QUATERNARY RESEARCH **45,** 254–262 (1996)
ARTICLE NO. 0026

Sea Level Changes in the Last Several Thousand Years, Penghu Islands, Taiwan Strait

YUE-GAU CHEN AND TSUNG-KWEI LIU

Department of Geology, National Taiwan University, 245 Choushan Road, Taipei 106, Taiwan, Republic of China

Received May 15, 1995

Holocene shore-face and beach-face deposits form plains <5 m above present sea level along Taiwan Strait. We measured the ^{14}C ages of detrital mollusk shells and coral in such deposits at the Penghu Islands. Twelve carbonate samples—mainly from the largest island, Makung—were dated. Age measurements for two coral samples and one mollusk sample from the same outcrop imply that the ^{14}C ages of mollusk shells give the best approximation of depositional age. The highest Holocene relative sea level in the Penghu Islands occurred about 4700 years ago with a height about 2.4 m above the present sea level. Thereafter, relative sea level appreciably fell without detectable fluctuations to its recent position. Our sea level data are consistent with other studies from the central and western Pacific, except for the timing of peak sea level position. This variation may reflect local crustal response to hydroisostatic effects on the continental shelf.

INTRODUCTION

Local variations in late Holocene sea level change can reflect local crustal rheology (Walcott, 1972; Kidson, 1982). To identify such variations, it is important to infer local sea level change from water level indicators found in tectonically stable areas. Geological and neotectonic evidence implies that the Penghu Islands have been very stable, both on long (several million years) and short (several thousand years) time scales. Hence, the islands are an appropriate place to evaluate local Holocene sea level change on the continental shelf of Asia (Fig. 1A).

The only materials suitable for dating Holocene sea level changes in the Penghu Islands are coarse-grained detrital mollusk shells and corals in shore-face to beach-face deposits. Because the present positions of sampling points do not necessarily reflect the sea level at the time the samples were deposited, using the elevation of sampling points as an indicator to determine the ancient sea level can sometimes be misleading (Pinot, 1979; Kidson, 1982). To avoid this problem, we used the altitude of geomorphic surfaces, at sites where the samples were collected, as indicators of past sea level positions. The surfaces are coastal plains, at an altitude below 5 m, that approximate past positions of ancient mean high tide level (MHTL, Fig. 2B).

The resulting age–altitude plot allows evaluation of late Holocene relative sea level change in the Penghu Islands. We then compare the Penghu Islands data with sea level changes elsewhere in the central and western Pacific region.

GEOLOGICAL BACKGROUND

Plate Tectonic Framework

During the early and middle Cenozoic the continental margin near Taiwan underwent extension and the development of rift basins (Sun, 1982). Volcanism during the Miocene formed the Penghu Islands. The post-Miocene geologic history is marked by convergent tectonics due to the collision between the Asian continental margin and Philippine oceanic plate (Ho, 1982; Teng, 1987). This period of convergent deformation is known as the Penglai Orogeny. The Penglai orogenic belt is located 100 to 200 km east of the Penghu Islands. Several studies have shown that deformation related to the Penglai Orogeny does not extend into the Penghu Islands (Chow *et al.,* 1991; Hsiao *et al.,* 1991; Yang *et al.,* 1991).

Long-Term Crustal Stability

Four observations imply that the Penghu Islands have been tectonically stable since the late Miocene. (1) Late Miocene basalt and sedimentary strata (8–16 myr; Jaung, 1988; Lee, 1990, 1994), which formed near sea level, are located near modern sea level. Based on the sea level curve of Haq *et al.* (1987), late Miocene sea level was as much as 50 m higher than modern sea level and as much as 80 m lower than modern sea level. Consequently, there is almost no net vertical crustal movement since late Miocene (Liu, 1989). (2) The late Miocene sedimentary strata are not known to be tilted or faulted (Lee and Chen, 1992). (3) The youngest basalt found in Penghu Islands was erupted 8 myr ago (Juang, 1988; Lee and Chen, 1992; Lee, 1994). This suggests that extensional tectonics and associated normal faulting, which had characterized the early and middle Miocene in

