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Young Age Bias of Radiocarbon Dates in Pre-Holocene Marine Deposits of Hong Kong and Implications for Pleistocene Stratigraphy

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Abstract

Radiocarbon dates of pre-Holocene marine deposits in Hong Kong ranging from 21,580 ± 1,210 to 45,700 ± 2,000 years BP are found to be younger than uranium-series dates of mollusks and other indirect age evidence. Two mollusk samples yielded last interglacial ages of 130,500 ± 5,300 and 142,000 ± 20,000 years BP, respectively. Palynological and oxygen-isotope evidence shows that the marine deposits containing the mollusks were formed under marginally warmer temperature conditions than in the present day, which is consistent with a last interglacial age. Since old radiocarbon dates are likely to be minimum age estimates, similar studies carried out elsewhere would be of value to Pleistocene stratigraphy.

Introduction

Numerous finite radiocarbon dates in the range of 25,000 to 40,000 years BP, which are, if correct, last interstadial, have been cited as proof that sea level stood above its present position at least once during the last interglacial time (Bloom 1983). However, radiocarbon ages near the upper limit of the method are notoriously sensitive to contamination. For an age of about 25,000 years BP, 1% modern carbon can change the age by a factor of two while dates of 39,000 years BP are as good as infinite. In a critical review of high interstadial sea levels during the last glaciation (Thom 1973), the need for reliable radiometric dates was stressed. An appropriate way to check the reliability of the results obtained by any radiometric method of dating is to use another method which is known to be more reliable for that particular age range. For example, last interstadial ages obtained by radiocarbon dating may be checked by uranium-series dating. In the latter method, samples of non-recrystallized corals are preferred to mollusks because they are less susceptible to open system exchanges (Kaufman and others 1971, Stearns 1984). In the absence of coral samples, reliable dates are obtainable from mollusks only if they have remained under a closed system since burial. Consequently, it is also desirable to check the validity of dates against results obtained by other indirect methods of dating.

Hong Kong is situated near to the mouth of the Pearl River Estuary just south of the Tropic of Cancer on the northern part of the South China Sea (Fig. 1). It lies on the South China coast which is regarded as forming part of a passive continental margin (Taylor and Hayes 1980). Because of rapid population growth and a great shortage of flat land for urbanization, engineering work, particularly that involving coastal land reclamations, have provided excellent opportunities for the study of Quaternary deposits. Pre-Holocene marine deposits have been encountered in boreholes and sea bed excavations carried out (Yim and Li 1983; Yim 1984a and 1984b; Wang and Yim 1985; Yim and others 1988). Previous radiocarbon datings of these deposits were found to range from 30,560 ± 580 to 36,230 ± 680 years BP (Yim 1986). If a last interstadial age is accepted, it is necessary to invoke post-depositional uplift of Hong Kong because the deposits reached an elevation of at least −9 m Principal Datum (P.D. which in Hong

