Tidal Studies on Aldabra

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[Plate 10]

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The oceanic tide at Aldabra possesses a very large range for an atoll owing to the influence of the Moçambique Channel. The mean spring-tide range, expressed as 2 (M_2+S_2), is 2.74 m. This is much greater than the 0.5 m common to the majority of central Pacific atolls, and the 0.7 to 1.7 m for Indian Ocean atolls. Ten tide-recording stations were set up by members of the expedition. Foxboro–Yoxall tide-gauge records were obtained from most sites, though there are few accessible rock ledges near deep water suitable for the instrument, especially in the lagoon. Visual records were used extensively in a detailed study of the tidal system in Passe Houareau.

Tidal predictions for Aldabra found in Admiralty Tide Tables possess marked lagoonal characteristics. They originate from 'Grand Poste', a site well within Grande Passe. It is recommended that records for Passe du Bois be taken as standard since they most closely represent the oceanic tide. Empirically derived tide-predicting graphs are presented for key stations around the atoll, using Kilindini as standard port.

Reduction in tidal range is pronounced in the lagoon and is conspicuous even near the mouths of the major channels. Within Passe Houareau spring-tide amplitudes may be a mere 1.2 m only 500 m from the channel mouth where the oceanic range is 3.3 m. Time lag increases lagoonwards more rapidly at Passe Houareau than at either Passe du Bois or Grande Passe, and is greater at low water than at high because of the very shallow nature of the lagoon floor. The greatest recorded phase lag occurs at the head of Bras Cinq Cases, where high water is delayed by $4\frac{1}{4}$ h at major spring tides: at neaps the whole region is dry at high water.

Harmonic analyses are presented for one oceanic and two lagoonal stations. Computer synthesis of neap tides in the lagoon demonstrates a monthly masking effect produced by prominent shallow water harmonics. This results in the lagoon being virtually tideless on the smallest neap tides. Strong higher harmonics are indicated by visual records for Ilot Marquoix at the eastern end of the lagoon. These are characterized by a plateau-like high water, where the level commonly remains stationary for over 3 h.

Lagoon tide curves are markedly asymmetrical, and often show linear ebb profiles, indicating that the lagoon behaves as a simple water-filled basin in many areas. Drainage off lagoon platforms is slow, water level falling by only 3 to 5 $\mathrm{cm\,h^{-1}}$. This results in the tide ebbing for $9\frac{1}{2}$ to 10 h out of the $12\frac{1}{2}$ h cycle. Towards spring tides more water enters the lagoon through Passe Houareau than can drain away before the next tide. Water level gradually builds up until at major springs a foot of water covers the lagoon platform at low tide. Extreme low water coincides with neap tides. Because of this ponding effect significant differences in insolation are experienced by marine bottom communities. On oceanic platforms extreme low water coincides with spring tides and occurs at midday: in the lagoon, platforms are most exposed between 06h00 and 08h00 and are always covered at noon. The effects of solar insolation are therefore minimal throughout much of the Aldabra lagoon, but are at a maximum around the coast.

Tidal currents were measured in each of the Passes. In the western channels maximum values of 1.5 $\mathrm{m\,s^{-1}}$ (3 knots) were recorded in Passe du Bois. In Passe Gionnet a peak ebb value of 3.7 $\mathrm{m\,s^{-1}}$ (7.2 knots) was attained at high springs, with 3 $\mathrm{m\,s^{-1}}$ (6 knots) sustained for over 2 h. Flow/ebb current reversals are rapid, and in Passe Gionnet accompanied by the development of standing waves. Many channels are floored with trains of reversing sand megaripples. Elsewhere scour is appreciable; a wire mesh shark cage on the floor of Passe du Bois being undercut by 25 cm in 2 weeks. Transitory megarippled sandbanks occur on the eastern flank of Passe Houareau, and bottom facies throughout the lagoon are sculptured by the strong tidal scour.

1. INTRODUCTION

(a) *The tidal range on Aldabra in relation to other reef islands*

Aldabra possesses one of the largest tidal ranges known from a truly oceanic island, with mean spring-tide range (expressed as $2\,(M_2+S_2)$) of 2.74 m (8.4 ft). The majority of central Pacific atolls have mean spring-tide ranges of only 0.5 m. The Solomon Islands, situated within the centre of an amphidromic area, have a range of only 0.12 m. In the Indian Ocean spring-tide ranges are a little higher, varying from 0.7 m in the Laccadives to 1.7 m in the Chagos Archipelago. No records are shown on Dietrich's map (1963, chart 6) between the Seychelles, with a 1.2 m spring-tide range, and the Comoro Islands, where the range has increased to 3.3 m. The position of Aldabra is clearly critical for an understanding of the limits of influence of the Moçambique Channel on western Indian Ocean tides. The build up of tides through the channel in relation to normal truly oceanic values may be seen from figure 1. Aldabra possesses a semi-diurnal tide ($F = 0.205$), and lies in the Moçambique Channel régime (Bauer 1933) rather than in the belt which runs from the Laccadives, through the Seychelles and Cargados Carajos to Mauritius and Réunion, where the tides are of mixed, predominantly semi-diurnal type (Dietrich 1944). Thus, the Aldabran tide is clearly related to the bathymetric configuration of the Moçambique Channel region, both in its range and in its type.

The great tidal range of Aldabra renders it unlike the majority of oceanic atolls, but very similar in tidal characteristics to a large part of the Great Barrier Reef of Australia, where spring-tide ranges of around 3 m are found along the length of reef from Cape Grenville in the north to Bowen (Maxwell 1968, fig. 42, p. 75). The tide is likewise of semi-diurnal or mixed, predominantly semi-diurnal type.

(*b*) *Tidal records for Aldabra*

Tidal observations have been made on Aldabra by the Hydrographic Department of the Admiralty and by members of the Royal Society Expedition. The first records were taken by H.M.S. *Owen* from a channel-side reef site in Grande Passe. A harmonic analysis of observations from 14 January to 12 February 1962 has been made. The survey ship *Vidal* carried out a shorter series of observations from 4 to 8 September 1967, which included a 'transfer of sounding datum' for Grand Poste (near Anse Owen), Passe du Bois and Ile Sylvestre. Subsequent long period tide-gauge records obtained by members of the Expedition have demonstrated the

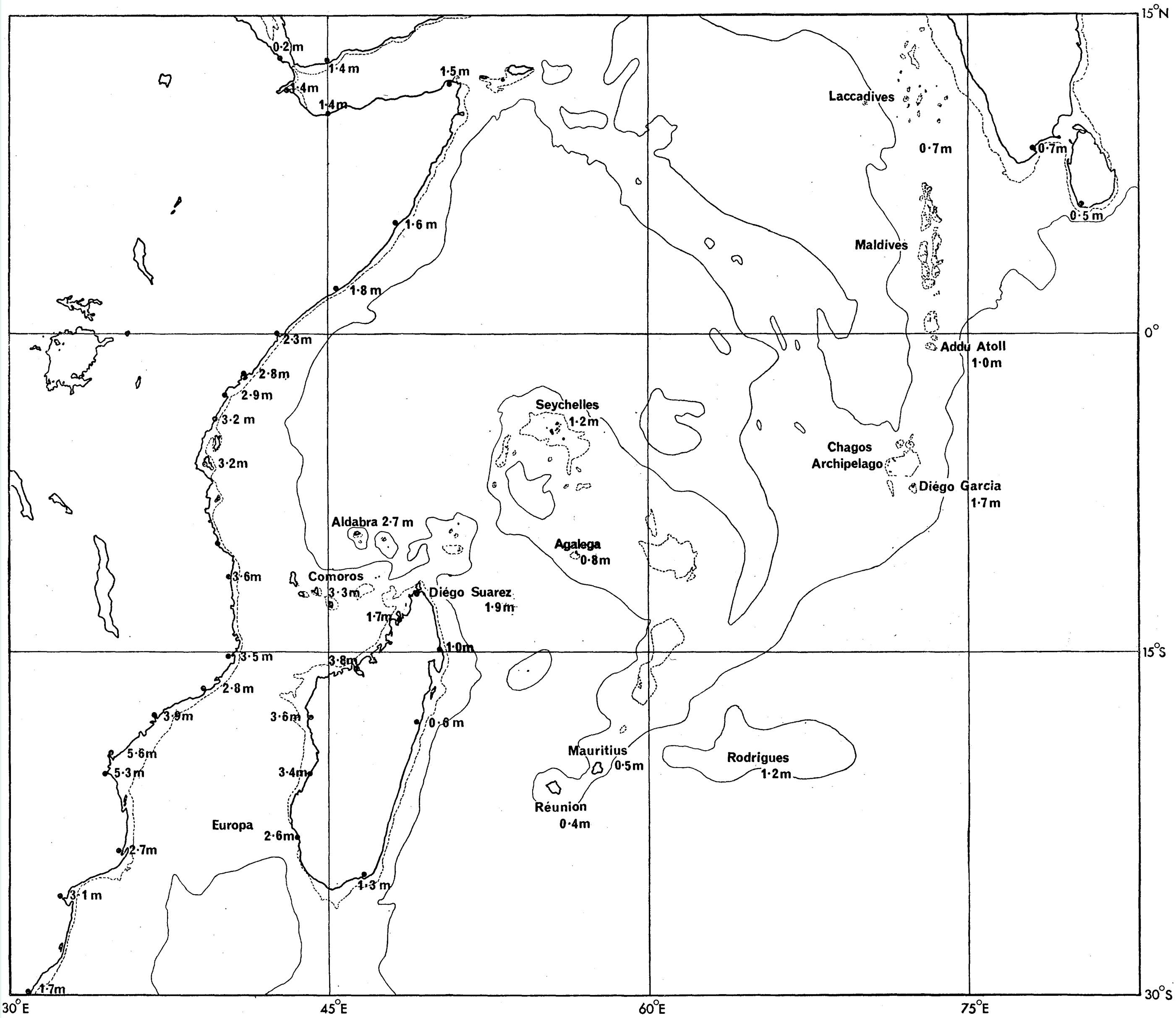

FIGURE 1. Map of the western Indian Ocean, showing spring tide ranges, expressed as $2(M_2+S_2)$. The tidal range on Aldabra is much greater than that on other atolls, because of the effect of the Moçambique Channel. Data from Admiralty Tide Tables (1968). 200 and 2000 fathom contours are shown (366 and 3660 m).

unsatisfactory nature of the two naval sites in Grande Passe as tidal standards for the atoll, since they show appreciable lagoonal distortion of the tide curve. It is recommended that the Passe du Bois site be made the standard for the atoll with which all other tides should be compared; since this site more closely approaches truly oceanic conditions than any other practicable locality.