0033-5894/96 $18.00

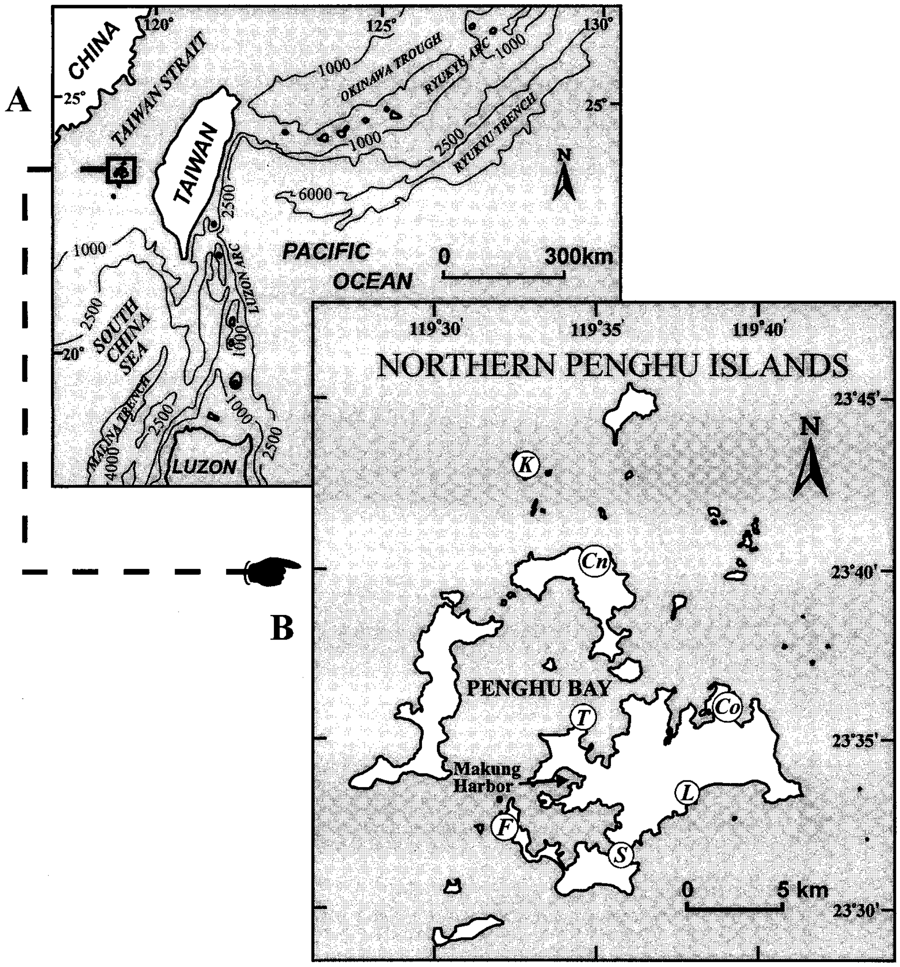

FIG. 1. Maps of (A) Taiwan and its vicinity, (B) study area and sampling localities. Cn, Chihkan; Co, Chinglo; L, Lintou; S, Sokang; F, Fengkuei; T, Tashihpi; K, Kupoyu.

this area, probably ceased 8 myr ago. (4) Seismic profiles near the Penghu Islands (Chow *et al.,* 1991; Hsiao *et al.,* 1991; Yang *et al.*, 1991) show that the strata younger than the Miocene are neither penetrated by the underlying normal faults nor deformed by the collision event that occurred in Taiwan.

Short-Term Crustal Stability

Additional evidence implies that the Penghu Islands were relatively stable during middle and late Holocene: (1) Raised coral reefs have not been found on land (Lin, 1967; Ting, 1990), although many vast reef flats are developed under the sea surrounding the Penghu Islands. This indicates that little crustal uplift has occurred during postglacial time. (2) Holocene shore-face deposits are widespread on the coastal plains (Lin, 1967). They have been interpreted as the product of the Holocene high sea level stand, a general trend observed around the western Pacific (Adey, 1978). This implies that significant subsidence has not occurred in the Penghu Islands during the past several thousand years. (3) Few earthquakes have occurred historically at the Penghu Islands relative to tectonically active Taiwan (Tsai *et al.,* 1977; Tsai, 1986).

Evidence on both Neogene and Holocene time scales thus supports our presumption that the Penghu Islands have been tectonically stable for the past several million years. The Penghu Islands, therefore, are well suited to record Holocene sea level changes in Taiwan Strait.

COASTAL PLAINS AND DEPOSITS

Geomorphic Characteristics

Coastal plains are common in the Penghu Islands, especially along marine embayments and in basaltic lowlands. The plains are somewhat similar to marine terraces described by Woods (1980) and Kern (1977). Elevations of the terrace

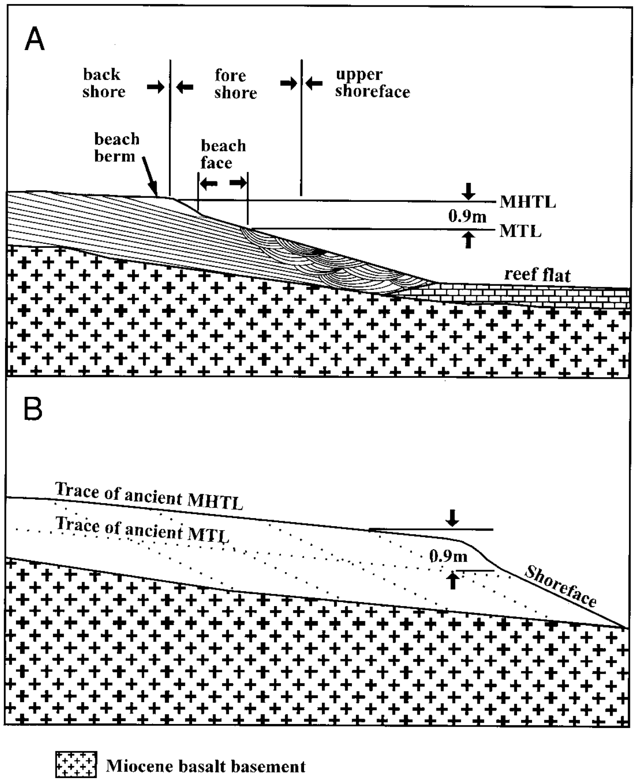

FIG. 2. (A) Generalized cross-sections of the modern coast at Penghu. (B) Schematic cross-section showing the relationship between modern ground surface and ancient shore face at Penghu. Inclined dotted lines schematically represent ancient shore-face profiles.

surfaces and shoreline angles are mainly 2–4 and 5–6 m, respectively. Terrace widths range from several meters to several hundred meters. The widest terraces are located beside modern marine embayments, such as the embayment at Chihkan (Fig. 3A).