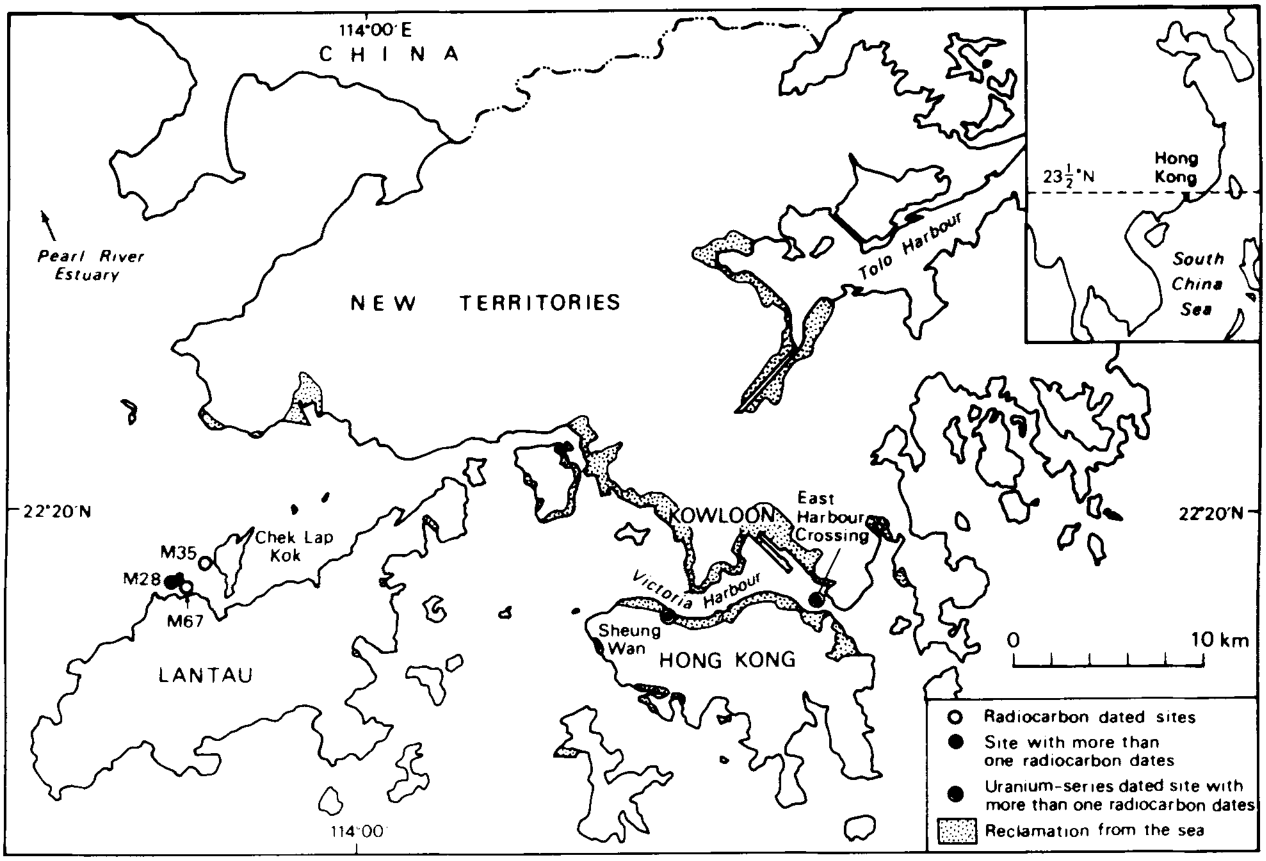

Figure 1. Location map of radiometrically dated sites referred to in the present study.

Kong is approximately 1.15 m below mean sea level). Based on the eustatic sea level of −41 m during the last interstadial inferred from coral reef terraces in New Guinea (Bloom and others 1974), the amount of uplift is about 30 m. This paper presents results of a study carried out to check the reliability of last interstadial ages obtained by radiocarbon dating, by means of uranium-series, and other indirect methods. The possibile implications of the results to Pleistocene stratigraphy are discussed briefly.

Materials and Methods

In the present study, samples were collected for radiometric dating from two localities involving major coastal engineering projects (Fig. 1): firstly, from the excavation of a land reclamation in the central district of Hong Kong Island to below the former sea bed level at the Sheung Wan Station on the Island Line of the Mass Transit Railway Corporation, and secondly, grab samples were obtained from dredging and boreholes of the sea bed for the tunnel of the East Harbour Crossing. The stratigraphy of the sedimentary successions at the two sites are summarised in Fig. 2.

Following the recommendation of Geyh and others (1974), all samples selected for radiocarbon dating in the present study were oven-dried soon after their collection in the field to avoid unreliable results caused by bacterial uptake of recent carbon dioxide. Seven samples including one from Sheung Wan and six from the East Harbour Crossing were submitted to the Australian National University for radiocarbon dating. The Sheung Wan sample was collected from pre-Holocene marine deposits and comprises a complete oyster shell identified as *Crassostrea gigas*. Previously, two radiocarbon dates of 30,560 ±580 and 36,230 ± 680 years BP, respectively, were obtained on two oyster shells which formed part of the same oyster bed (Yim 1986). All these oyster shells were identified to be preserved in their growth position. The six samples from the East Harbour Crossing were collected from pre-Holocene marine deposits including four mollusk and two organic mud samples. The mollusk samples include one of unidentified bivalves and snails, *Andara* sp., *Ostrea* sp., and *Crassostrea gigas*, respectively.

