QUATERNARY STUDIES ON THE WESTERN COAST OF INDIA: PRELIMINARY OBSERVATIONS

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INTRODUCTION

WE present here the results of our studies on Holocene sea level changes on the Maharashtar coast and their inter-disciplinary implications*. In starting these investigations we had the following aims in view:

i) Determination of Quaternary eustatic changes and their dating;
ii) The effect of eustasy on coastal and fluvial geomorphology;
iii) The use of i) and ii) for dating the implementiferous fluvial sediments and thus defining the temporal placement of the Stone Age industries; and
iv) The reconstruction of palaeoclimatic and palaeoecological changes based on pollen and diatom studies.

The first (i) part is covered in this paper; the last aspect (iv) is being reported by Vishnu-Mittre and Guzder (in press). Other facts of the study will be reported elsewhere.

In the context of the problems discussed here, we may group the present controversies in the field of Holocene eustasy, round the two main theories that:

i) Sea level rose rapidly up to the end of the Atlantic period (7,700 to 5,000 B. P.) reaching a height of 2 to 3 m above the present level and has fluctuated with varying amplitude since then (Fairbridge, 1961).
ii) The sea level rose steadily, reaching the present level c. 3,600 B. P., but has not risen above this datum during the Holocene (Shepard, 1960, 1963; Fisk, 1951; McFarlan, 1961).

We will evaluate the significance of our data in the light of these controversies.

THE AREA STUDIED

To begin with, we have concentrated in the Maharashtra coastal region, between 15°-20°N latitude (Fig. 1); later on, we will extend the work to other areas also. Geologically this area is comprized of the Deccan basalts and the coastal laterites. The western Ghats ranging from 600-1300 metres rise abruptly to the east of the coastal plain, which is 30-60 km wide. The small rivers originating in the Ghats debouch into the Arabian Sea. South of Bombay, the rocky coast is broken by a series of small bays and beaches lying between prominent headlands.

The main cosideration in selecting the west coast was its length combined with the fact that peninsular India has remained relatively stable during the Quaternary (Chatterjee, 1962). The only major earthquake occurred in 1967 at Koyna and was allegedly caused by the tremendous pressure of water in the reservior of the Koyna dam. There is no other reported evidence of any major tectonic activity in this area during the Quaternary. The general stability of the coastline finds further support from port-records of the last hundred years, which show a steady rise of sea level south of 20°N latitude (Lele, 1967). North of this, however, the coastal regions are reported to be quite active tectonically (Pascoe, 1964), and by contrast, the sea level in the last hundred years at Bhavnagar (21°45!N Lat.) shows violent fluctuations (Lele, 1967).

Furthermore the Maharashtra coastal region is ideal for studying the geomorphological effect of eustatic changes on the lower reaches of the short rivers flowing from the

*The main institutions that have helped us are: Birbal Sahni Institute of Palaeobotany, Lucknow and the National Institute of Oceanography, Panaji, Goa.

Ghats into the Arabian Sea. The correlation of fluvial geomorphology with a dated eustatic curve assumes greater importance in view of the fact that many of these river gravels contain Stone Age implements.

For the Holocene sea levels, on the west coast of India (Fig. 1), two main types of formations have been studied so far i) emerged beaches and coral; and ii) the continental shelf. We have concentrated on the emerged beaches preserved in the form of beach-rock between 20°-10°N. Lat. Nair (p.c. & 1971) has carried out investigations on the continental shelf and the samples collected by him were also dated at the Tata Institute. Gupta has studied raised beaches and inland reefs of the Saurashtra peninsula (24°-20°N. Lat.) (Gupta, in press). We have used all these results in the present discussion. The coastal swamps around Bombay have been examined for pollen by Vishnu-Mittre and Guzder (in press), while diatoms from the same deposits will be studied by Desikachary (Madras University). The foraminifera from the beach-rock samples and swamp deposits from Bombay have been preliminarily identified (Setty, p.c.; Singh & Kalia, p.c.).

In geological literature, (Pascoe 1964) littoral concrete (beach-rock) is reported from Daman (20°24′50″N. Lat.) to Goa (15°36′N. Lat.). We have ourselves observed it, in broken stretches, (Fig. 1) from Mahim (19°40′N. Lat.) to Ratnagiri (17°N. Lat.) and dated such samples (Table 1) from different sites. As a well preserved example, we describe below the beach-rock at Manori (19°12′10″N. Lat.) north of Bombay.