Sedimentary Environment

The coastal plains are composed of marine deposits of variable thickness. The thickness can exceed 10 m but more commonly is less than 5 m. The major constituents of the Holocene deposits are detrital bioclastics, including corals, mollusks, and foraminifers. This sediment composition indicates predominantly marine sources. In outcrop most of these marine deposits are well sorted. Planar beds and large-scale (i.e., several meters) trough cross-beds are the dominant sedimentary structures (Fig. 2A). Stratification dips gently seaward (Fig. 2A) and is laterally continuous. Lenses of poorly sorted bioclastic debris and basaltic gravel are present but less common. The sedimentary environment of the stratified deposits is best interpreted as upper shore face to beach face. Storm berms may be represented by poorly sorted deposits.

Depositional Model

Because most of the sedimentary deposits of the coastal plains probably formed on the upper shore face to beach face, and because the stratified deposits dip seaward, many of the bedding surfaces can be treated as ancient shore-face and beach-face surfaces (Fig. 2). Each such bedding surface represents an ancient shoreline profile (Fig. 2B). We propose that the deposits formed during and after the time when Holocene sea level reached its maximum (Fig. 2B). When relative sea level was highest, the shoreline was near the base of the basaltic hills and the coastal plains had not yet been developed. Then, as sea level dropped, the shore-face and beach-face sediments prograded seaward to build the low coastal plains. This process continues to the present. Where berm deposits are negligible, the coastal plain surface can be treated as a track of falling MHTL (Fig. 2B). The ancient sea level position, hence, can be easily derived by subtracting half of the mean tidal range from the altitude of coastal plain surface.

RADIOCARBON SAMPLES

Sample Position

To minimize possible tidal differences among sample localities, samples for radiocarbon dating were collected as near as possible to Makung Harbor, whose tidal record was used as a vertical datum. Twelve carbonate samples were collected from seven localities (Fig. 1B). The localities are Chihkan, Chinglo, Lintou, Sokang, Fengkuei, Tashihpi, and Kupoyu, shown in Figs. 1B and 3A to 3G.

Using a tripod-mounted level, we measured coastal plain heights where we collected ^{14}C samples, assuming tide level at the time of leveling as reference zero. Then we adjusted the measured heights to a common datum by using the mean water line of Keelung Harbor, northern Taiwan. Each surveyed level represents an ancient MHTL, which corresponds to the sample age that will be reported later. The leveling precision is about ±10 cm according to our tentative measurement. The local tidal record used in this study was measured at Makung Harbor, by the Central Bureau of the Ministry of Transportation and Communication, Republic of China.

Age Data

The conventional ages, displayed in Table 1, were determined by the ^{14}C dating laboratory of the Precision Instrument Development Center, National Science Council, Republic of China, located in the Department of Geology, National Taiwan University. Sample qualities were all checked by X-ray diffraction analysis to assure the purity, and the aragonite content is expressed in Table 1 as >95% if calcite peaks were not found. Corrections for reservoir and initial