Two complete valves of *Crassostrea gigas* from the

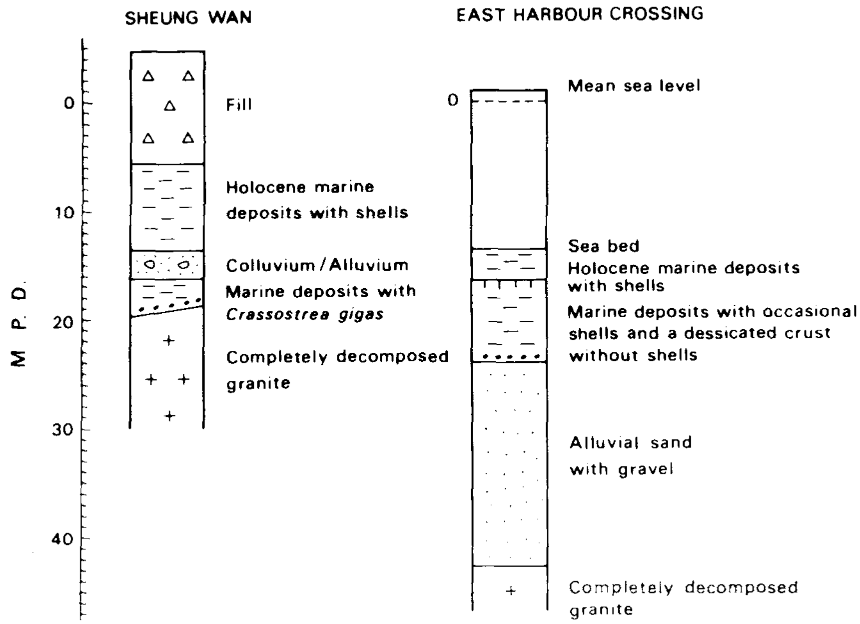

Figure 2. Summary of Quaternary stratigraphy at Sheung Wan and the East Harbour Crossing. All samples used for radiometric dating in the present study are from the stratum of pre-Holocene marine deposits.

Sheung Wan site and the second valve of the same *Andara* sp. specimen from the East Harbour Crossing were selected for uranium-series dating. They were chosen because both were buried in low permeability mud in their position of growth which is helpful to ensure that they have remained under a closed system without exchanges of uranium isotopes and their daughter products.

The isotope dilution/alpha-spectrometry methods used are described in some detail in Lally (1982) and Ivanovich (1982). After dissolution of the sample, weighed amounts of 229_{Th} and 236_{U} spike solutions are added. After 24 hours of equilibration, an ammonia solution is added resulting in the precipitation of ferric hydroxide. The flocculent precipitate is separated from supernatant liquid by centrifugation. The uranium and thorium coprecipitated with iron are redissolved and then passed through an anion exchange column to separate uranium and iron from thorium. The uranium and thorium fractions are then purified on separate ion-exchange columns and prepared for electro-deposition on stainless steel planchets for alpha-spectrometric analysis. The dateability of mollusks by the uranium-series disequilibrium methods are also discussed in Ivanovich (1982), references therein, and in Ivanovich and others (1983). In the present work, the mollusk samples were dissolved in 2 N nitric acid yielding negligible amounts of acid-insoluble detritus. Consequently, no correction of impure calcite conditions were necessary.

Information on the palynological study of borehole samples carried out was presented in Yim and others (1988). Only part of the results are included in this paper as they will be published in greater detail elsewhere.

Results of Radiocarbon Dating

A summary of possible last interstadial radiocarbon dates from marine deposits in Hong Kong, including the seven new dates obtained in the present study, is shown in Table 1.