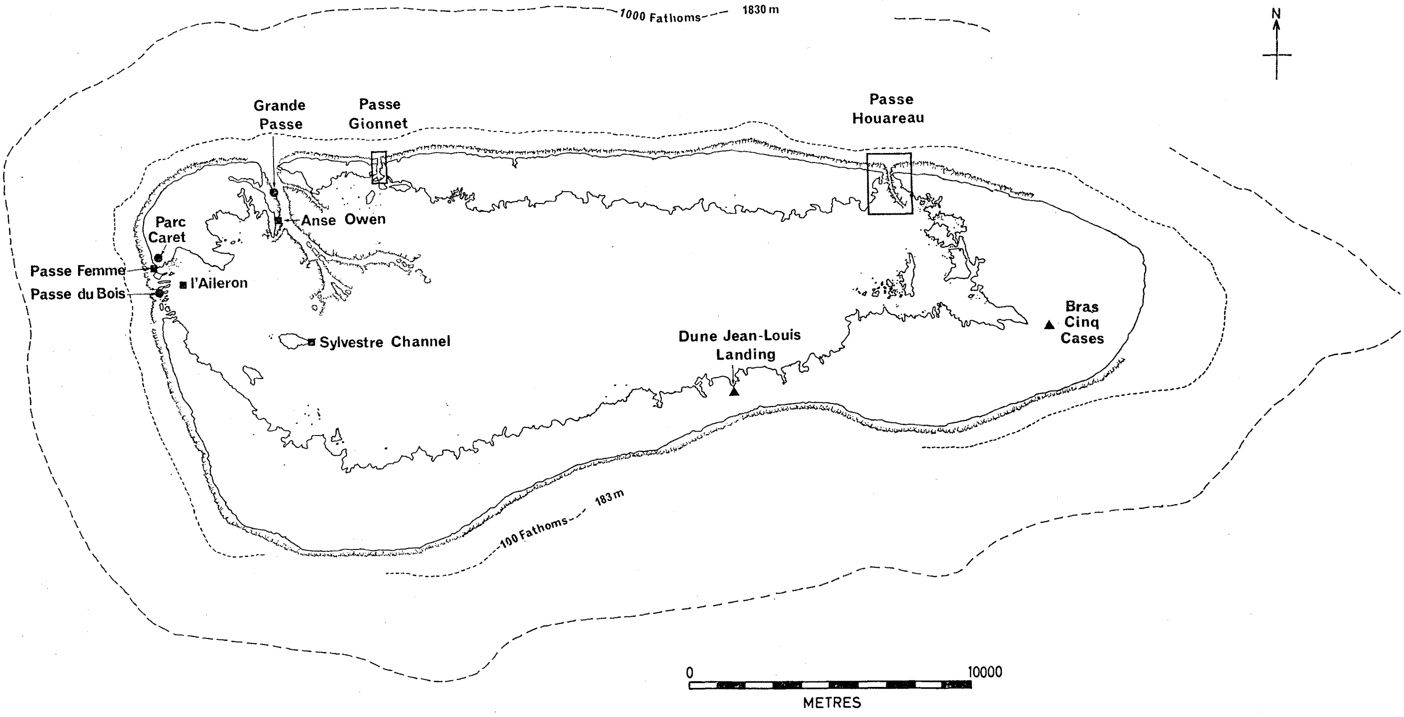

FIGURE 2. Map showing tidal stations established on Aldabra. ●, More than 28 days' records; ■, 14–28 days' records; ▲, isolated day's records. The boxed regions indicate areas of more detailed investigation, but where daylight observations only are available.

Ten tidal stations have so far been occupied by members of the Expedition. Of these, two have provided unsatisfactory gauge records (North Esprit and Passe Houareau). The remaining stations, for which valid observations are available, are shown on figure 2. The duration of most records is short, owing to the limited occupation of out-camps, but for the four stations near Settlement observations are satisfactory. At the Dune Jean-Louis Landing (Bras Anse du Bois) and Bras Cinq Cases isolated days' observations are limited to time lag at high-water springs and semi-quantitative estimates of tidal range. At Passe Houareau a detailed study of lag was conducted over 30 days, connected with molluscan growth studies on the oceanic platform and in the lagoon, involving eleven stations. Gauge records for the period were unsatisfactory and observations are limited to the hours of daylight. A similar study, but of shorter duration, was carried out at Passe Gionnet, coinciding with one of the highest spring tides of the year. This was largely to check maximum possible tidal current velocities in the channel. Current data are available for each of the four major channels, and observations on sediment transport patterns and bed forms related to flow régimes are presented.

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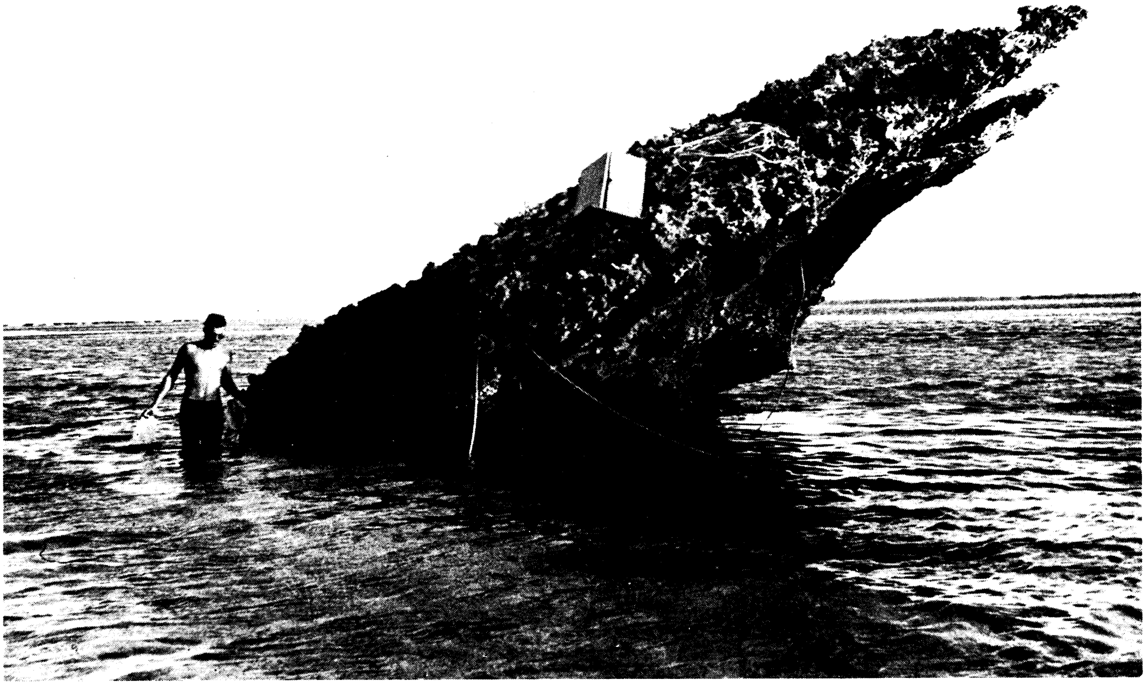

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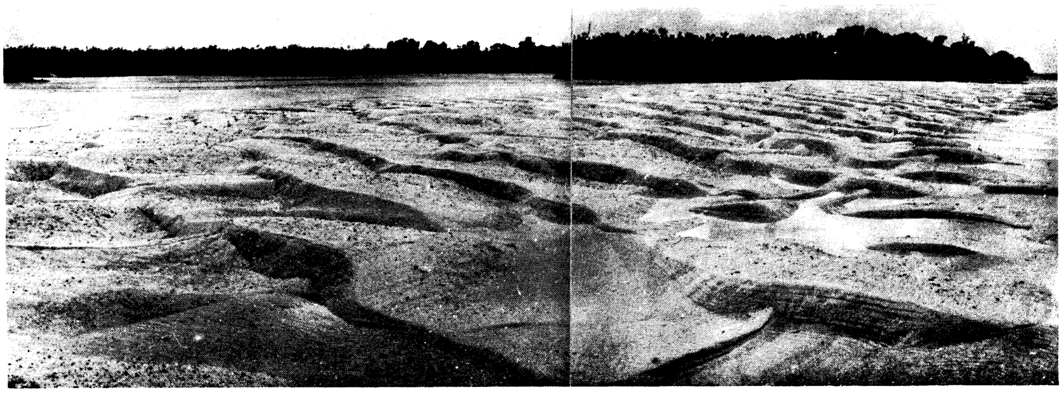

FIGURE 3. Foxboro–Yoxall tide gauge on l'Aileron, collapsed champignon islet east of Passe du Bois.

FIGURE 4. Foxboro–Yoxall tide gauge on champignon overhang in creek leading to the Dune Jean-Louis landing, Bras Anse du Bois. The low tidal range is evident from the low amplitude of the solution notch.

FIGURE 16. Megarippled sandbank, southwest of Ilot Elisabeth, Passe Houareau, formed by ebb tidal currents.

(c) *Methods and problems of tide recording on Aldabra*

The two methods of tide recording used were direct observation of tide poles for varying periods and continuous recording by means of Foxboro–Yoxall tide gauges. Currents were measured with a Carruthers totalizing current meter and by timing various objects in the water column over a measured distance.

The direct observation method is fairly accurate and it is possible to take simultaneous readings of several points within the observer's range of view, but it takes a great deal of time and can only be carried out in daylight. The tide gauges keep continuous records for up to a week between visits and can be made to work very accurately (to within 0.03 m), though times of high and low water can be read only to within 15 min or more. They tend to be temperamental, however, and must be calibrated regularly against a tide pole to correct for scale drift. They need to be overhauled thoroughly once a month. Strong currents in the vicinity of the diaphragm-head frequently caused the cable union to fracture, and for future studies on Aldabra a stronger, less brittle junction must be used if continuous records are sought from current swept regions.