This formation extends over 3 km and lies between two rock outcrops on the north and south extremities. It appears that a sand-spit was formed between the two hills during the period of marine transgression. The subsequent regression probably resulted in the elevation of the sandspit above the HWL and its consolidation due to leaching down of $CaCO_3$. A situation, probably analogous to this, has resulted in the elevation of the sand bar at Bhatti-Mirya, Ratnagiri (Fig. 1). The maximum height of the Manori deposit is 3 to 5 m above the high water level (HWL) with a ~9° seaward dip. The angle of the strike of the beach-rock does not conform to that of the present day beach, thereby distinguishing it from the modern beach processes.

OUR DATA & C^{14} DATES

The beach-rock is a well consolidated deposit comprized of finely comminuted shells and sand. A typical sample of beach-rock from Erangal-Bhatti (19°11′N. Lat.) contained the following micro-fauna (Setty, p.c.):

a) *Ammonia beccari* ...predominant
b) *Elphidium excavatum* ...15-20%
c) *Quinqueloculina semniulum* ...2-5%
d) *Milliamina fusca* ...2-5%
e) *Cibicides mollis* ...rare
f) *Nonion formosum* ...rare

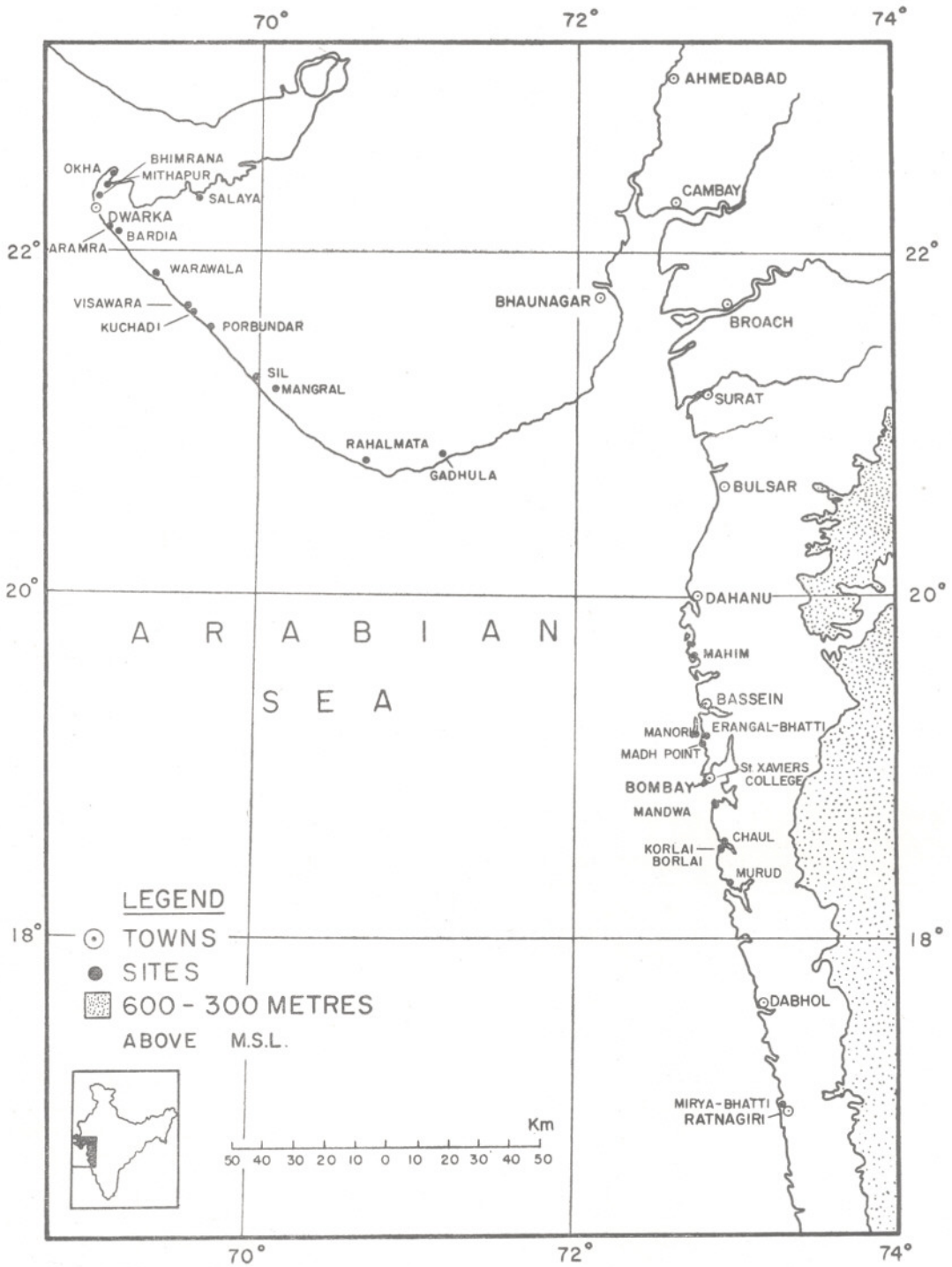
In addition, there appear fragments of shell and wood, whole and fragmented Ostracods and also bits of coral. This faunal assemblage constitutes nearly 25-30% of the given sample. The presence of (a), (b), (c) and (e) shows that the rock belongs to the littoral zone. *Ammonia beccari* especially thrives in the surface waters only.