The dates show the general trend of shell materials being the oldest in relative age followed by wood and organic mud. Because the shells are low in faunal diversity and are perfectly preserved in most cases, recycling of transported shells is considered to be unlikely. At the same time, the muds enclosing the shells are indicated by their particle size distribution to be from a low to moderate energy environment. This rules out the transportation of large shells by current action. Although the natural distribution of *Crassostrea gigas* is not fully known (Morris 1985), in present day Hong Kong it is cultivated in Deep Bay where it lives on intertidal mud flats under estuarine conditions. In contrast to oysters, the comparatively thick walled *Andara* sp. is associated with a subtidal muddy bottom environment (B.S. Morton, personal communication, 1987).

All wood samples radiocarbon dated by RMP Encon (1982) were collected from boreholes. Since the sample weights available were small and did not exceed 10 g, they were all dated by the accelerator method. Because their ages show a tendency to be younger than the shells, they are probably derived from *in situ* plant rootlets rather than driftwood. However, no information was available to confirm this. On the other hand, the two youngest ages obtained for the two organic mud samples from the East Harbour Crossing concur with subaerial exposure of the deposits during the low sea level stand

Table 1. Summary of possible last interstadial radiocarbon dates from marine deposits in Hong Kong

Locality	Reference	Sample type	Elevation (m P.D.)	Laboratory code	Age (years BP)
East Harbour Crossing	present study	organic mud	−20	ANU 6168	21,580 ± 1,210
East Harbour Crossing M21	present study	organic mud	−20.8	ANU 6169	23,980 ± 2,055
Chek Lap Kok M28	RMP Encon (1982)	wood	−25.5	BETA 4139	26,770 ± 840
Chek Lap Kok M67	RMP Encon (1982)	wood	−25.5	BETA 4144	27,660 ± 590
Sheung Wan	Yim (1986)	*Crassostrea gigas*	−18	KWG 569	30,560 ± 580
Sheung Wan	Yim (1986)	wood	−15.5	KWG 483	31,450 ± 610
East Harbour Crossing	present study	bivalves and snails	−20	ANU 5968	31,500 ± 2,000
Chek Lap Kok M35	RMP Encon (1982)	wood	−26.5	BETA 4140	33,440 ± 1,740
East Harbour Crossing	present study	*Crassostrea gigas*	−20	ANU 5965	34,880 ± 1,230
Sheung Wan	Yim (1986)	*Crassostrea gigas*	−17	KWG 482	36,230 ± 680
Chek Lap Kok M28	RMP Encon (1982)	wood	−24.2	BETA 4138	37,590 ± 1,590
East Harbour Crossing	present study	*Andara* sp.	−20	ANU 5967	39,460 ± 2,320
East Harbour Crossing	present study	*Ostrea* sp.	−20	ANU 5966	39,910 ± 2,460
Sheung Wan	present study	*Crassostrea gigas*	−17	ANU 5964	45,700 ± 2,000

P.D.—Principal Datum in Hong Kong is approximately 1.15 m below mean sea level
A number of infinite dates which may also be last interstadial have not been included

of the Last Glacial Maximum at about 18,000 years BP. The radiocarbon ages of 21,580 ± 1,240 and 23,980 ± 2,055 years BP are transitional between the last glacial and last interstadial which is best explained by contamination of the samples through the introduction of "new" carbon during the last glaciation.

The frequency with which the period 28,000 to 38,000 years BP recurs in radiocarbon dates from samples in coastal deposits and on the continental shelf implies either a consistent degree of 1–3% contamination of a variety of marine organisms of otherwise infinite or background age, or that a real event has taken place (Thom 1973). A real count is ruled out in the present study because of the high elevation of the samples. In the coastal region of South China, rates of uplift found by Huang and others (1984) cannot account for their present day elevation. If the elevation of last interstadial sea level stand of −41 m inferred from coral reef terraces in New Guinea by Bloom and others (1974) is accepted, then the amount of post-interstadial uplift is about 30 m. However, evidence to support uplift of such magnitude is lacking in Hong Kong. Furthermore, although an age of 29,000 years BP was assumed for reef complex II (Bloom and others 1974), the age was obtained by radiocarbon dating and has not been checked by uranium-series dating. The radiocarbon dates of shells are therefore more likely to represent minimum ages which may be caused by post-depositional changes in the calcite/aragonite ratio through recrystallization in addition to other causes.