One of the major difficulties in using tide gauges on Aldabra is finding a suitable site for the instrument, since much of the lagoon dries out at low tide and there are very few accessible rock ledges for the instrument box near deep water. The dual requirements of siting the diaphragm below the level of the lowest tide and the instrument box in a quasi-horizontal position on a nearby overhang which is above the highest spring tides rules out many of the lagoon islets, whose tops are usually awash at springs. Some idea of the type of site which has to be chosen may be obtained from figure 3, plate 10, which shows the Foxboro–Yoxall instrument stationed on l'Aileron, an islet of collapsed champignon situated 500 m lagoonwards of the western channels. Figure 4, plate 10 demonstrates an unsatisfactory site near the Dune Jean-Louis Landing, which dries out for long periods at low water (and is probably not even covered at neap high water). However, such sites are not infrequently the only ones available, and although they are unsuitable for prolonged analysis of the local tide, they nevertheless provide information on high-water phase lag and maximum range, which are of extreme importance in the logistics of lagoon navigation. As no detailed levelling of the island has yet been carried out, it is impossible to relate the levels of the records at the different sites to each other, except between channel stations used in the visual studies in Passe Houareau and Gionnet. H.M.S. *Vidal* carried out a 'transfer of sounding datum' between Grand Poste (Grand Poche), Passe du Bois and Ile Sylvestre, but this was based on only 4 days' records, and does not appear to be accurate.

2. The oceanic tide and tidal prediction

(a) *Tide-gauge records for Passe du Bois—standard for Aldabra: harmonic constants*

Figure 5 shows the Foxboro–Yoxall tide-gauge record for August and September 1968 for Passe du Bois. Allowance has not been made for density differences due to temperature and salinity effects, but these are not likely to be great, judging from the records kept. A tide pole was erected on the southern edge of the channel at the western end of Ilot du Bois, about 5 m north of the Vidal trig. point: the tide gauge was sited beside this benchmark. The pole was accurately levelled with respect to the benchmark and the heights related to the Sounding Datum established by H.M.S. *Vidal*. This is 3.536 m below the trig. point.

Tables 1 and 2 give a comparison of the harmonic constituents and approximate harmonic constants for Kilindini (Mombasa), Passe du Bois, Grand Poste and l'Aileron. The mean range for Passe du Bois is 1.7 m, while the range for Grand Poste, the recording site used by H.M.S. *Owen*, on which predictions found in the Admiralty Tide Tables are based, is only 1.4 m. This suggests that shallow water distortion and attentuation of the tidal wave play a smaller part

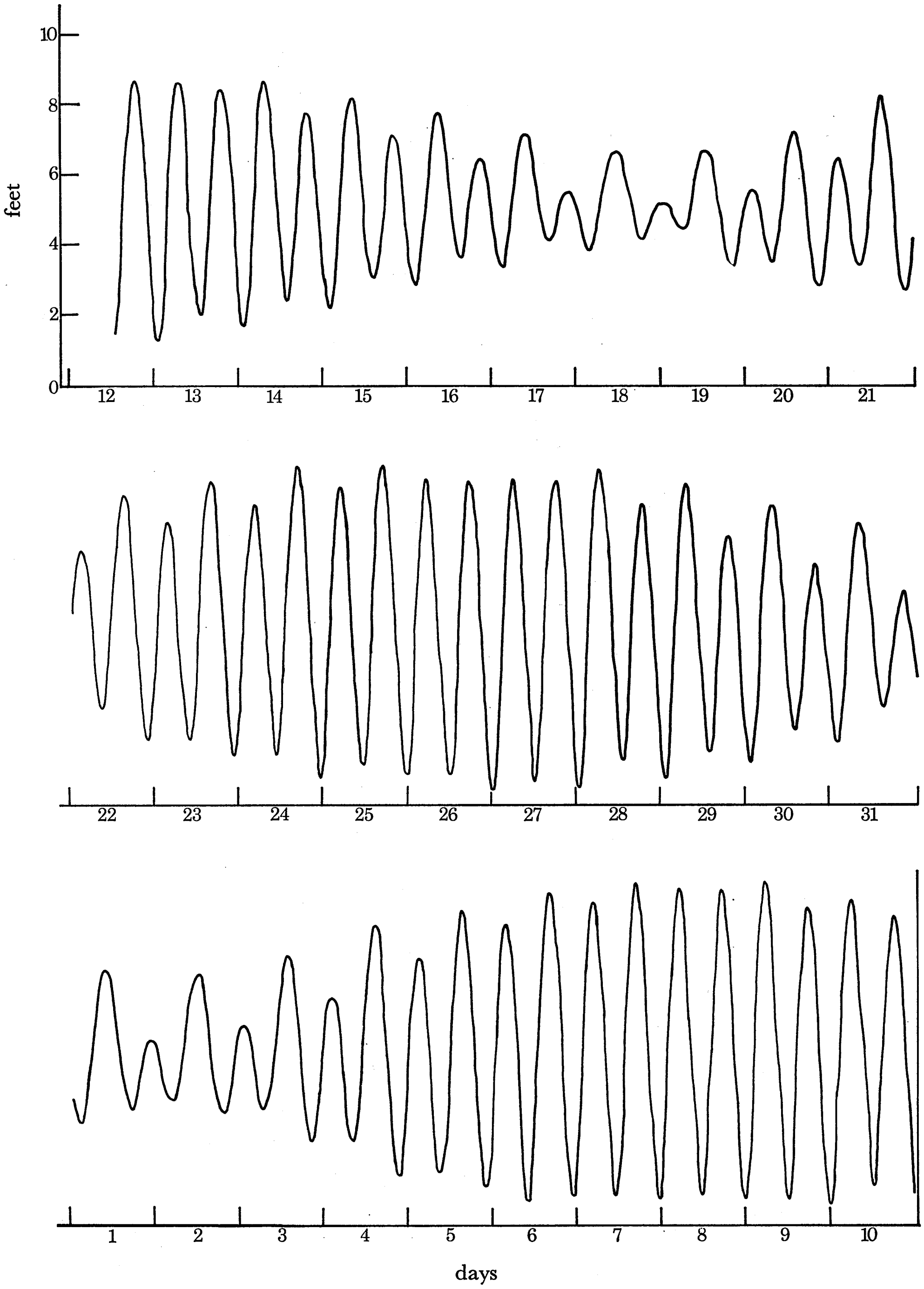

FIGURE 5. Foxboro–Yoxall tide-gauge record for Passe du Bois, Aldabra; from 12 August to 10 September 1968.

at the former site, which makes it more suitable for establishing a true oceanic prediction. The size of the quarter diurnal constituents at Passe du Bois does however indicate some shallow water distortion, which may, in part, be due to a shelf effect.

TABLE 1. HARMONIC CONSTITUENTS

	Kilindini		Passe du Bois		Grand Poste		l'Aileron	
	H	g	H	g	H	g	H	g
O_1	0.4	041	0.314	053.2	0.30	060	0.264	076.4
P_1	—	—	0.167	051.1	—	—	0.164	065.2
K_1	0.6	044	0.504	052.1	0.40	054	0.497	066.1
μ_2	—	—	0.116	216.0	0.03	197	—	—
N_2	—	—	0.422	097.1	0.40	099	0.418	124.1
M_2	3.6	112	2.802	118.4	2.30	119	2.176	130.1
S_2	1.8	153	1.363	163.1	1.17	168	1.052	172.3
K_2	—	—	0.371	164.2	0.32	168	0.286	173.2
M_4	—	—	0.117	112.1	0.10	006	0.074	176.3
MS_4	—	—	0.162	162.1	—	—	0.073	206.2
$2MS_6$	—	—	0.094	122.9	—	—	0.108	197.1
Z_0 ft	6.1	—	5.170	—	4.00	—	5.300	—

TABLE 2. APPROXIMATE HARMONIC CONSTANTS

	Kilindini		Passe du Bois		Grand Poste		l'Aileron	
	m	ft	m	ft	m	ft	m	ft
m.h.w.s.	3.5	11.5	2.8	9.2	2.3	7.5	2.6	8.5
m.h.w.n.	2.4	7.9	2.0	6.6	1.5	5.1	2.0	6.5
m.l.w.s.	0.2	0.7	0.3	1.0	0.2	0.5	0.6	2.1
m.l.w.n.	1.3	4.3	1.1	3.6	0.9	2.9	1.2	4.1
mean range	2.2	7.2	1.7	5.6	1.4	4.6	1.3	4.4

(*b*) *Prediction of oceanic tides from Kilindini tide tables*

It is possible to predict the tides for Passe du Bois from the harmonic constituents given in table 1, but unless this is undertaken with a tide-predicting machine or computer program it is easier in practice to derive a prediction empirically from Kilindini values given in the Admiralty Tide Tables. The Kilindini prediction is used in preference to Zanzibar because the former resembles the Aldabran tide more closely.

In order to predict the height of a high or low tide for Passe du Bois one converts the predicted height for Kilindini by means of figure 6, The times of high water for Kilinidini and Passe du Bois rarely vary by more than a few minutes, but must of course be corrected for local time. Low water at Kilindini is 15 min earlier, on average, than at Passe du Bois.

Example. To predict the time and height of high and low water on the 22 August 1968.

Kilindini prediction (from A.T.T.):

03h44 2.64 m (8.7 ft) 09h32 0.85 m (2.8 ft) 15h47 3.18 m (10.5 ft) 22h10 0.48 m (1.6 ft).

These times are U.T. + 2, so that an hour must be added for local time (U.T. + 3). A further 15 min is added to the time of low water. The height conversions are taken directly from figure 6.

Passe du Bois predictions are therefore:

04h44 2.18 m (7.2 ft) 10h47 0.73 m (2.4 ft) 16h47 2.61 m (8.6 ft) 23h25 0.45 m (1.5 ft).

The tides recorded for that day were in fact:

04h45 2.21 m (7.3 ft) 10h45 0.79 m (2.6 ft) 16h45 2.70 m (8.9 ft) 23h30 0.51 m (1.7 ft).