The samples collected from the coastal swamps also yielded microforaminifera. Preliminary investigations (Singh & Kalia p.c.) indicate the presence of *Bulimina* sp., *Bolivina, Elphidium* sp., *Orbulina universa, Spiroluculina indica* and other Globigerinidae. These are essentially salt-water organisms and the changes in their frequency with depth in the cores, are being studied further to relate them with the marine transgressions and regressions.

DATES

Tables 1 and 2 and Figure 2 show the C^{14} dates of the changes in sea level. The data plotted are based on our samples and also on those collected by Gupta (in press), Nair (p.c. & 1971) and Prabhakar Rao (p.c; see also Agrawal *et al.*, 1967, 1970).

Fig. 2 clearly shows that the post-glacial marine transgression on the Western coast rises quite steeply from 9,000 to 6,000 B. P. Between 6,000 B. P. and today, the sea level has fluctuated. The Saurashtra coast samples show a rise of about +3 to +5 metres (above the HWL) around *c.* 5500 ± 1000 B. P. There are as yet no dates between *c.* 5,000-3,000 B. P. This period may represent a phase of regression. We have however, not been able to collect samples from any significant depth below



TEXT-FIG. 1 — Map of the West coast of India showing the main C^{14}-dated coastal sites.

TABLE 1

Site	District/ Location	Material	TF No.	C^{14} Date in Years B.P. (5730±40 half-life	Height in Metres Above/Below HWL
Manori	Bombay	Littoral concrete	1192	4,245±85	−1·0
Manori	,,	,,	1193	4,540±100	+1·0
Manori	,,	,,	1194	4,385±110	+3·0
Erangal-Bhatti	,,	,,	938	1,765±95	+3·5
Erangal-Bhatti	,,	,,	972	2,730±95	+3·0
Erangal-Bhatti	,,	,,	981	5,070±105	+0·80
Madh Point	,,	,,	1186	2,115±90	+0·55
St. Xavier's College	,,	,,	1197	2,800±110	+1·55
Mandwa	Kolaba	,,	1230	2,050±105	+0·05
Chaul	,,	,,	1231	2,180±95	−3·0
Korlai-Borlai	,,	,,	1232	2,410±95	+0·50
Mirya-Bhatti	Ratnagiri	,,	1080	2,800±110	+5·9
Mirya-Bhatti	,,	,,	1079	2,305±95	+6·0

Table 1: C^{14} dates and elevations above HWL (high water level) of beach rock samples collected by the authors from the Maharashtra Coast. Fig. 2 shows the eustatic plot based on these and Table 2 data.