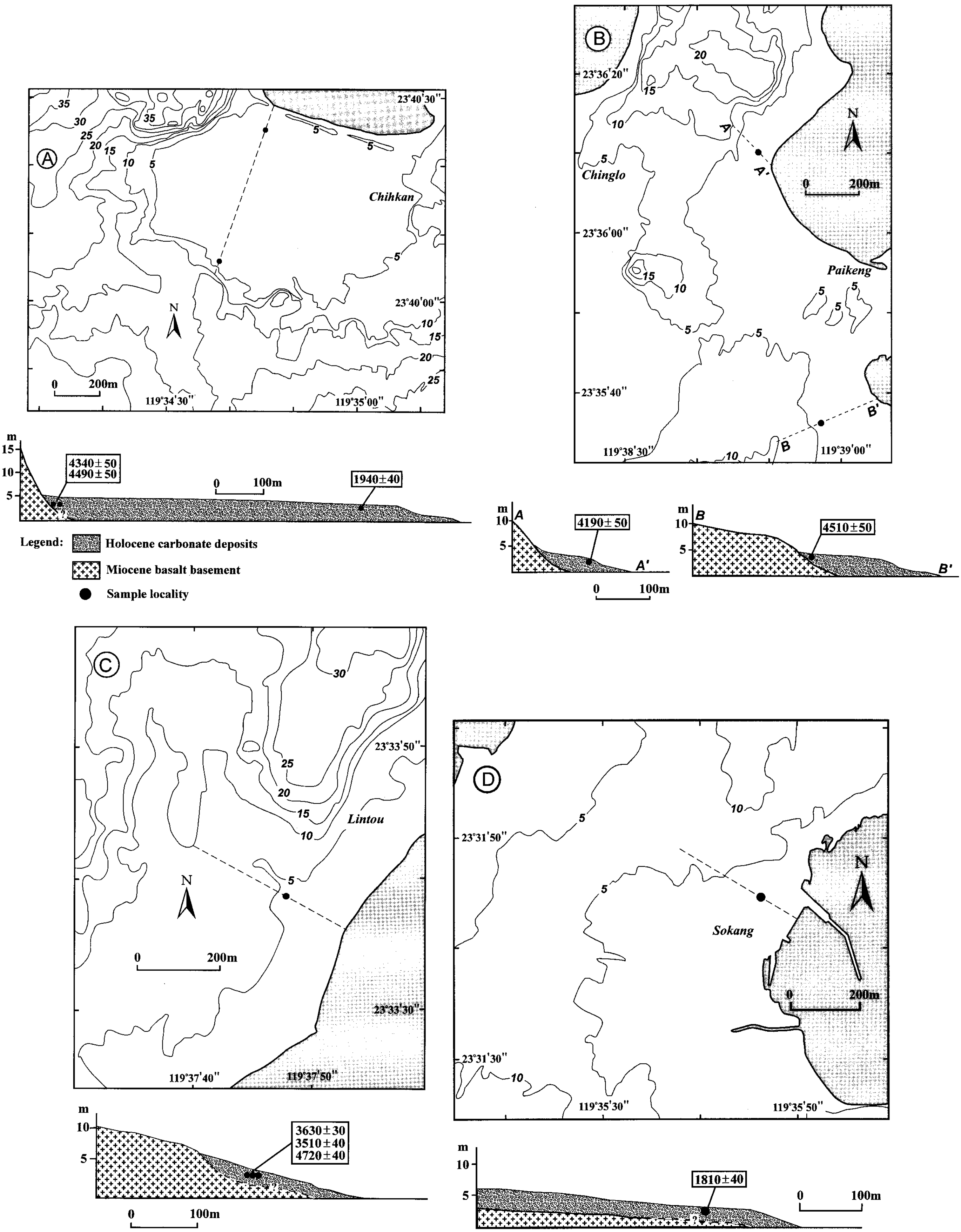

FIG. 3. Detailed topographic maps and cross-sections of sampling areas in this study. The vertical exaggeration of each cross-section is about ten times. Age unit is ^{14}C yr B.P. (A) Chihkan; (B) Chinglo; (C) Lintou; (D) Sokang; (E) Fengkuei; (F) Tashihpi; and (G) Kupoyu.