3. Lagoon tides

(*a*) *Reduction in amplitude*

Tide-gauge records were analysed by plotting the deviation in time or height of any tide from the prediction for Kilindini, against the predicted Kilindini amplitude for that tide (high tide preceding low tide). Since many observations were involved a reduced major axis regression was adopted. Figure 7 shows the results from three stations sited lagoonwards of Passe du Bois at the western end of the lagoon. The graphs may be used to predict heights for any station from the Kilindini tables, but only at Passe du Bois are the heights thus predicted related to chart datum. The other sites are related to an arbitrary mean tide level identical to that at Passe du Bois. Figure 8 presents similar results from four lagoon stations within the Passe Houareau region (shown on figure 14, p. 111) but here the graph cannot be used for predicting height of low water at small amplitudes, since a linear relation does not apply, and the appropriate end corrections are not shown. The curves for tide prediction are presented as figure 18 in the detailed section on Passe Houareau which follows later (§4*c*(v)). The datum used was platform level adjacent to the eastern end of Ile Malabar, which is approximately 0.3 m above chart datum.

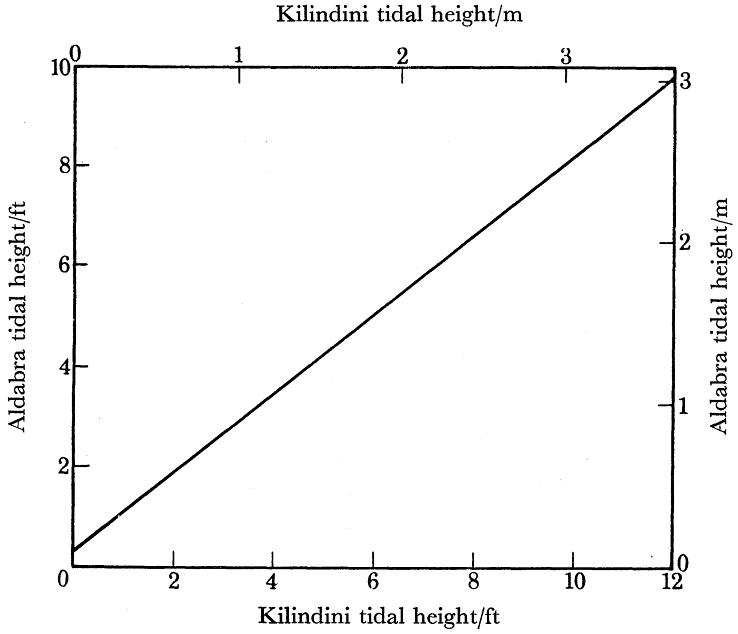

Figure 6. Graph used to predict tidal heights in Passe du Bois from Kilindini values.

Figures 7 and 8 show that within the lagoon the tidal amplitude is considerably smaller than at the oceanic station (Passe du Bois) and this effect is seen even at l'Aileron, only 500 m from the Passe du Bois station, but at the lagoon end of the channel. The differences decrease for tides of smaller amplitude (neaps) and are smaller at high tide than at low tide. Thus, at high spring tides the range at Sylvestre (1.8 m) is half the oceanic range: at l'Aileron it is almost 1.2 m less, but at neaps this difference is only 0.3 m, high water being the same in the lagoon as in the ocean. The decrease in amplitude and increase in time lag in the lagoon are shallow water effects and since the water is shallower at low tide than at high, the effects of friction are greater then (increased resistance per unit volume of water). At stations showing the greatest shallow water effect, the low-water level varies very little between spring and neap tides.

Moving eastwards from Passe du Bois, the slopes of the low water lines on figure 7 become steadily less, but are still 'normal' in character (i.e. extreme low water is coincident with spring tides). At the eastern end of the lagoon, however, on the platforms surrounding Passe Houareau, the slopes of the low-water lines are 'reversed' (figure 8), demonstrating a greater shallow water effect than in the western region. This results in extreme low water coinciding with neap tides and is caused by a ponding effect discussed in §4*c*(i). Logically there must occur, somewhere between Esprit and Passe Houareau, a region where the slope of the low-water line is zero, and neap and spring tide low-water marks are identical. This region has not yet been located. One explanation for the absence of any 'reversed' trend of the low-water lines at the western end of the lagoon may be found in the much smaller volume of water which enters the western channels on each tide, due both to their shallow depth and narrow width. A greater elevation of the lagoon platform around Ilot Marquoix compared with the l'Aileron–Sylvestre region would similarly produce a more pronounced shallow water effect.

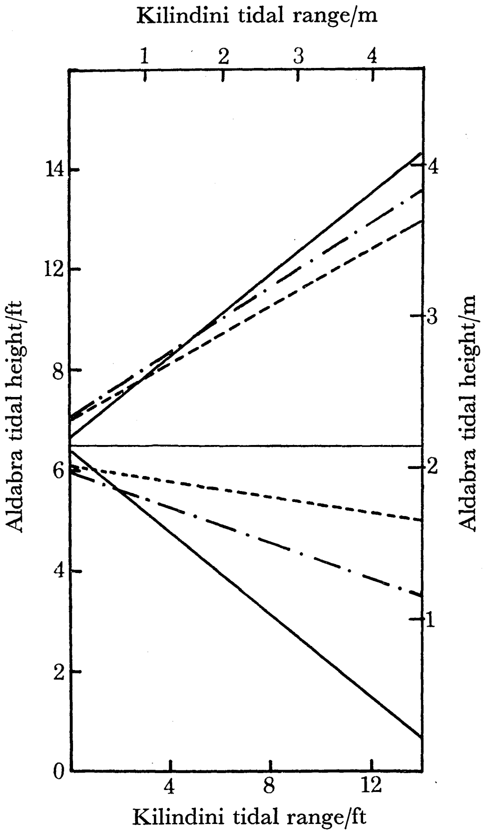

Figure 7. Graph showing diminished amplitudes of tides at the western end of the lagoon, Aldabra. Heights of high and low water (relative to arbitrary m.s.l.) for Passe du Bois (———), l'Aileron (—·—) and Sylvestre Channel (– – – –) plotted against Kilindini range.

(*b*) *Phase lag at high and low water*

Delays in the time of arrival of the tidal wave are always greater at low water than at high, because of the shallow water effect (figures 9 and 10). A sinusoidal relation exists between time lag and tidal amplitude, so that the prediction of lagoon tides is more complicated than for oceanic stations around the periphery of the atoll. Data for western and eastern ends of the lagoon have been analysed differently. For Passe du Bois, l'Aileron, and Sylvestre (figure 9), Brander has plotted the mean lag for all tides in the range 2.0 to 2.9 ft, 3.0 to 3.9 ft (0.6 to 0.9 m, 0.9 to 1.2 m), etc. For the Passe Houareau stations shown on figure 10, Farrow has plotted consecutive day's time lags at different stages throughout the tidal cycle.

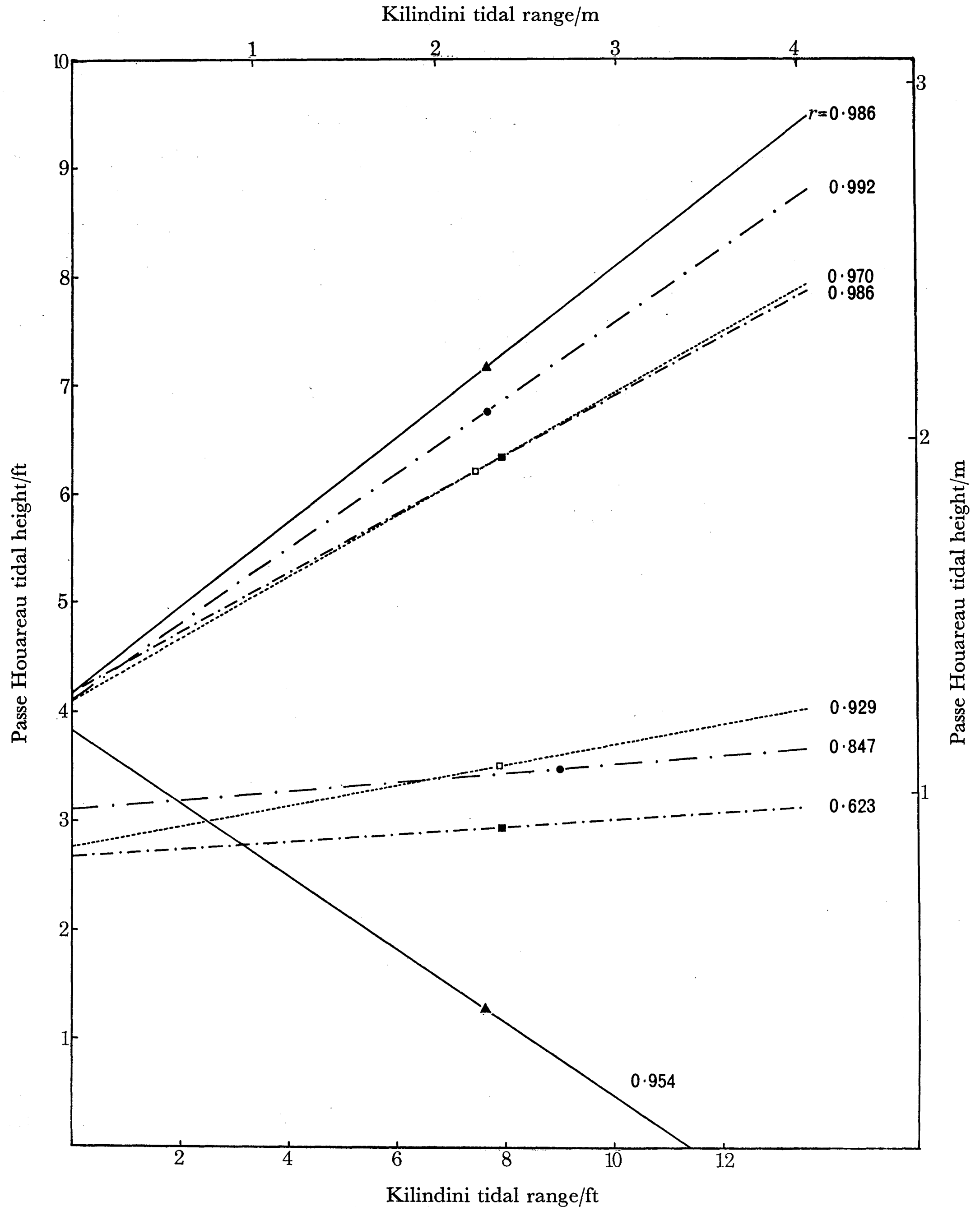

FIGURE 8. Graph showing diminished amplitudes of tides at the eastern end of the lagoon, Aldabra. Heights of high and low water for Malabar Platform (—▲—), Tide Race Point (·—●—·). Ilot des Requins (·—·■·—·) and Ilot Marquoix (--□--) plotted against Kilindini range, using reduced major axis plot. Location of stations is shown in figure 14. Local base level is 0.3 m above Passe du Bois sounding datum.