TABLE 2

Site	District/ Location	Material	TF No.	C^{14} Date in Years B.P. (5730±40 half-life)	Height in Metres above/ below HWL	Reference
Bhimrana	Saurashtra Coast	Shell	908	5,430±110	+3·0	S. K. Gupta, in press*
Salaya	,,	Coral	911	5,220±105	+2·8	,,
Warawala	,,	Coral	1014	6,185±115	+3·2	,,
Warawala	,,	Coral	1015	4,575±105	+3·6	,,
Gadhula	,,	Shell	1044	6,670±280	+3·0	,,
Rahalmata	,,	Shell	1045	6,320±270	+4·8	,,
Mangral	,,	Shell& Coral	1051	4,700±245	+5·0	,,
Sil	,,	Shell	1052	5,820±300	+3·9	,,
Willington Island	Cochin-off Shore	Wood	965	8,315±125	−16·75	E. Nielson, p.c.
Chavara-Kayankulam	Kerala-off Shore	Shell	203	5,610±115	−1·8 to −3·6	G. Prabhakar Rao, p.c.
Chavara-Kayankulam	,,	Shell	204	6,295±115	−3·9 to −5·2	,,
Karwar	Off Karwar-Continental Shelf	Shell	983	9,135±130	−58·5	R. R. Nair, p.c.

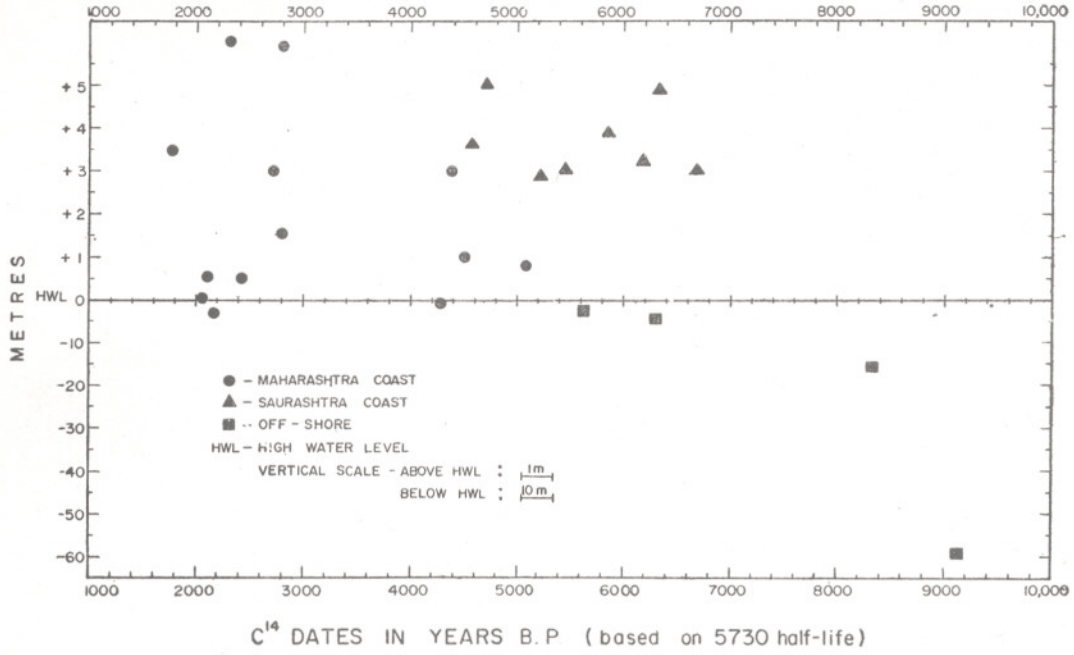
Table 2: C^{14} dates and height/depth from the HWL (high water level) of samples collected from the Saurashtra Coast, and off the Malabar coast.

*Gupta's samples were originally collected with reference to Monsoon High Tide Level and have been re-calculated by him to HWL (high water level).

MSL for lack of coring facilities so far; therefore, without actual dates, the evidence for a regression cannot be emphasized. The sea level rises again *c.* 2,500±200 B. P. to about +2·5 m (HWL). Since the dates are so far based on beach rock and shells, too much precision cannot be expected.

TECTONICS VS. EUSTASY

Early geological literature (Blanford, 1867; Fox, 1922; Pascoe, 1964), explained the presence of the raised beaches on the west coast, as being the product of land movements. The raised beach at Manori



TEXT-FIG. 2 — Plot of the C^{14} dates of samples from raised beaches/corals and the continental shelf, and their respective height/depth from the present-day high water level (HWL).