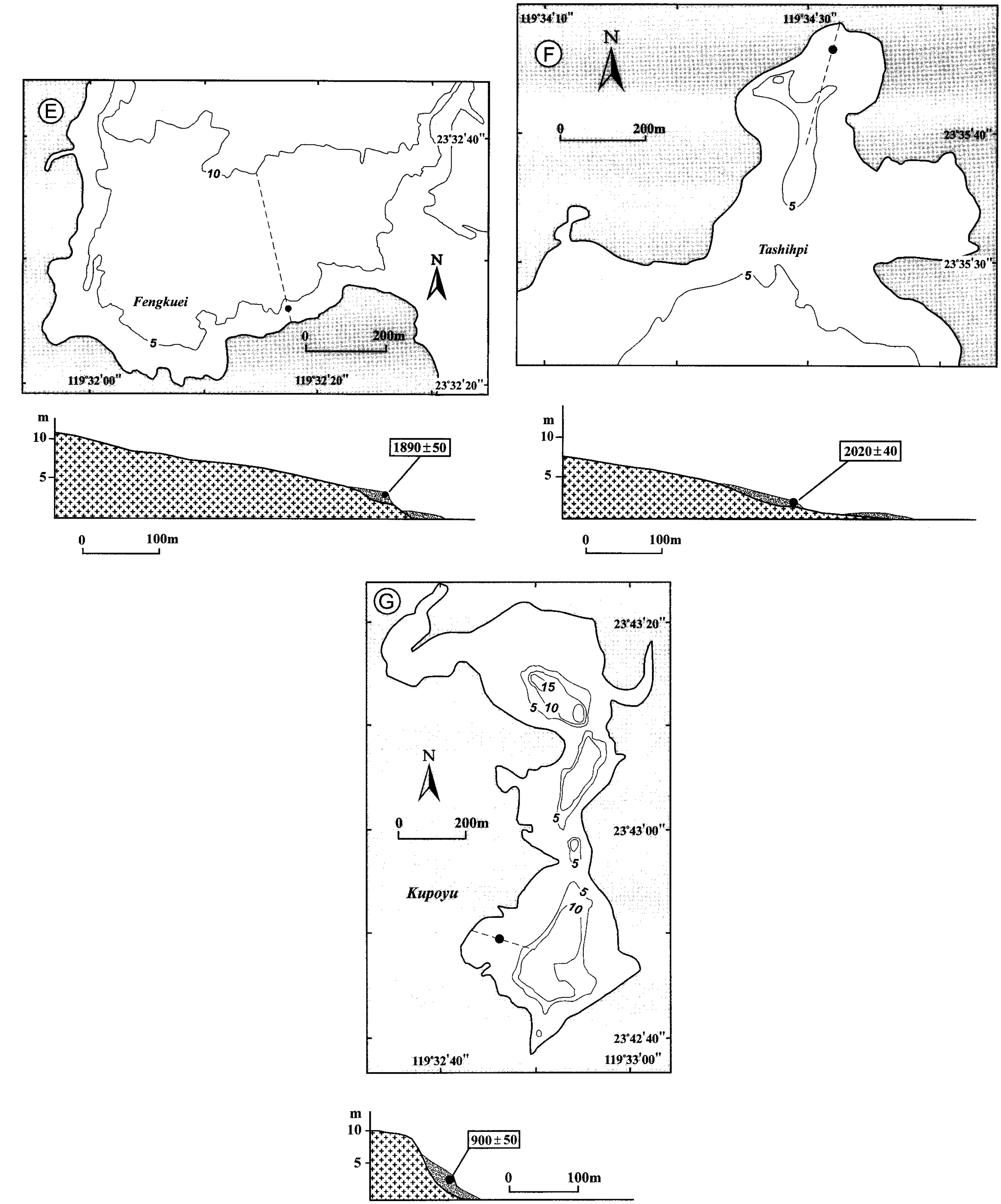

FIG. 3—*Continued*

TABLE 1
^{14}C Ages from the Penghu Islands

Sample	NTU Laboratory	Locality	Longitude/latitude	Depth (m)	^{14}C Age (yr B.P.)[a]	Calibrated Age (cal yr B.P.)[b]	Sample type[c]	Sample composition (Aragonite %)
PH770710A	NTU-1148	Chinglo	119°38′49″/ 23°36′11″	0.8	4190 ± 50	4110–4400	Coral (D)	>95
PH-BKA	NTU-1178	Paikeng	119°38′57″/ 23°35′37″	0.5	4510 ± 50	4530–4820	Mollusks (b, c)	>95
PH-CKA	NTU-1175	Chihkan	119°34′38″/ 23°40′06″	2.8	4340 ± 50	4340–4570	Mollusks (b)	>95
PH-CKC	NTU-1176	Chihkan	119°34′40″/ 23°40′05″	2.8	4490 ± 50	4510–4810	Mollusks (b)	>95
PH790404A	NTU-1342	Chihkan	119°34′46″/ 23°40′25″	1.7	1940 ± 40	1380–1560	Mollusks (b, c)	>95
PH-FKA	NTU-1180	Fengkuei	119°32′17″/ 23°32′26″	0.7	1890 ± 50	1310–1530	Mollusks (b, c, l)	>95
PH-GBP	NTU-1182	Kupoyu	119°32′47″/ 23°42′49″	0.8	900 ± 50	440–560	Mollusks (b)	>95
PH800831A	NTU-1501	Tashihpi	119°34′32″/ 23°35′45″	0.2	2020 ± 40	1480–1680	Mollusks (b, c, l)	>95
PH800905A1	NTU-1498	Lintou	119°37′47″/ 23°33′38″	2.1	3630 ± 30	3440–3590	Mollusks (b)	>95
PH800905A2	NTU-1499	Lintou	119°37′47″/ 23°33′38″	2.0	3510 ± 40	3310–3460	Coral (B)	>95
PH800905A3	NTU-1502	Lintou	119°37′47″/ 23°33′38″	2.0	4720 ± 40	4830–5040	Coral (D)	>95
PH800908B	NTU-1510	Sokang	119°35′46″/ 23°31′45″	1.8	1810 ± 40	1270–1410	Mollusks (b,c)	>95

[a] All the conventional ages were calculated using the ^{14}C half-life of 5568 yr and were corrected for mass fractionation of carbon isotopes by normalizing the $\delta\,^{13}$C values of the samples to −25 ‰ relative to PDB, an international standard.
[b] Age data were calibrated according to Stuiver and Braziunas (1993). We assume a standard reservoir correction ($\Delta R = 0$) and an error multiplier of one ($k = 1$). The calibrated age ranges represent two standard deviations under phase assumptions.
[c] (D) represents dome-type coral and (B) branching-type. Mollusks used in this study are *Barbatia bicolorata* (b), *Cardita variegata* (c) and *Lioconcha sp.* (I).

value effects, proposed by Stuiver and Braziunas (1993), were also applied to the ^{14}C ages of the samples analyzed. The final results are presented in Table 1 with the age unit of calibrated years before 1950 (cal yr B.P.).

Samples collected at the shoreline angle gave greater ages (i.e., PH-CKA, PH-CKC, and PH-BKA; see Figs. 3A and 3B) than those samples collected at the outer edge (i.e., PH790404A, PH800908B, PH-FKA, and PH-GBP; see Figs. 3A, 3D, 3E, and 3G). This age distribution pattern supports our model of deposition during shoreline recession.

Sample Selection

The major sample type used in this study is aragonitic shell of mollusks that have relatively short lifespan and low porosity. We conservatively estimate a typical lifespan shorter than five years because our dated samples are all less than 5 cm in diameter (Krantz *et al.*, 1984). Samples from organisms with short lifespans should provide a closer range of ^{14}C ages. In addition, samples of low porosity should be more subject to contamination than those of high porosity.

Samples from three different types of organisms (PH800905A1, mollusk; PH800905A2, dome-coral; PH800905A3, branching coral; see Fig. 3C), all from one site at Lintou, were dated to test what type of carbonate sample yields the most reliable estimate of depositional time. The dome-type coral sample gave an age older than the other two types, probably because of its long lifespan and its possible recycling from older deposits. Sometimes dome-type corals can grow, either continuously or intermittently, for 1000 years. Some shore-face clasts may consist of the inner portion of such long-lived corals. If the dated dome-coral sample came from the core of the coral, the sample could be centuries older than its time of deposition. On the other hand, larger debris can survive after several depositional cycles. Even if measured on a short-lived organism, the sample age can be much older than its time of deposition. Besides, it is possible that we collected a detrital core of a large coral.