At high water the curves for the most oceanic stations (namely, Passe du Bois and Pt Malabar) fluctuate sinusoidally about zero (relative to Kilindini). Time corrections are negligible in the western channels, but on the Malabar Platform at certain stages of the lunar cycle, especially during the days preceding the major spring tides, the sinusoidal wave becomes more extreme (figure 10*c*(i)). For tides with Kilindini amplitudes of 1.8 m, the tidal wave arrives 40 min early: with 2.4 m amplitudes, 25 min later. It is also very noticeable that at this stage the correction curve for Ilot des Requins is precisely in phase with the Malabar curve, though the two are very different in character for the remainder of the cycle. During the period of decreasing tidal range following the minor springs the high-tide wave reaches the Malabar Platform progressively earlier. The observed curve for the period (figure 10*a*(i)) is out of phase with the mean Passe du Bois curve, though at all stages in the lunar cycle the consistently shorter wavelength of the Malabar curves shows the existence of appreciable shallow water effects even on the more oceanward platforms in the channel regions.

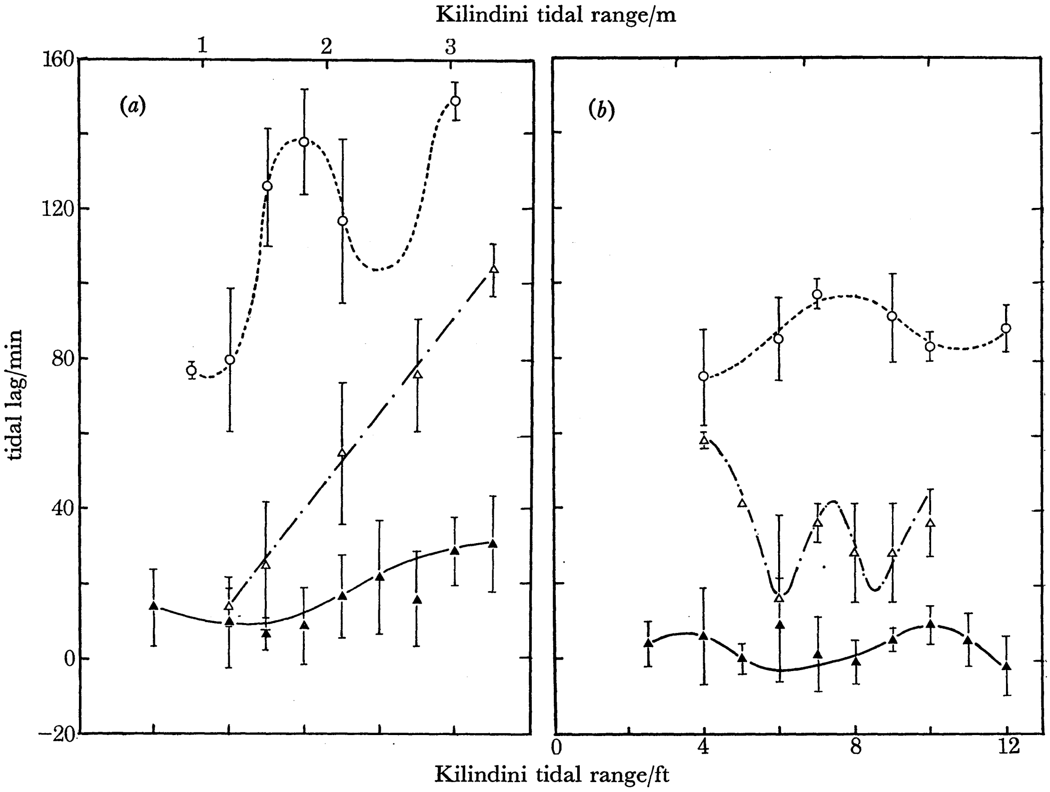

Figure 9. Tidal lag times in the Aldabra lagoon (western end) at: (*a*) low tide, (*b*) high tide, relative to Kilindini. ▲, Passe du Bois; △, l'Aileron; ○, Sylvestre. One standard deviation is plotted on each side of the mean for all values of given Kilindini amplitude.

The times of arrival of high water at the two stations at the head of Passe Houareau are radically different. On the eastern platform (figure 14) the lag is slight, but at Ilot Marquoix on the western side of the channel the lag may be as much as 2½ h. The Marquoix curve may be strikingly out of phase with the more oceanward platforms, especially at Kilindini amplitudes of about 1.8 m. Thus on 18 October 1968 (figure 10*c*(i)) the high-water wave reached Pt Malabar 40 min ahead of the Kilindini prediction, but was 2 h 30 min behind at Ilot Marquoix; a total lag of more than 3 h, compared with ½ h on the opposite side of the channel. The mean

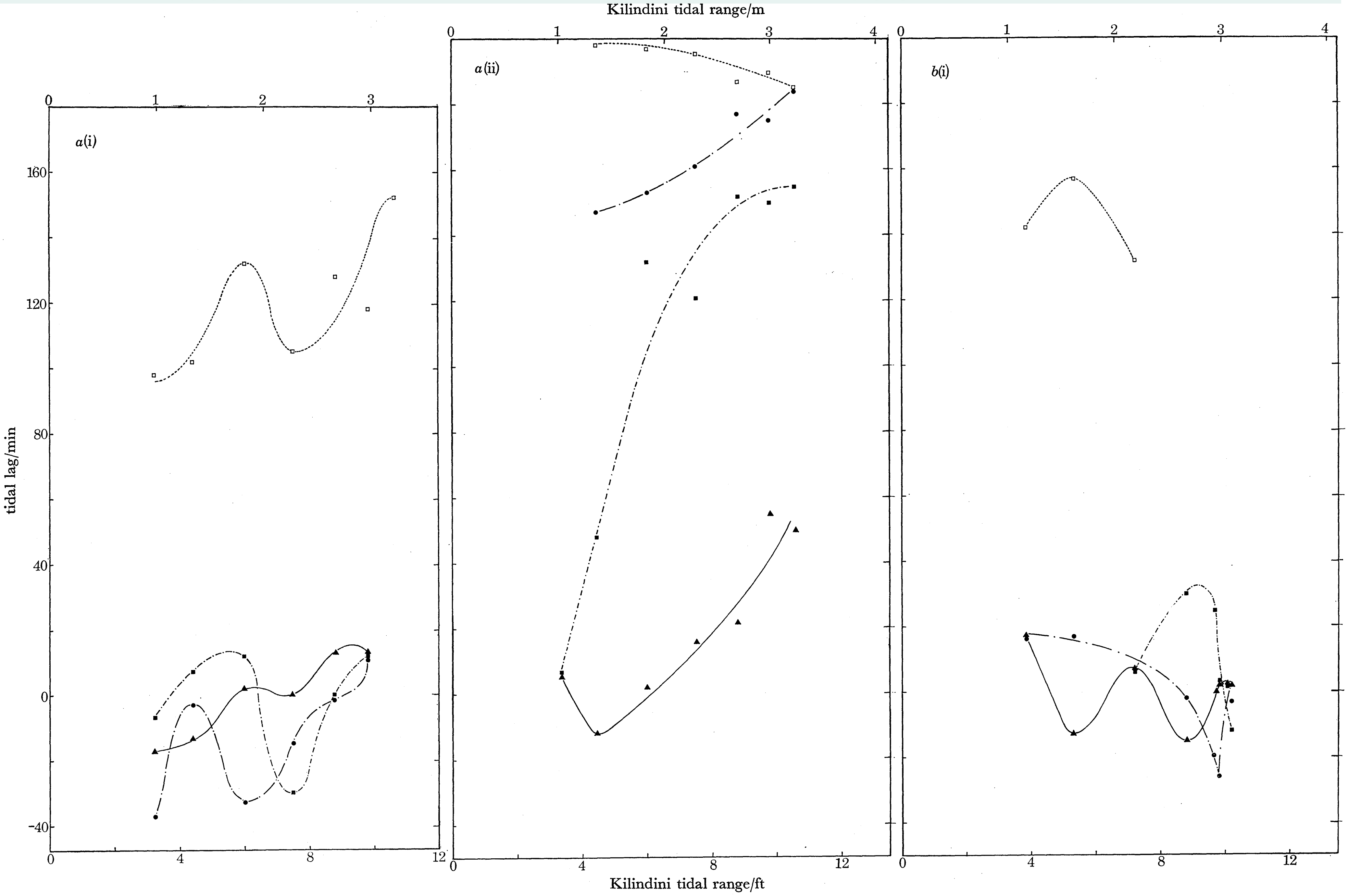

Fig. 10(*a*). For legend see facing page.