(on the western side of Bombay) and the submerged forests discovered, *in situ*, during the excavations at Prince's Dock on the eastern side of Bombay, were believed to be caused by local upheaval and subsidence (Buist, 1851). Tectonic movements resulting from the presence of a strike fault may be quite a valid explanation for pre-Quaternary events, but we feel that the raised beaches and submerged forests can be better understood in terms of eustatic changes of the sea level. The occurrence of beach-rock from Daman (20°24'50"N. Lat.) to Goa (15°36'N. Lat.) and further south on the west coast without any signs of warping, is a point strongly in favour of the eustatic explanation, ruling out any major tectonic activity. Moreover, if the raised beaches and the submerged forests were the result of a tectonic tilting, both should be coeval. But the C^{14} dates of beach rock from different areas along this coast fall within the Holocene and are therefore more likely to be manifestations of world-wide phenomena (Fairbridge, 1961). The submerged forests of Bombay could not be dated for want of samples. But if the date from the Kulur (Mangalore) submerged forest further south can be used to extrapolate the age of the buried woods of Bombay, the C^{14} date (TF-966) places both beyond the dating range of radiocarbon. Another date from a buried forest in Ceylon is $>$ 45,000 B. P. It is a known fact that during the last glaciation the sea levels were universally lowered by 100 metres below the present level. Correspondingly the vegetation belt would also shift into the then exposed area of the continental shelf. With the mid-Wisconsin and early Holocene marine transgressions all these forests were submerged. Thus the Holocene dates of the raised beaches and the late Quaternary ($>$40,000 B. P.) ages of the buried forests indicate that these two events are separated in time, and hence both could not have been caused by a tilting of the land. On the other hand, glacio-eustasy convincingly explains these events as part of universal Quaternary phenomena. These inferences found further support from E. D. Gill with whom the data were discussed in detail.

DISCUSSION

For a number of years the magnitude of eustatic changes during the Holocene

has been a much debated problem. Fairbridge (1961) and Schofield (1960) have collected data from Australia and New Zealand showing a rise of 1 to 4 metres above the present day sea level, between 6,000-1,000 B. P. On the other hand, Jelgersma (1961), on the basis of the Netherlands evidence, and Shepard and Curray (1967), on the basis of their work on the Gulf Coast of the United States, have stated that the sea level did not rise above the present level.

Our data, collected mainly from the Maharashtra coast, for the period from 10,000 to 6,000 B. P. agrees with the curves of Shepard, Curray, Jelgersma (we must keep in mind that the Continental Shelf samples were dredged and not cored). After 6,000 B. P., however, the curve shows a concordance with Fairbridge's oscillations. Haile has reported (Haile, 1970) +1 to +6 m higher than present sea levels, from Western Malaya and the Sunda Shelf area, datable to 5,000-5,5000 B. P. Similar high sea levels have been reported from Vietnam (+4 m) at 4,500 B. P., Madagascar (+1, +3 m) at 2,250 B. P. and from Morocco (+2 m) at 6,000 B. P. (Guilcher, 1969). The cumulative evidence certainly indicates a Holocene marine transgression of +1 to +6 m between 6,000 to 2,000 B. P. at least in the Indian ocean area. Even Curray, who was a leading critic of this view, has recently accepted it for certain areas (1969).

CLIMATIC IMPLICATIONS

In certain areas, like the Netherlands (Jelgersma, 1961) the correlation of sea level changes with pollen zones and climatic phases has been very successful. With growing data on regional pollen sequences similar correlations will be possible in India too. However, the extensive borings done in the Bombay coastal swamps have not yielded enough pollen to draw any significant inferences (Vishnu-Mittre & Guzder, in press) so far. Nevertheless, further studies on pollen, diatoms and foraminifera are in progress.

Recently Gurdip Singh's palynological work (1971) has brought important information on the climatic-ecological changes in Rajasthan. It is interesting to note a wet phase between *c.* 10,000-3000 B. P. in his diagram. Roughly this corresponds with the period of the steep rise of sea level also (Fig. 2). Perhaps it may give an indication that interglacial periods marked by marine transgressions — can be equated with pluvial conditions inland on the subcontinent. Further work on climatic geomorphology (Allchin & Goudie, 1971) and pollen sequences (G. Singh, 1971) will make regional and then continental climatic correlations feasible. At the moment, the interdisciplinary data are too nebulous to arrive at any viable climatic implications. But if more work is done along such cross-disciplinary lines, with an integrated approach, we should hope to have some valid reconstructions very shortly.

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REFERENCES

AGRAWAL, D. P. & KUSUMAGAR, S. (1967). Radiocarbon Dates of some Prehistoric and Pleistocene Samples. *Curr. Sci.* **36**(21): 566-568.