Results of Uranium-Series Dating

Dates obtained on shells other than corals by the uranium-series method are highly questionable (Kaufman and others 1971, Stearns 1984). However, in Hong Kong corals from pre-Holocene marine deposits have not yet been found so it was therefore necessary to attempt dating of available mollusks.

The migration of uranium-series isotopes out of and/or into mollusks was considered by Kaufman and others (1971) to pose a serious obstacle to age determination. Because of this, it is essential to select shells which have remained in a closed system since burial. In the present study, both oyster shells chosen exceeded 12 cm and the *Andara* sp. shell exceeded 6 cm, therefore a derived origin may be ruled out due to their large size. Furthermore, since these shells were all found buried in their growth position within a mud of low permeability, they should stand a reasonable chance of being successfully dated. This was partly confirmed by the results (Table 2). The first

Table 2. Uranium-series disequilibrium obtained from three mollusk shell samples in Hong Kong

Locality	Sample code	Uranium (ppm)	Activity ratio $234_{U}/238_{U}$	Activity ratio $230_{Th}/234_{U}$	Activity ratio $230_{Th}/232_{Th}$	Age (years BP)	Initial $(234_{U}/238_{U})_{o}$
Sheung wan[a]	H 4893	0.152 ± 0.003[c]	1.28 ± 0.03	1.33 ± 0.03	22	—	—
Sheung Wan[a]	H 4894	0.42 ± 0.01	1.15 ± 0.01	0.715 ± 0.016	37	130,500 ± 5,300	1.20 ± 0.02
East Harbour Crossing[b]	H 5261	0.10 ± 0.005	1.44 ± 0.08	0.77 ± 0.06	13	142,000 ± 20,000	1.66 ± 0.12

[a] *Crassostrea gigas*
[b] *Andara* sp
[c] All quoted values are one standard deviation uncertainties due to nuclear counting statistics only

specimen (H 4893) yielded a $230_{Th}/234_{U}$ activity ratio greater than unity and a finite age could not be inferred from it. Since both *Crassostrea gigas* specimens were derived from the same location, the relatively low uranium content (0.152 ppm) in the first specimen H 4893) compared with the second (H 4894, 0.42 ppm) may be indicative of loss of uranium since deposition. Coupled with its nonmarine $234_{U}/230_{U}$ activity ratio, which is considerably greater than the sea water value of 1.15 suggested by Thurber and others 1965), it has been concluded that the shell (H 4893) remained an open geochemical system and therefore could not be dated. The second specimen (H 4894) yielded a finite age of 130,500 ±5,300 years BP. it is suggested that this age is reliable because the $230_{Th}/232_{Th}$ activity ratio is well in excess of 20 and no correction for detrital thorium was required. Since only negligible amounts of acid-insoluble detritus were obtained from both specimens, detrital mineral analysis was not carried out. This age is regarded as likely because the initial $234_{U}/230_{U}$ activity ratio is within two standard deviations of the sea water value of 1.15 ± 0.01. Therefore, it is reasonable to suppose that the shell remained a closed geochemical system. The third specimen (H 5261) yielded an age of 142,000 ± 20,000 years BP in comparison with a radiocarbon age of 39,460 ± 2,320 years BP obtained for the other valve. Although the uncertainties are rather large due to a combination of small sample weight and low uranium content (0.1 ppm), the age is within one standard deviation of the 130,500 years of the second specimen (H 4894). However, the initial $234_{U}/238_{U}$ activity ratio of 1.66 ± 0.12 is considerably greater than the sea water value of 1.15, and the inferred age should be viewed with caution. The high $234_{U}/238_{U}$ activity ratio of this sample may be the consequence of post-depositional influx of dissolved uranium in soil or groundwater. Its presence would modify the true age of the specimen to different degrees depending on whether this influx was continuous throughout its burial in the deposit or was a recent episode. In any event, the age of sample H 5261 appears to be much greater than suggested by its radiocarbon age.