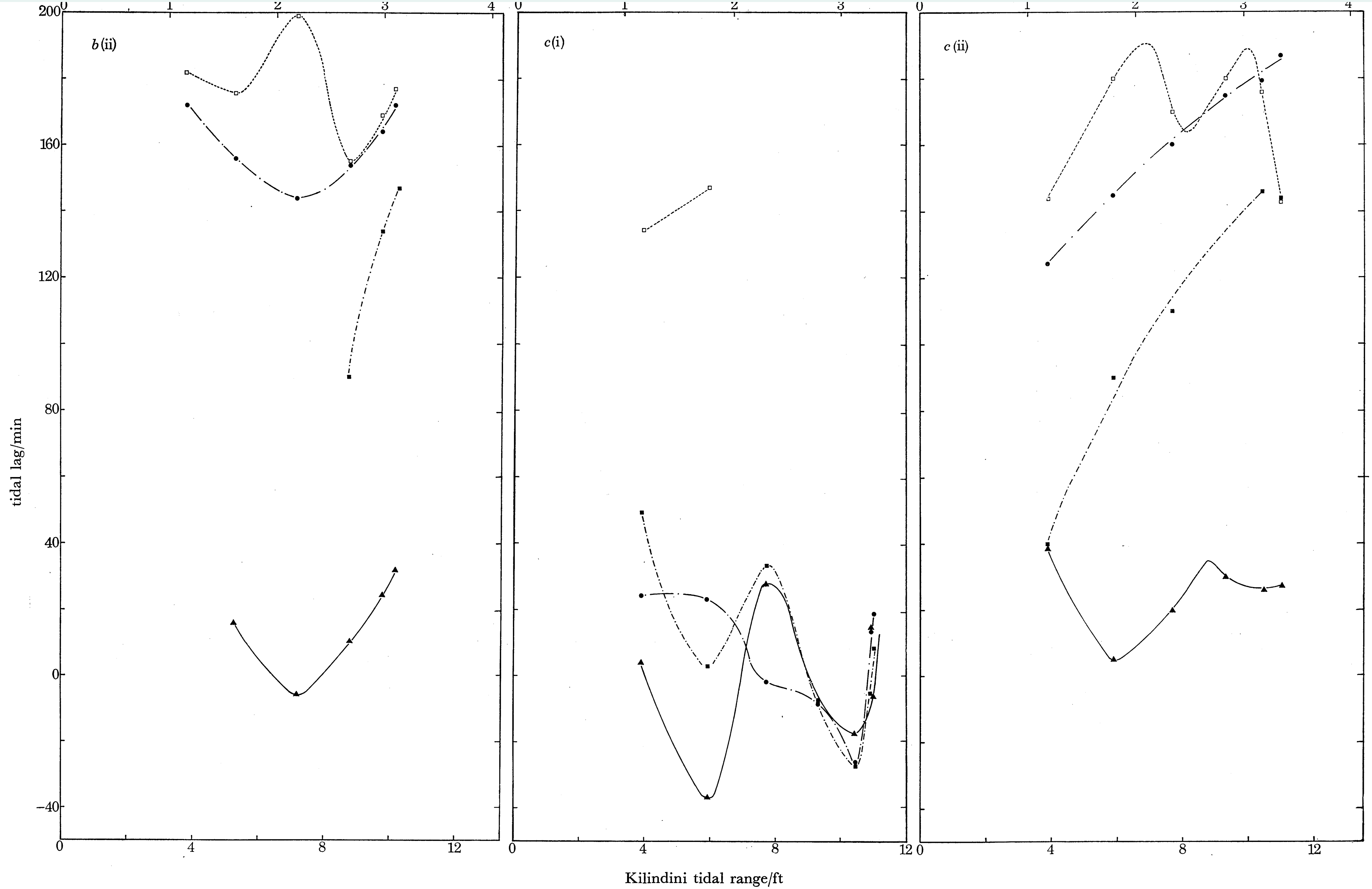

FIGURE 10. Tidal lag times in the Aldabra lagoon (eastern end) at: (i) high tide, (ii) low tide, relative to Kilindini. —▲—, Point Malabar; —·●·—, Tide Race Point; -·-■-·-, Ilot des Requins; --□--, Ilot Marquoix. (*a*) 9 to 15 October, decreasing amplitude; (*b*) 1 to 6 October, increasing amplitude; (*c*) 17 to 22 October, increasing amplitude.

curves for the analogous stations at the western end of the lagoon are also out of phase (figure 9(i)), though the maximum lag at Sylvestre (100 min) is substantially less than for the Marquoix Platform.

The form of the time correction curves for high water at the Tide Race Point near Middle Camp does not appear to be sinusoidal. During the period of decreasing tidal range (figure 10*a* (i)) the curve begins with an 'oceanic' shape, but at the lower amplitudes assumes lagoonal proportions. This gives rise to the anomalous situation where high water may be reached 40 min earlier than on the Malabar Platform. During the periods of increasing tidal range (figure 10*b*(i), *c*(i)) lag decreases from + 20 min at 1.2 m amplitudes to − 30 min at 3 m amplitudes, after which a very rapid rise takes place, which may also be experienced at Pt Malabar and Ilot des Requins.

Whereas most of the curves of phase lag against amplitude are sinusoidal for the arrival of high water, they rarely appear to be so for low water. The oceanic standard station at Passe du Bois (figure 9(ii)) is one such example, with relatively long wavelength. Lag increases to 25 min at spring tides, and this represents the only correction of sufficient magnitude to affect markedly the use of Kilindini predictions. The only other clearly sinusoidal curve is that for the Sylvestre channel. Here it is of shorter wavelength, with considerable fluctuations. The lag is 75 min at 0.9 m Kilindini amplitudes, but rises steeply to 2 h 20 min at 1.8 m amplitudes. It is of significance that these two stations are the only ones not situated in platform areas.

The remaining stations have relatively high base levels and may dry out on several days during each tidal cycle. The locations of the two stations Ilot des Requins and l'Aileron are comparable in terms of their basement heights and positions relative to the channel mouth. They have comparable curves for low-water lag times. For l'Aileron the mean relation appears to be linear, but for Ilot des Requins the curve is an upwardly convex hyperbola at all stages in the cycle, though its steepness may vary towards the lower amplitudes. There is zero lag for both stations with tides of 0.9 m amplitudes, after which lag increases more rapidly at the Passe Houareau station, to 2 h at 1.8 m amplitudes (figure 10*a* (ii)), than lagoonwards of the western channels, where the lag is only 40 min.

On the Malabar platform the low-tide lag curve appears to be parabolic, though the apex of the parabola, marking the amplitude of zero lag, shifts from 2.1 through 1.2 to 1.8 m. Low water may lag by up to an hour at spring tides (figures 10*a* (ii)), and up to 40 min at neaps (figure 10*c* (ii)). At the Tide Race Point the curves compare with the Malabar Platform for part of the cycle, being parabolic (figure 10*b* (ii)), and with l'Aileron for the remainder, showing an almost linear relation between lag and amplitude. This form is characteristic of a basin draining at a uniform rate, where the greater the quantity of water in the basin, the longer it takes to drain. The complicating factor of residual water remaining in the basin at the onset of tidal flow causes slight upward convexity from neaps to springs, and concavity from springs to neaps. Lag times vary from 2 to over 3 h. This basin effect is considered further in the section on the tidal system in Passe Houareau (§4*c* (i)).

Little variation occurs in low-water lag at Ilot Marquoix at times of decreasing tidal amplitude (figure 10*a* (ii)). The lag at neaps (3h 20 min) is greater by only 10 min than that at springs. During increasing tidal amplitudes, however, the curves are erratic in a way that defies prediction (figure 10*b* (ii), *c* (ii)). It may be that the time of low water is very much affected by slight changes in the local wind circulation, but there is nothing to show that such changes were any greater at this stage in the cycle. Alternatively, shallow water harmonics may be particularly strong at this stage.

The available data on tidal lag in the Aldabra lagoon indicate that both high- and low-water lag times increase lagoonwards more rapidly at Passe Houareau than at either the western channels or in the region of Grande Passe. Thus the maximum high-tide lag is 100 min in the Sylvestre Channel, 6.5 km from the mouth of Grande Passe, while it is 160 min at Ilot Marquoix, only 1.8 km from the mouth of Passe Houareau. The maximum lag occurring anywhere in the lagoon is experienced at the head of Bras Cinq Cases (figure 2), where at major spring tides high water is delayed by 4¼ h. Lag is appreciable along the southern shore of the lagoon. At the Dune Jean-Louis landing, lag at minor spring tides is 3½ h at high water. Both these sites remain dry at neap high water.

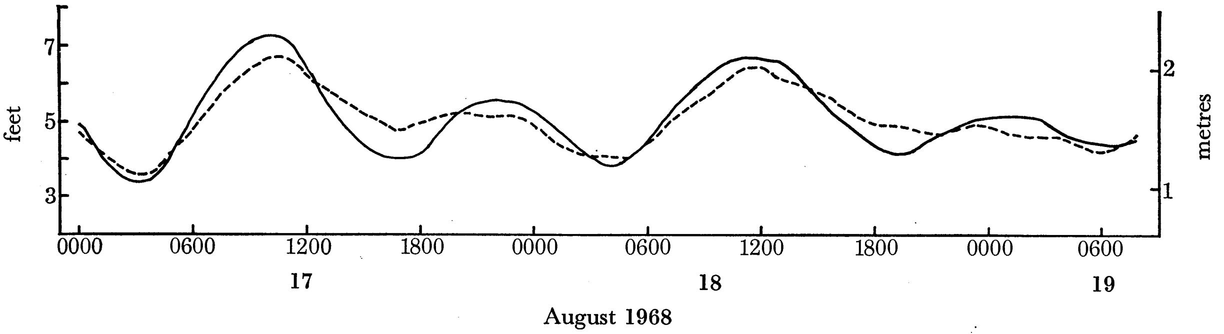

Figure 11. Computer synthesis of the neap tides of 17, 18 and part of 19 August in Passe du Bois (—); and l'Aileron (lagoon) (---); showing the masking effect caused by the prominent shallow-water harmonics.

4. Channel systems

(a) *Passe du Bois*

The tidal system and its effect on currents and other physical factors was studied in some detail in Passe du Bois. During August and September 1968 the team of four divers from Menai Bridge worked there daily as part of a sublittoral survey. Regular records of temperature, salinity, current speed and time of slack water were kept. A tide gauge was established at the lagoon end of the Passe on the collapsed champignon islet of l'Aileron, (figure 3, plate 10) in order to have a record for comparison with the oceanic station at the seaward end. The two stations were about 500 m apart, but it was impossible to carry out a sufficiently accurate levelling to relate the two to the same datum.

Table 1 (p. 99) gives the results of the harmonic analysis carried out on the data from both stations, although for the lagoon site only 15 days' records were available. The mean range at the oceanic site is 1.7 m compared with 1.34 m for the lagoon end. From the harmonic constituents it appears that this reduction in amplitude is due to the attenuation of the harmonic wave rather than shallow-water distortion. The reason for this lack of shallow-water distortion is probably that although the channel is very shallow (3 to 7.6 m below m.t.l.), it is also very short.