TABLE 2
Modern Altitudes of Ancient Sea Level

Locality	Calibrated ^{14}C Age (cal yr B.P.)	Ground surface altitude (m) at sample position[a]	Altitude correction (m)	Modern altitudes of Paleo sea level (m)
Paikeng	4530–4820	3.3 ± 0.1	0.9	2.4 ± 0.1
Chihkan	4510–4810	3.1 ± 0.1	0.9	2.2 ± 0.1
Chinglo	4110–4400	3.0 ± 0.1	0.9	2.1 ± 0.1
Lintou	3440–3590	3.0 ± 0.1	0.9	2.1 ± 0.1
Tashihpi	1480–1680	1.3 ± 0.1	0	1.3 ± 0.1
Chihkan	1380–1560	1.4 ± 0.1	0.9	1.5 ± 0.1
Fengkuei	1310–1530	2.5 ± 0.1	0.9 + (0.2 ± 0.1)	1.4 ± 0.2
Sokang	1270–1410	2.2 ± 0.1	0.9	1.3 ± 0.1
Kupoyu	440–560	2.3 ± 0.1	0.9 + (0.7 ± 0.1)	0.7 ± 0.2

[a] Uncertainties from measurement of modern ground altitudes do not exceed 10 cm.

Samples collected from mollusks and branching corals, which both have short lifespans, recorded a younger and more realistic deposition age. Due to their original small size and irregular shape, these organisms sustain fewer cycles of erosion before being completely destroyed. The branching coral sample shows a slightly younger age than that of the mollusk shell, which may be due to pores containing impurities that went undetected by X-ray diffraction.

Only complete shells were analyzed to minimize dating of reworked, old material. Two complete mollusk samples (i.e., PH-CKA, PH-CKC; see Fig. 3A), separated several meters from one another along the same horizon, were collected at Chihkan to check for repeatability. The ^{14}C ages determined for these two samples are statistically comparable (Table 1).

To further reduce possible errors from dating of transported shells, we dated only three species of mollusks: *Barbatia bicolorata*, *Cardita variegata* and *Lioconcha sp.* Samples of *Cardita variegata* and *Lioconcha sp.* were used only to complement *Barbatia bicolorata* where specimens of the latter species were too small to yield a reliable ^{14}C age. Because all three mollusk species belong to the same reef environment (Kira, 1965), which is adjacent to the upper shore face in Penghu Islands (Fig. 2A), dated shells need not have traveled far or long before deposition. In addition, each species has a large, thick shell that provides enough material for dating.

HOLOCENE SEA LEVEL CHANGE

As inferred above, the ground surface of the coastal plain approximates ancient positions of MHTL at Paikeng, Chihkan, Chinglo, Lintou, and Sokang; berm deposits are not developed in these areas. However, at Fengkuei and Kupoyu, the ground surface probably represents an ancient berm crest, comparable to modern berms nearly. We measured the present heights of modern berms at Fengkuei and Kupoyu several times during 1991 and 1992 and obtained their average berm heights of 0.2 ± 0.1 and 0.7 ± 0.1 m, respectively. The difference in berm heights is probably related to local wave energy during deposition.

A thin lenticular unit at Tashihpi resembles modern deposits along the coast of Penghu Bay, which has very low wave energy (Fig. 3F). The modern deposits contain only a small amount of detrital carbonate that forms a lens near MTL. Based on this analogy, we interpret the height of the lenticular unit at Tashipi as indicating ancient MTL. Therefore, no correction would be needed to its leveled altitude (Table 2).

The modern mean tidal range measured from Makung

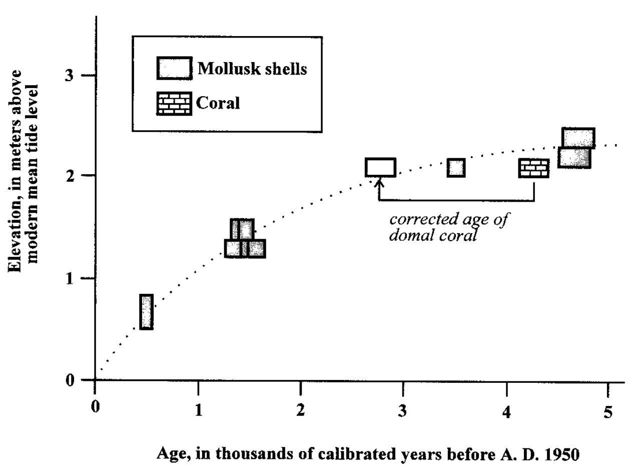

FIG. 4. Age–altitude plot of Holocene sea level in the Penghu Islands. Eight shaded rectangular boxes represent ancient sea level positions, whose ages are derived from mollusk shells. Arrow shows age correction of dome-type coral from Chinglo (see text). All boxes cover the total error range of each sample. The total error is composed of age error (2σ) and altitude measuring error. The smooth curve, drawn to intersect all the sample boxes, represents a best-guess Holocene sea level trace.

Harbor is 1.8 m (1991 and 1992 tidal record, reported by the Central Bureau of the Ministry of Transportation and Communication, Republic of China). If the tidal range around Makung Harbor has been relatively constant for the past several thousand years, the approximate difference between MHTL and MTL has been close to 0.9 m. We use this value to correct the ancient MHTL to ancient MTL in the other places that lack berm deposits. At the Fengkuei and Kupoyu localities, we further corrected for the berm height based upon their modern values, 0.2 ± 0.1 and 0.7 ± 0.1 m respectively (Figs. 3E and 3G; Table 2). Based on these parameters, the modern altitudes of ancient sea levels have been calculated (Table 2).

The age of 4110–4400 cal yr B.P. for a dome-type coral located near Chinglo is probably older than its depositional time. We apply a correction of 1100 years (Fig. 4), based on the age difference observed between the dome-type coral sample (PH800509A1) and the mollusk sample (PH800509A3) at Lintou.