Indirect Evidence and Implications of a Last Interglacial Age on Pleistocene Stratigraphy

The two finite ages of 130,500 ±5,300 and 142,000 ± 20,000 years BP obtained are indistinguishable from the 125,000 years B.P. of the last interglacial period (Kaufman 1986) and oxygen isotope stage 5e (Shackleton and Opdyke 1973). This is supported by two indirect lines of evidence. Firstly, palynological studies of marine boreholes from the coastal waters of Hong Kong have revealed that the pre-Holocene marine deposits shown in Fig. 2 possess a plant assemblage indicating a paleotemperature at least as high if not higher than in the present day. Table 3 provides a summary of the spores and pollen of common occurrence present in the last interglacial marine deposits of Hong Kong. Based on the present day distribution of the two mangrove species, *Sonneratia alba* and *Sonneratia caseolaris* (Muller 1969) which are both absent in Hong Kong in the present day, a mean annual temperature of about 22°C at sea level was exceeded by at least 2°C during the last interglacial period. Many of the species shown in Table 3 are found south of Hong Kong in the present day. Secondly, evidence obtained from oxygen-isotope study of planktonic foraminifera from a core in the continental slope of the northern South China Sea (Wang and others 1986) indicated that the last interglacial period is the only time period when paleotemperatures approached the level of the present day during the last 130,000 years.

The two last interglacial ages obtained by uranium-series dating, palynological and oxygen-isotope evidence, have shown that the last interstadial ages presented in Table 1 are likely to be erroneous. The radiocarbon dates are minimum estimates of the true age but in spite of this, the trend in ages shown by shell, wood, and organic mud sample types are useful in reflecting the change in paleoenvironmental con-

Table 3. Spores and pollen of common occurrence in last interglacial marine deposits of Hong Kong

Fern spores	Wood pollen
Acrostichaceae	Altingiaceae
Acrostichum aureum L.*	*Altingia chinensis* (Champ.) Oliv.
Cyatheacea	*Liquidambar formosana* Hance
Cyathea brunnoneana Wall.	Euphorbiaceae
C. podophylla (Hock.) Copel.	*Macaranga denticulata* (Bl.) M.A.
Dennstaediaceae	Myrsinaceae
Microlepia caudiformis Ching	*Aegiceras corniculatum* (L.) Blanco*
M. Crass Ching	Myrtaceae
Dicksoniaceae	*Syzygium cumini* (L.) Skeels
Cibotium barometz (L.) J. Smith	Palmae
Gleicheniaceae	Rubiaceae
Dicranopteris linearis (Burman f.) Underw. var. *linearis*	*Randia merrillii* Chun
D. linearis (Burman f.) Underw. var. *tetraphylla* (Rosenst.) Nakai	Rhizophoraceae
Diplopterygium chinensis (Rosenst.) DeVol	*Bruguiera sexangula* (Lour.) Poir.*
D. laevissimum (Christ) Nakai	*Kandelia candel* (L.) Druce*
Grammitidaceae	*Rhizophora apiculata* Bl.*
Prosaptia urceolaris (Hay.) H. Ito	*R. mucronata* Lam.*
Lygodiaceae	*R. stylosa* Griff.*
Lygodium microphyllum (Cav.) R. Br.	Sonneratiaceae
Polypodiaceae	*Sonneratia alba* J. Smith*
Polypodium niponicium Mett.	*Sonneratia caseolaris* (L.) Engl.*
Pteridaceae	Verbenaceae
Pteris hainanesis Ching	*Avicennia marina* (Forsk) Vierk*
P. maclurei Ching	Podocarpaceae
P. taiwanensis Ching	*Dacrydium pierrei* Hickel
	Podocarpus sp.

* Mangrove species

ditions which have taken place. The older ages shown by the shell samples and the younger ages shown by the organic mud samples are consistent with subaerial exposure of the last interglacial deposits during the Last Glacial Maximum when sea level fell to about −130 m (Emery and others 1970). The latter is supported by the recognition of a desiccated crust such as that occurring in the East Harbour Crossing (Fig. 2).