(i) *Computer synthesis of the effect of shallow-water harmonics at neap tides*

Using the harmonic constituents obtained from Foxboro–Yoxall tide-gauge records for Passe du Bois and l'Aileron (table 1) an hour-by-hour computer print-out of tidal heights was obtained for the period 00h00 17 August to 08h00 19 August. These have been plotted on figure 11. This shows both the attenuation of the tide and the lag, but more interestingly a pronounced masking effect of the afternoon lagoon low tide. The morning low tides are virtually identical at the oceanic and lagoon stations, both in height and time, but on the night of 18 August low tide is barely perceptible in the lagoon, lagging $2\frac{1}{2}$ h behind oceanic. The succeeding period of flow is limited to 1 h, giving a tidal range of only 75 mm. This clearly demonstrates that with very small tides shallow-water distortion becomes more important. A curious feature of this masking is that it only seems to appear on every second neap, i.e. monthly.

Several characteristics of the computed Passe du Bois curves for neap tides are shared by stations in Passe Houareau, though here they appear at other stages in the tidal cycle. One is the plateau-like high tide at l'Aileron on the night of 17 August, which is much stronger around Ilot Marquoix at intermediate tides (figure 17). Another is the terraced effect after high water at the oceanic station on 18 August which is a very prominent feature at the oceanic station Pt Malabar in Passe Houareau (figure 15*a*).

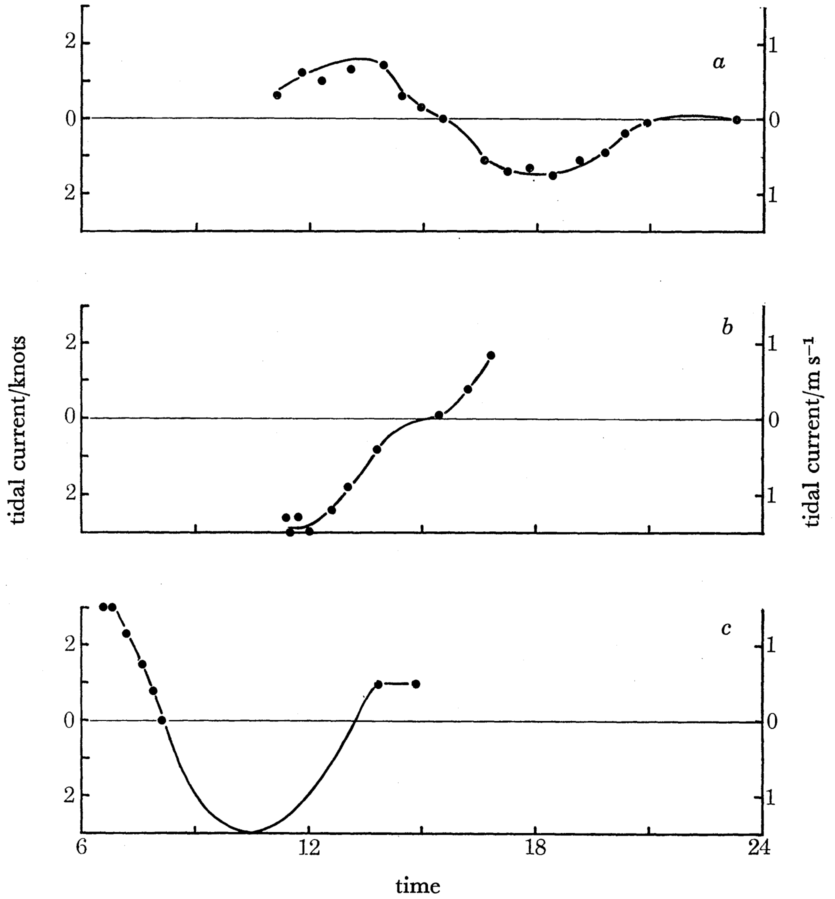

FIGURE 12. Tidal currents in Passe du Bois. (*a*) Neap tide of 19 August, 1968. (*b*) Spring tide of 27 August, 1968. (*c*) Spring tide of 9 September, 1968. The top half of each graph shows flow, and the bottom half ebb.

(ii) *Currents*

As implied by the difference in times of high tide and low tide between the two ends of the channel, the ebb current continues until well after oceanic low, and flow until after oceanic high. In practice we found that high-water slack occurs $1\frac{1}{2}$ to 2 h after oceanic high water and lasts 5 to 10 min, while low-water slack lasts for 1 to 2 h and starts within $\frac{1}{2}$ h of low water.

Figure 12 shows the currents recorded over periods of several hours at spring and neap tides.

Measurements were made in the middle of the channel at depths of 0 to 1.5 m. The ebb period in figure 12*c* represents an average current of 1 m s^{-1} (1.9 knots), measured over the entire period by means of the Carruther's totalizing meter. Currents are greatest at springs, when they rise to a recorded maximum of 1.5 m s^{-1} (3 knots) on both the ebb and flow. At neaps the maximum is about 0.8 m s^{-1} (1.5 knots).

Experiments with fluorescein showed that the surface layer is affected by the fast south-easterly prevailing wind, but, except along the sides, the rest of the water column moves uniformly. The flow is much slower along the sides of the channel, where eddying takes place among the coral heads. The bottom, which is entirely devoid of live coral, is subject to considerable scouring.

A common feature of the bed of this and other channels was the sand megaripples. In Passe du Bois amplitudes of up to 70 cm and wavelengths of about 200 cm were measured. They reversed with the current and varied greatly in extent from one week to the next. Stones up to 15 cm in diameter and bigger were carried by the current. A shark cage of wire mesh construction, used for maintaining station when sampling quadrats during periods of strong current activity, was undercut to a depth of 25 cm within 2 weeks.

Temperature observations made while diving in the Passe showed that a layer of cold sea water flows in underneath the warm water in the Passe at the start of the period of inflow, forming a visible thermocline. G. W. Potts has recorded an identical thermocline in the shallower Passe Femme. On 27 October at 17h05, 2 h after oceanic low water, the temperature of the upper layer was 28.7 °C while the lower 130 cm was at 27.0 °C. The lower layer was flowing in under the stationary warm layer. The thermocline gradually moved upward until the whole water column was moving in.

(*b*) *Passe Gionnet*

The tide race in Passe Gionnet is spectacular, owing to both its tortuous course and narrow cross-section. Very high values had been claimed for the tidal currents, but actual scientific data were lacking. The period leading up to one of the highest spring tides of the year was therefore chosen to evaluate the maximum possible current. Six tide poles were erected along the channel and in the mangrove on the Polymnie shore, but no lag was recorded at neap or spring high water. Currents were measured through the narrow 65 m passage separating Polymnie from Ile Malabar, about 250 m from the open ocean. Two sets of observations were undertaken, on the shelf and along the axis of the deepest part of the channel. These are shown on figure 13. Slack high water occurs consistently 1½ h after oceanic high. Maximum currents on the shelf are attained 2½ h after, but in the channel itself, 4¼ h after. At the spring tide of 21 November the ebb current exceeded 3 m s^{-1} (6 knots) for over 2 h, reaching a peak value of 3.7 m s^{-1} (7.2 knots). Since this spring tide was only 9 cm less than the highest tide of the year it is doubtful whether current velocities of more than 4 m s^{-1} (7½ knots) are ever attained in Passe Gionnet. A phenomenon of especial interest, since it has not been observed in other channels on Aldabra, is the development of standing waves shortly after the flow/ebb current reversal. The waves appear with strict regularity, from 22 min after slack high water at neap tides to 13 min after at springs: they may last for up to 5 min.

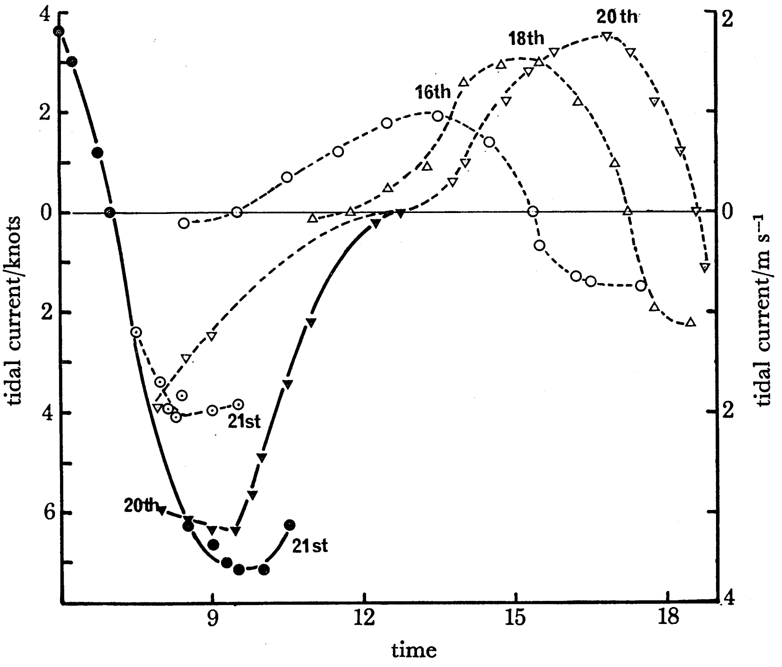

Figure 13. Tidal currents in Passe Gionnet, November 1968. Solid lines and symbols represent maximum currents flowing along the axis of the channel. Broken lines represent currents flowing over the channel-side shelf. The top third of the graph shows flow and the bottom two-thirds ebb.

(*c*) *Passe Houareau*

Under tropical conditions the effects of insolation on extensive littoral platforms are considerable. In order to assess its role in controlling the distribution and growth rate of *Tridacna* populations on oceanic and lagoon platforms, a detailed investigation of tidal lag was carried out from 23 September to 24 October 1968 in Passe Houareau. Figure 14 shows the configuration of the channel, the local nomenclature and the location of tide poles used in the study. Originally, a slightly more extensive investigation was envisaged, with the use of self-recording tide gauges. However, owing to cable union fracture only one of the three available instruments was operational, elsewhere in the lagoon. The 'Tide Gauge' site shown on figure 14 marks the position in which an instrument was set up, but failed to record faithfully because of leakage at the diaphragm head/cable union. It was therefore necessary to mount a 12 h daylight watch on eleven stations, using the Dumpy Level as telescopic alidade, erected at the nodal point of the system on the tip of the Tide Race Peninsula. This watch was sustained for 30 days, a sufficient period to embrace one complete lunar cycle and assess differences in amplitude and lag between major and minor spring tides: more than 7000 individual observations were involved. At low tide, the local base-level at each of the stations was surveyed, and related to zero on the Point Ile Malabar tide pole, which was taken as datum. From a comparison of figures 6 and 18 it would seem that the Passe Houareau Malabar Platform datum is 0.3 m higher than the Passe du Bois sounding datum.