Nine ancient sea level records—two from Chihkan and one from each of seven other localities—are plotted in Fig. 4. The records show that relative sea level reached a middle Holocene maximum about 2.4 m above that of the present day and that it subsequently fell to modern level without any fluctuation large enough for us to detect.

DISCUSSION

Holocene Sea Level Maximum

Because the most landward of the shore-face deposits gives the oldest ages, of about 4700 cal yr B.P., the highest Holocene sea level in Penghu Islands probably occurred about 4700 years ago. This age agrees with previous findings by Nakada (1986), who reported a high sea level from 4000 to 6000 yr B.P. in the central and western Pacific regions. The 2000-year variation in peak time may reflect the local properties of the Earth's crust (Walcott, 1972; Nakada, 1986).

After calibrating the ages reported by previous workers in the same way as has been done in this study, we find two end members for the timing of the sea level maximum. One end member is from the neighboring areas on the continental side of Penghu, such as eastern China coast (Huang *et al.*, 1987; Pirazzoli, 1991), Japan (Fujii and Fuji, 1967; Sugimura, 1977), and Vietnam (Morner, 1983). In these areas, the Holocene sea level maximum occurred at around 6000 years ago. The other end member is from the areas on the oceanic side of Penghu—mid-ocean islands (Kayanne *et al.*, 1988; Miyata *et al.*, 1988; Sugimura *et al.*, 1988; Pirazzoli, 1991) and the southern Ryukyu Islands (Ota *et al.*, 1985). In these areas, the Holocene sea level maximum occurred at around 4000 years ago. The Penghu Islands are intermediate in geographic position and in the timing of Holocene sea level maximum. These results support the hypothesis of Walcott (1972) that postglacial sea levels may differ with geographical setting.

CONCLUSION

Based on geologic and neotectonic evidence, the Penghu Islands have been tectonically stable, both since late Miocene and during Holocene. Thus, it is an appropriate location to evaluate Holocene sea level change in this part of the western Pacific. Based on a progradational deposition model, the altitude and age of nine ancient sea levels have been reconstructed by leveling the ground surface of the coastal plains and by determining the ages of the coarse-grained detrital bioclastics found within the coastal plains. The highest sea level in the Penghu Islands occurred about 4700 years ago at roughly 2.4 m above present sea level. Afterward, sea level appears to have fallen to its present position without large fluctuations. The different peak times of Holocene sea levels between the Penghu Islands and nearby areas demonstrate that Holocene sea level changes were variable among different geographic localities.

ACKNOWLEDGMENTS

We thank Dr. Jack C. L. Liu and Dr. Kenneth Ridgway for their valuable comments and help in polishing the draft. We also thank Dr. Arthur L. Bloom and an anonymous referee for suggestions in content and writing of this paper, and Miss Hwa-Wen Chen for fossil identification.

REFERENCES

Adey, W. H. (1978). Coral reef morphogenesis: A multi-dimensional model. *Science* **202,** 831–837.

Chow, J., Chen, H. M., Chang, T. Y., Kou, C. L., and Tsai, S. F. (1991). Preliminary study on hydrocarbon plays around Nanjitao basin. Taiwan Strait. *Petroleum Geology of Taiwan* **26,** 45–56.

Fairbridge, R. W. (1961). Eustatic changes in sea level. *Physics and Chemistry of the Earth* **5,** 99–185.

Fujii, S., and Fuji, N. (1967). Postglacial sea level in the Japanese islands. *Journal of Geoscience, Osaka City University* **10,** 43–50.

Haq, B. U., Hardenbol, J., and Vail, R. P. (1987). Chronology of fluctuating sea levels since the Triassic. *Science* **235,** 1156–1167.

Ho, C. S. (1982). ''Tectonic Evolution of Taiwan.'' Ministry of Economic Affairs, Taipei, Taiwan, Republic of China.

Hsiao, P. T., Hu, C. C., Lin, K. A., Hsu, S. H., Fuh, S. C., Chang, T. Y., Hsiuan, T. H., Sheen, H. C., Kuo, C. L., and Lee, C. J. (1991). Hydrocarbon potential evaluation of the Penghu Basin. Petrol. Geol. Taiwan **26,** 215–229. [In Chinese]

Huang, Z. G., Li, P. G., Zhang, Z. G., and Zong, Y. Q. (1987). Sea level changes along the coastal area of south China since late Pleistocene. *In* ''Late Quaternary Sea level Changes'' (Y. Qin and S. Zhao, Eds.), pp. 142–154. China Ocean Press.

Juang, W. S. (1988). Geochronology and chemical variations of late Cenozoic volcanic rocks in Taiwan. Ph.D. dissertation, Institute of Oceanography, National Taiwan University. [In Chinese]

Kayanne, H., Yonekura, N., Ishii, T., and Matsumoto, E. (1988). Geomorphic and geologic development of Holocene emerged reefs on Rota and Guam, Mariana Islands. *In* ''Sea Level Changes and Tectonics in the Middle Pacific,'' Report of the HIPAC Projection 1986 and 1987, pp. 35–57. Department of Geography, University of Tokyo.

Kern, J. P. (1977). Origin and history of upper Pleistocene marine terraces, San Diego, California. *Geological Society of America Bulletin* **88,** 1553–1566.