A last interglacial age for pre-Holocene deposits in Hong Kong has two important implications on Pleistocene stratigraphy. Firstly, sedimentation rates of inshore waters during the Late Pleistocene are greatly reduced. A shift in age from last interstadial to last interglacial has increased the duration of the disconformity existing between the last glacial terrestrial deposits and earlier marine deposits by more than three times. This reinforces the view that the Pearl River Delta, with the highest sedimentation rate in the region at present, was essentially formed after the Holocene transgression. Secondly, sea level and associated paleoenvironmental changes during the Late Pleistocene are more consistent with the world-wide scenario. The identification of last interglacial marine deposits in Hong Kong reaching an elevation of at least −9 m P.D. (Yim 1986) concurs with global evidence that sea levels in stable crustal regions during this time were close to or perhaps even slightly higher than in the present day. This is consistent with a number of localities, including Australia (Marshall and Thom 1976, Szabo 1979) and Oahu (Ku and others 1974), in the world where uranium-series dating of corals have revealed last interglacial deposits between 2 to 9 m above present sea level. In Hong Kong this is further supported, although admittedly controversially, by the presence of marine erosional features including wave-cut platforms and sea caves present on exposed rocky headlands a few meters above present sea level.

Because of the recognition of the last interglacial sea level in Hong Kong, last interstadial sea levels along the coast of the People's Republic of China recognized solely on the basis of radiocarbon dating should be treated with extreme caution. It is desirable to carry out uranium-series dating of corals if available and mollusks if corals are absent, and, to examine palynological and oxygen-isotope evidence to determine the validity of the last interstadial age.

Conclusions

Extreme caution is necessary in the interpretation of old radiocarbon dates not supported by other lines of evidence. In the present study, uranium-series dating of mollusks unaffected by the migration of uranium isotopes and their daughter products since burial, may be a valuable adjunct for checking the reliability of last interstadial ages determined by radiocarbon dating. This method could have widespread application in the study of Late Pleistocene marine deposits where corals are absent and mollusks are available. Although uranium-series dating of further samples would be desirable, the last interglacial dates obtained in the present study agree with indirect evidence, and together, they invalidate the radiocarbon ages, which are too young. Both palynological and oxygen-isotope evidence are found to be indicative of marginally warmer temperature conditions than the present, which is in excess of the last interstadial. Therefore, similar studies carried out elsewhere would be of value to improve our understanding of Pleistocene stratigraphy as would follow-up oxygen-isotope studies on mollusks to provide paleotemperature data to confirm their last interglacial origin.

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References

Bloom AL (1983) Sea level and coastal morphology of the United States through the Late Wisconsin Glacial Maximum. In: Wright HE Jr (ed) Late Quaternary Environments of the United States. University of Minnesota Press, Minneapolis, pp 215–229

Bloom AL, Broecker WS, Chappell JMA, Matthews RK, Mesolella KJ (1974) Quaternary sea level fluctuations on a tectonic coast: new $230_{Th}/234_{U}$ dates from the Huon Peninsula, New Guinea. Quaternary Research 4:185–205

Emery KO, Niino H, Sullivan B (1970) Post-Pleistocene levels of the East China Sea. In: Turekian KK (ed) Late Cainozoic Glacial Ages. Yale University Press, New Haven, pp 381–390

Geyh MA, Krumbein WE, Kudrass H-R (1974) Unreliable ^{14}C dating of long-stored deep-sea sediments due to bacterial activity. Marine Geology 17:45–50

Huang Y, Xia F, Huang D, Lin H (1984) Holocene sea level changes and recent crustal movements. In: Whyte RO (ed) The Evolution of the East Asian Environment, Vol. 1. Centre of Asian Studies, University of Hong Kong, Hong Kong, pp 271–287

Ivanovich M (1982) Spectroscopic methods. In: Ivanovich M, Harmon RS (ed) Uranium Series Disequilibrium: Applications to Environmental Problems in Earth Sciences. Clarendon Press, Oxford, pp 107–144

Ivanovich M, Vita-Finzi C, Hennig GJ (1983) Uranium-series dating of molluscs from uplifted Holocene beaches in the Persian Gulf. Nature 302:408–410

Kaufman A (1986) The distribution of $230_{Th}/234_{U}$ ages in corals and the number of last interglacial high-sea stands. Quaternary Research 25:55–62