AGRAWAL, D. P. *et al.* (1970). Radiocarbon Dates of some Quaternary Samples. *Ibid.* **39**(10): 219-222.

ALLCHIN, B. & GOUDIE, A. (1971). Dunes, aridity and early man in Gujarat, Western India. *Man.* **6**(2): 248-265.

BLANFORD, W. T. (1867). On the Traps and Intertrappean Beds of Western and Central India. *Mem. geol. Surv. India.* **6.**

BRAY, J. R. (1971). Solar-Climate Relationships in the Post-Pleistocene. *Science*. **171**: 1242-1243.

BUIST, G. (1851). Geology of the Island of Bombay. *Geol. Papers on Western India.*

CHATTERJEE, S. P. (1961). Fluctuations of Sea Level around the Coasts of India during the Quaternary Period. *Leit. Geomorph. Sup.* **3**: 48-56.

CURRAY, J. R. (1969). In Stanley, D. J. (ed.). The New Concepts of Continental Margin Sedimentation. *Pubs. Am. Geol. Inst.*

FAIRBRIDGE, R. W. (1961). Eustatic Changes in Sea Level. In: Ahrens, L. H. et al. (eds.). Physics and Chemistry of the Earth. *New York*. **4**: 99-185.

FISK, H. N. (1951). Loess and Quaternary Geology of the Lower Mississippi Valley. *J. Geol.* **59**: 333.

Fog, C. S. (1922). The Occurrence of Bitumen in Bombay Island. *Rec. geol. Surv. India.* **54**: 117-128.

GUILCHER, A. (1969). Pleistocene and Holocene-Sea Level Changes. *Earth-Sci. Rev.* **5**: 69-97.

GUPTA, S. K. Chronology of the Raised Beaches and Inland Coral Reefs of the Saurashtra Coast. In press.

HAILE, N. S. (1970). Radiocarbon dates of Holocene emergence and submergence in the Tambelan and Bunguran Islands, Sunda Shelf, Indonesia. *Bull. geol. Soc. Malaysia.* 3: 135-137.

JELGERSMA, S. (1961). Holocene Sea Level Changes in the Netherlands. *Meded. geol. Sticht.* **C-VI**: 1-101.

LELE, V. S. (1967). Mean Sea Level: Studies at Bhavnagar, Bombay and Cochin. *J. Instn. Engrs.* (India) Poona Centre. **8**; 41-46.

MCFARLAN, E. (1961). Radiocarbon Dating of Late Quaternary Deposits, South Louisiana. *Bull. geol. Soc. Am.* **72**: 129-158.

NAIR, R. R. Personal Communication.

NAIR, R. R. (1971). Beach Rock and associated Carbonate Sediments on the 50 fathom flat, a submarine terrace on the outer continental shelf, off Bombay. *Proc. Indian Acad. Sci.* **73**(B)(3): 148-155.

PASCOE, E. H. (1964). A Manual of the Geology of India and Burma. Govt. of India Press. New Delhi.

PRABHAKAR RAO, G. Personal Communication.

SCHOFIELD, J. C. (1960). Sea-Level Fluctuations during the Past Four Thousand Years. *Nature.* **185**(4716): 836.

SETTY, A. P. Personal Communication.

SHEPARD, F. P. (1960). Rise of Sea Level along North-west Gulf of Mexico: 338-344. In Shepard, F. P. et al. (eds.). Recent Sediments, North-west Gulf of Mexico, 1951-1958. *Am. Ass. Petrol Geol.* 394 p.

SHEPARD, F. P. (1963). Thirty-five thousand years of sea level. In *Essays in Marine Geology*: 1-10. *Univ. S. Calif. Press. Loss Angeles.*

SHEPARD, F. P. & CURRAY, J. R. (1967). Carbon 14 determination of Sea level changes in Stable areas. *Progr. Oceanog.*, **4**: 283-291.

SINGH, G. (1971). The Indus Valley Culture: Seen in the Context of Post-Glacial Climatic and Ecological Studies in North-West India. *Archaeol. Physica. anthrop. Oceania.* VI(2): 177-189.

SINGH, S. N. & KALIA, P. Personal Communication.

VISHNU-MITTRE & GUZDER, S. J. The Stratigraphy and Palynology of the Coastal Mangrove Swamps of Bombay and Salsette Islands. (In press.)