Kidson, C. (1982). Sea level changes in the Holocene. *Quaternary Science Reviews* **1,** 121–151.

Kira, P. (1965). ''Shells of the Western Pacific in Color,'' Vol. I. Hoikusha, Japan.

Krantz, D. E., Jones, D. S., and Williams, D. F. (1984). Growth rates of the sea scallop, *Placopecten maggellanicus,* determined from the $^{18}O/^{16}O$ record in shell calcite. *Biological Bulletin* **167,** 186–199.

Lee, C. Y. (1990). Late Miocene paleogeography reconstruction of Penghu Islands. Presented at the 1990 Annual Meeting of the Geological Society of China; abstracts with Program, p. 24. [In Chinese]

Lee, C. Y., and Chen, C.-H. (1992). Temporal and spatial variation of basalt in Penghu Islands. Presented at the 1992 Annual Meeting of the Geological Society of China, abstracts with Program, p. 92. [In Chinese]

Lee, C. Y. (1994). Chronology and geochemistry of basaltic rocks from Penghu Islands and mafic dikes from east Fujian: Implications for the mantle evolution of SE China since late Mesozoic, p. 226. Ph.D. dissertation, National Taiwan University. [In Chinese]

Lin, C. C. (1967). Geology of the offshore islands of Taiwan. Quar. Jour. Bank of Taiwan **18**(4), 229–256. [In Chinese]

Liu, T. K. (1989). Radiometric dates of rocks and sediments from Penghu Islands and Lutao, and their implication of vertical crustal movement. Technical report, Energy & Resources Laboratories of Industrial Technology Research Institute.

Miyata, T., Maeda, Y., Matsumoto, E., Matsushima, Y., Rodda, P., and Sugimura, A. (1988). Emerged notches and micro-atolls on Vanua Levu, Fiji. *In* ''Sea Level Changes and Tectonics in the Middle Pacific,'' Report of the HIPAC Project in 1986 and 1987, pp. 67–76. Department of Geography, University of Tokyo.

Morner, N. A. (1983). Differential Holocene sea level change over the global evidence for glacial eustasy, geoidal eustasy and crustal movements. *In* ''Abstracts of International Symposium on the Coastal Evolution in the Holocene,'' pp. 93–96. Japan Society for the Promotion of Science, Tokyo.

Nakada, M. (1986). Holocene sea levels in oceanic islands: Implications for the rheological structure of the Earth's mantle. *Tectonophysics* **121,** 263–276.

Ota, Y., Pirazzoli, P. A., Kawana, T., and Moriwaki, H. (1985). Late Holocene coastal morphology and sea level records on three small islands, the South Ryukyus, Japan. *Geographical Review of Japan* **58**(B), 2, 185–194.

Peltier, W. R., Farrell, W. E., and Clark, J. A. (1978). Glacial isostasy and relative sea level: A global finite element model. *Tectonophysics* **50,** 81–110.

Pinot, J.-P. (1979). Les indicateurs deceles par des methodes oceanographiques, geophysiques ou geochimiques. *Oceanis* **5,** 335–355.

Pirazzoli, P. A. (1991). ''World Atlas of Holocene Sea Level Changes.'' Elsevier Oceanography Series, Vol. 58. Elsevier, Amsterdam.

Shepard (1963). Thirty-five thousand years of sea level. *In* ''Essays in Honor of K. O. Emery,'' pp. 1–10. Univ. of Southern California Press, Los Angles.

Stuiver, M., and Braziunas, T. F. (1993). Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. *Radiocarbon* **35**(1), 137–190.

Sugimura, A. (1977). Ice sheets, continents and oceans. *Kagaku* **47,** 749–755. [In Japanese]

Sugimura, A., Maeda, Y., Matsushima, Y., Rodda, P., and Matsumoto, E. (1988). Lobau lowland, Viti Levu, Fiji. *In* ''Sea Level Changes and Tectonics in the Middle Pacific,'' Report of the HIPAC Project in 1986 and 1987, pp. 59–65. Department of Geography, University of Tokyo.

Sun, S. C. (1982). The Tertiary basins of offshore Taiwan. In (A. Salivar-Sali, Ed.), pp. 125–135. Technical Programme Committee, ASCOPE. 1981,

Teng, L. S. (1987). Stratigraphic records of the late Cenozoic Penglai Orogeny of Taiwan. Acta Geol. Taiwanica **25,** 205–224.

Ting, F. T. C. (1990). Subsidence in an uplifting environment: Case studies in Taiwan. *Proceedings of the Geological Society of China* **33**(1), 1–7.

Tsai, Y. P., Teng, T.-L., Chu, J. M., and Liu, H. L. (1977). Tectonic implications of the seismicity in the Taiwan region. *Memoir of the Geological Society of China* **2,** 13–41.

Tsai, Y. P. (1986). Seismotectonics of Taiwan. *Tectonophysics* **125,** 17–37.

Walcott, R. I. (1972). Past sea levels, eustasy and deformation of the Earth. *Quaternary Research* **2,** 1–14.

Woods, A. J. (1980). Geomorphology, deformation, and chronology of marine terraces along the Pacific coast of central Baja California, Mexico. *Quaternary Research* **13,** 346–364.

Yang, K. M., Ting, H. H., and Yuan, J. (1991). Structural styles and tectonic modes of Neogene extensional tectonics in southwestern Taiwan: Implications for Hydrocarbon exploration. *Petroleum Geology of Taiwan* **26,** 1–31.