Kaufman A, Broecker WS, Ku T-L, Thurber DL (1971) The status of U-series methods of mollusk dating. Geochimica et Cosmochimica Acta 35:1155–1183

Ku T-L, Kimmel MA, Easton WH, O'Neil TJ (1974) Eustatic sea-level 120,000 years ago on Oahu, Hawaii. Science 183:959–962

Lally LE (1982) Chemical procedures. In: Ivanovich M, Harmon RS (ed) Uranium Series Disequilibrium: Applications to Environmental Problems in Earth Sciences. Clarendon Press, Oxford, pp 79–106

Marshall JF, Thom BG (1976) The sea level in the last interglacial. Nature 263:120–121

Morris S (1985) Preliminary guide to the oysters of Hong Kong. Asian Marine Biology 2:119–138

Muller J (1969) A palynological study of the genus *Sonneratia* (Sonneratiaceae). Pollen et Spores 11:223–298

RMP Encon (1982) Replacement Airport at Check Lap Kok—Civil Engineering Design Studies Study Report No. 1—Site Investigation. Unpublished report, Engineering Development Department, Civil Engineering Office, Hong Kong Government, Hong Kong

Shackleton NJ, Opdyke ND (1973) Oxygen and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: Oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year cycle. Quaternary Research 3:39–55

Stearns CE (1984) Uranium-series dating and the history of sea level. In: Mahaney WC (ed) Quaternary Dating Methods. Developments in Palaeontology and Stratigraphy 7. Elsevier Science Publishers B.V., Amsterdam, pp 53–66

Szabo BJ (1979) Uranium-series age of coral reef growth on Rottnest Island, Western Australia. Marine Geology 29:11–15

Taylor B, Hayes DE (1980) The tectonic evolution of the South China Sea Basin. In: Hayes DE (ed) The Tectonic and Geologic Evolution of Southeast Asian Seas and Islands. Geophysical Monograph 23. American Geophysical Union, Washington, D.C., pp 89–104

Thom BG (1973) The dilemma of high interstadial sea levels during the last glaciation. Progress in Geography 5:167–246

Thurber DL, Broecker WS, Blanchard RL, Potratz HA (1965) Uranium series ages of coral from Pacific atolls. Science 149:55–58

Wang P, Min Q, Bian Y, Feng W (1986) Planktonic foraminifera in the continental slope of the northern South China Sea during the last 130,000 years and their paleo-oceanographic implications. Acta Geologica Sinica 60:1–11

Wang P, Yim WW-S (1985) Preliminary investigation on the occurrence of marine microfossils in an offshore drillhole from Lei Yue Mun Bay. Geological Society Hong Kong Newsletter 3/1:1–5

Yim WW-S (1984a) A sedimentological study of sea-floor sediments exposed during excavation of the East Dam site, High Island, Sai Kung. Geological Society Hong Kong Bulletin 1:131–142

Yim WW-S (1984b) Evidence for Quaternary environmental changes from sea-floor sediments in Hong Kong. In: Whyte RD (ed) The Evolution of the East Asian Environment, Vol. 1.

Centre of Asian Studies, University of Hong Kong, Hong Kong, pp 137–155
Yim WW-S (1986) Radiocarbon dates from Hong Kong and their geological implication. Journal Hong Kong Archaeological Society 11:50:63
Yim WW-S, Fan S-Q, Wu Z-J, Yu K-F, He X-X, Jim CY (1988). Late Quaternary palaeoenvironment and sedimentation in Hong Kong. In: Whyte P (ed) The Palaeoenvironment of East Asia from the Mid-Tertiary, Vol. 1. Centre of Asian Studies, University of Hong Kong, Hong Kong, pp 117–137
Yim WW-S, Li Q-Y (1983) Sea level changes and sea-floor surficial deposits off Chek Lap Kok. In: Yim WW-S, Burnett AD (ed) Geology of Surficial Deposits in Hong Kong. Abstracts 3, Geological Society of Hong Kong and Department of Geography and Geology, University of Hong Kong, Hong Kong, pp 48–59

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