, which faces Misaki, suddenly becomes deep, with water depths exceeding 1500 m in the central part of the bay, but Tokyo Bay is not as deep. Since the mean values of ΔR of this region (e, g, and h) appear similar, it is estimated that the influence by upwelling old water is minor. In the meantime, for the Izu Peninsula and Suruga Bay (region h in Figure 3), the mean value of ΔR is –36 ± 24 ^{14}C yr (n = 3), which is quite different from the reported value of 109 ^{14}C yr for Shimoda (Yoneda et al. 2000). The discrepancy between this result and the previous study is now under consideration. Because many shell midden ruins exist especially in the Kanto region, the local reservoir correction values acquired in this study are very helpful in refining the archaeological chronology.

Western Subtropical Pacific

Niijima Island in the Izu Islands is 160 km south of Tokyo (region f in Figure 1). It is washed by the Kuroshio Warm Current, and the mean ΔR value is a similar to those of the southwest islands of Japan, with a value of 21 ± 21 ^{14}C yr (n = 3). In the case of the Ryukyu Islands, 3 shell samples for Amami Island (region j in Figure 1 and Table 1) and 11 shell samples for Okinawa Island (region k) were analyzed. A mean ΔR of –25 ± 20 ^{14}C yr (n = 3) for the Amami region and 42 ± 11 ^{14}C yr (n = 11) for the Okinawa region were calculated. The estimated values for the Okinawa region showed good agreement to the mean ΔR of 29 ± 18 ^{14}C yr for Amami Island and the Okinawa region (Yoneda et al. 2007). On the other hand, the value for the Amami region seems to be smaller. The mean values of ΔR were estimated for the Amami region as 5 ± 15 ^{14}C yr (n = 6; 3 from this work and 3 from Yoneda et al. 2007), and for the Okinawa region as 38 ± 10 ^{14}C yr (n = 13; 11 from this work and 2 from Yoneda et al. 2007). The mean value for the Okinawa region is larger than that for the Amami region, but the value calculated only for Bivalvia shells was 4 ± 13 ^{14}C yr (n = 7) for the Okinawa region. The discrepancy between the ΔR values for the Amami region and those for the Okinawa region is now under consideration.

CONCLUSION

Local correction values for a total of 40 shell samples were calculated for 11 regions (Figure 4). In the region north of the main islands, the values were 12 ± 24 ^{14}C yr for point "a" and 18 ± 35 ^{14}C yr for point "b" in Figure 2, and it is estimated that the area containing "a" and "b" is affected by water masses of the Tsugaru Warm Current. Similarly, in the Ryukyu Islands and the Izu Islands where the Kuroshio Warm Current is an influence, the mean values of ΔR were comparatively small: 21 ± 21 ^{14}C yr (n = 3) for the Izu Islands; 5 ± 15 ^{14}C yr (n = 6) for the Amami region; and 38 ± 10 ^{14}C yr (n = 13) for the Okinawa region. On the other hand, in the central part of the main islands, the values were rather high. The mean ΔR values for Chiba Prefecture (region e in Figure 3) were estimated at 81 ± 15 ^{14}C yr (n = 7), and those for Tokyo Bay (region g in Figure 3) were 61 ± 22 ^{14}C yr (n = 3), and those for the Miura Peninsula and Sagami Bay (region h in Figure 3) were 89 ± 22 ^{14}C yr (n = 54). Since many shellmounds are distributed throughout the Kanto District, this value is very useful for correctly determining archaeological ages.

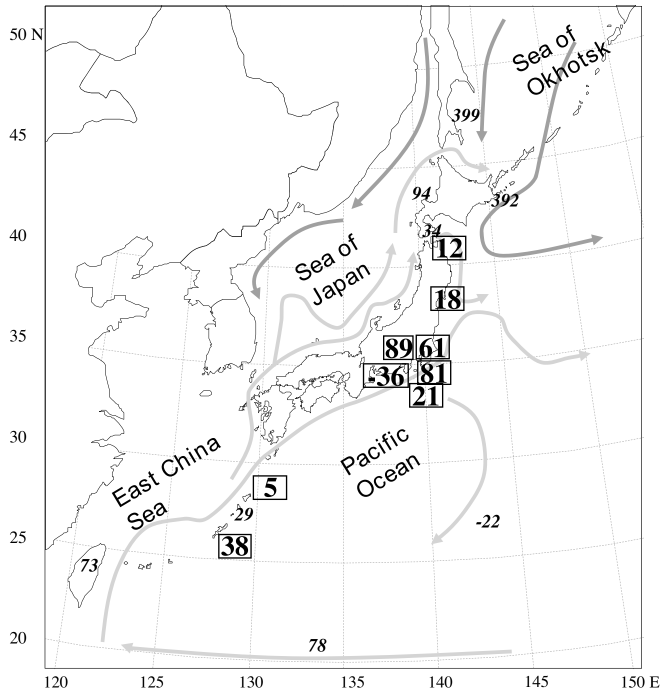

Figure 4 The mean values of ΔR in the western Pacific. Numbers within squares are obtained by this work; italicized numbers are previous data.

The reservoir ages in the Pacific coast of the Japanese Archipelago were clarified in detail for the first time.

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