Details of base-level and tidal range at spring and neap tides are shown on table 3 for each of the stations in Passe Houareau. When plotted out, the tide curves show very little effects of disturbance caused by variations in the direction or strength of the wind field (figure 15), except at the two more oceanic stations, where long period swell sometimes made observation difficult. Elsewhere in the lagoon heights could be measured with great accuracy, to within ± 2.5 cm at the majority of stations.

The tidal system in the Passe will be analysed by considering the month's records for three key stations on the western side, which show increasingly strong lagoonal influence: Point Ile Malabar (standard); Tide Race Point (position of maximum tidal current on Western Platform); Ilot Marquoix (most remote station from ocean).

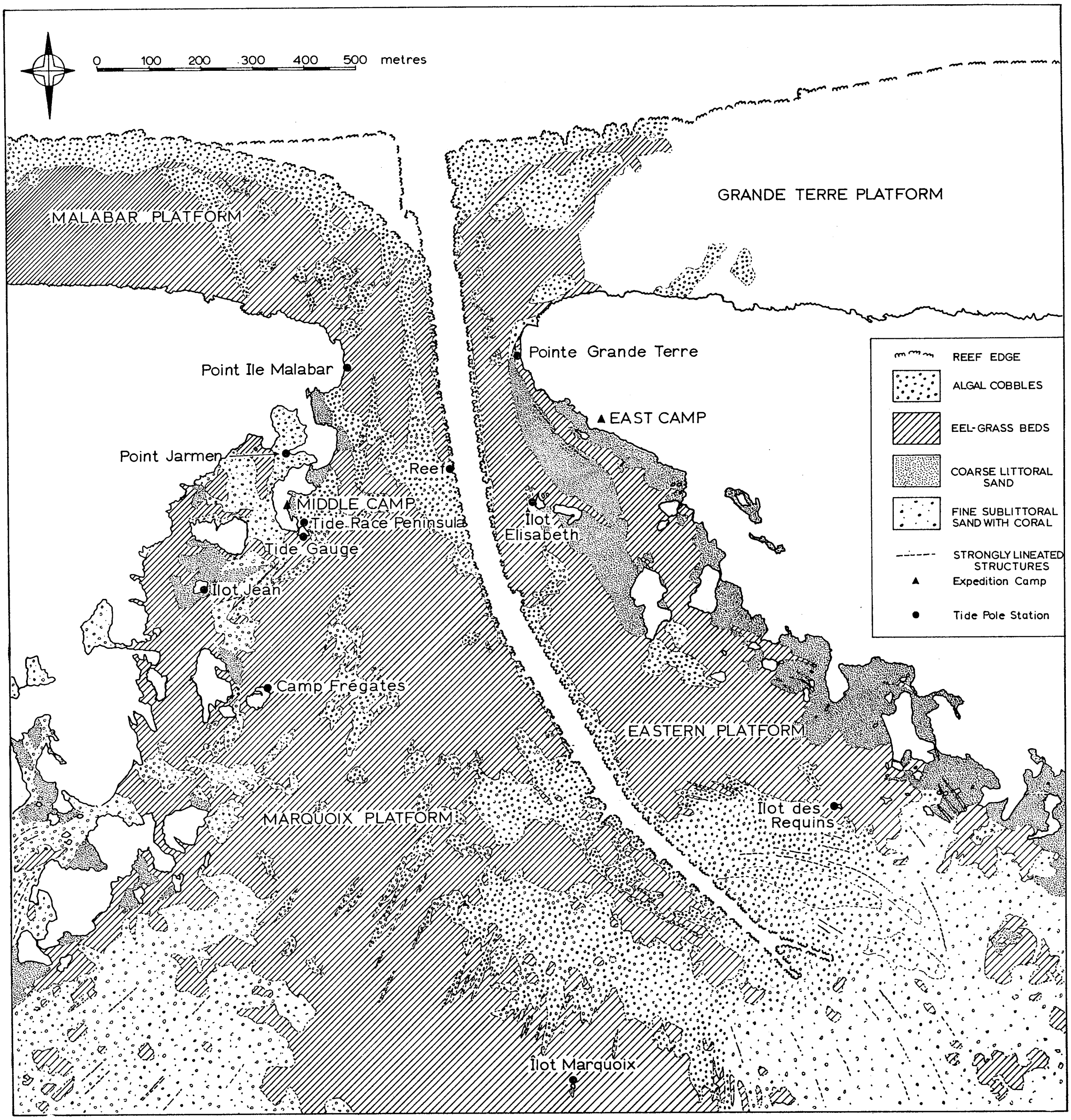

FIGURE 14. Map showing stations established in Passe Houareau to study tidal lag phenomena from 23 September to 24 October 1968. Bottom topography taken from aerial photographs, with limited ground cover.

TABLE 3. BASE-LEVELS AND TIDAL RANGES IN PASSE HOUAREAU

	base-level		tidal range			
			neap 15 Oct.		spring 24 Oct.	
	m	ft	m	ft	m	ft
West						
Point Ile Malabar	0	0	0.69	2.3	2.73	9.0
Channel-side Reef	−0.30	−1.0	0.69	2.3	3.04	10.0
Tide Race Point	+1.00	+3.3	0.51	1.7	1.48	4.8
Tide Gauge	+1.09	+3.6	0.48	1.6	1.21	4.0
Ilot Jean	+1.18	+3.9	0.42	1.4	1.15	3.8
Point Jarmen	+1.06	+3.5	0.48	1.6	1.18	3.9
Camp Frégates	+1.00	+3.3	0.51	1.7	1.18	3.9
Ilot Marquoix	+0.88	+2.9	0.39	1.3	1.18	3.9
East						
Pointe Grande Terre	0	0	0.64	2.1	2.73	9.0
Ilot Elisabeth	+0.36	+1.2	0.64	2.1	2.10	6.9
Ilot des Requins	+0.76	+2.5	0.58	1.9	1.37	4.5

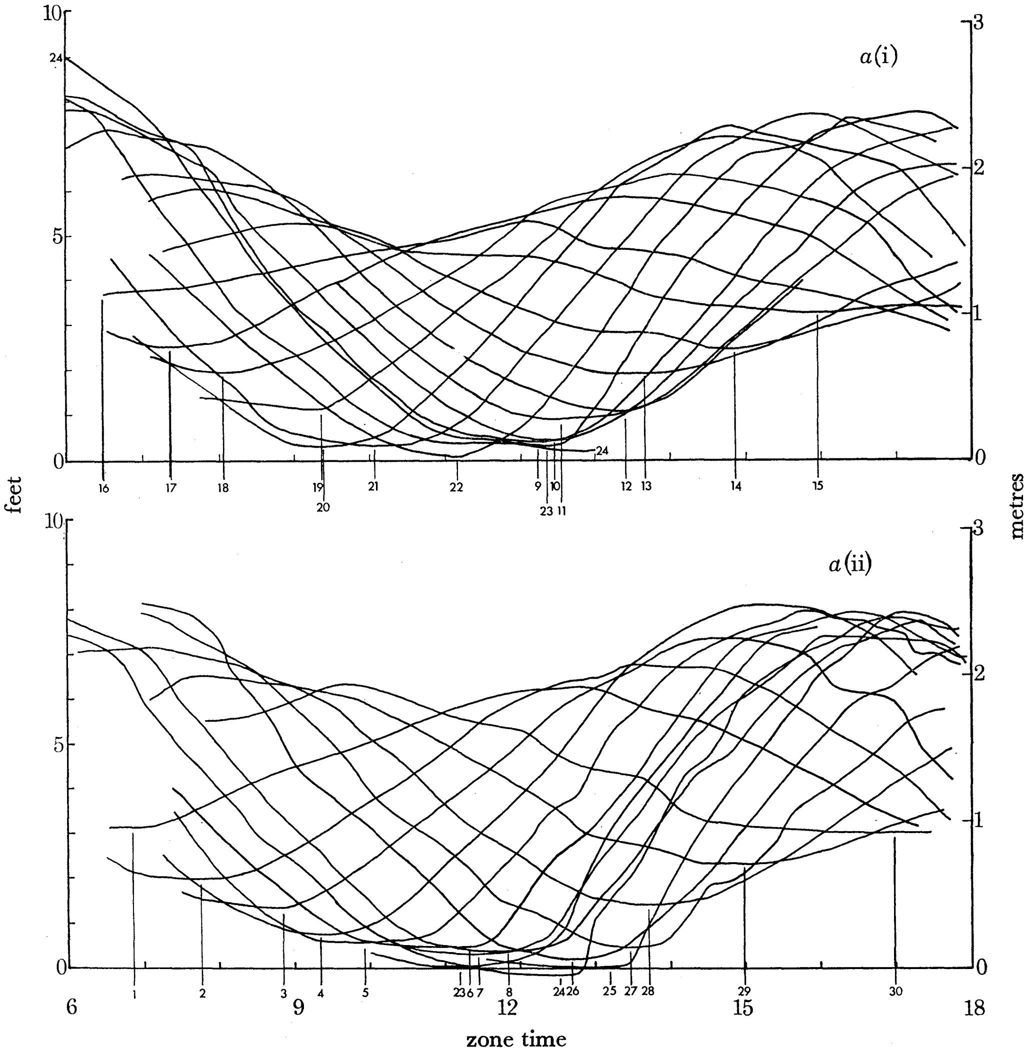

FIGURE 15. Visual tide records for Passe Houareau, 23 September to 24 October 1968, showing effects of lagoonal distortion on tide curves. (*a*) Point Malabar, curves slightly distorted on the flow and around high water by variations in wind intensity. (*b*) Tide Race Point, with linear 'basin drainage' and slight ponding effect at springs. (*c*) Ilot Marquoix, with considerable ponding effect at springs, and pronounced high water 'plateau' due to strong shallow-water harmonics.

(i) *Basin and ponding effects*

Figure 15 shows two particularly striking characteristics of the lagoon tidal system. First, the pronounced asymmetry of the Tide Race Point curves, with a prolonged linear ebb period. Secondly, the marked rise in low-water level during spring tides at Ilot Marquoix. These may be attributed to a 'basin' and a 'ponding' effect respectively.

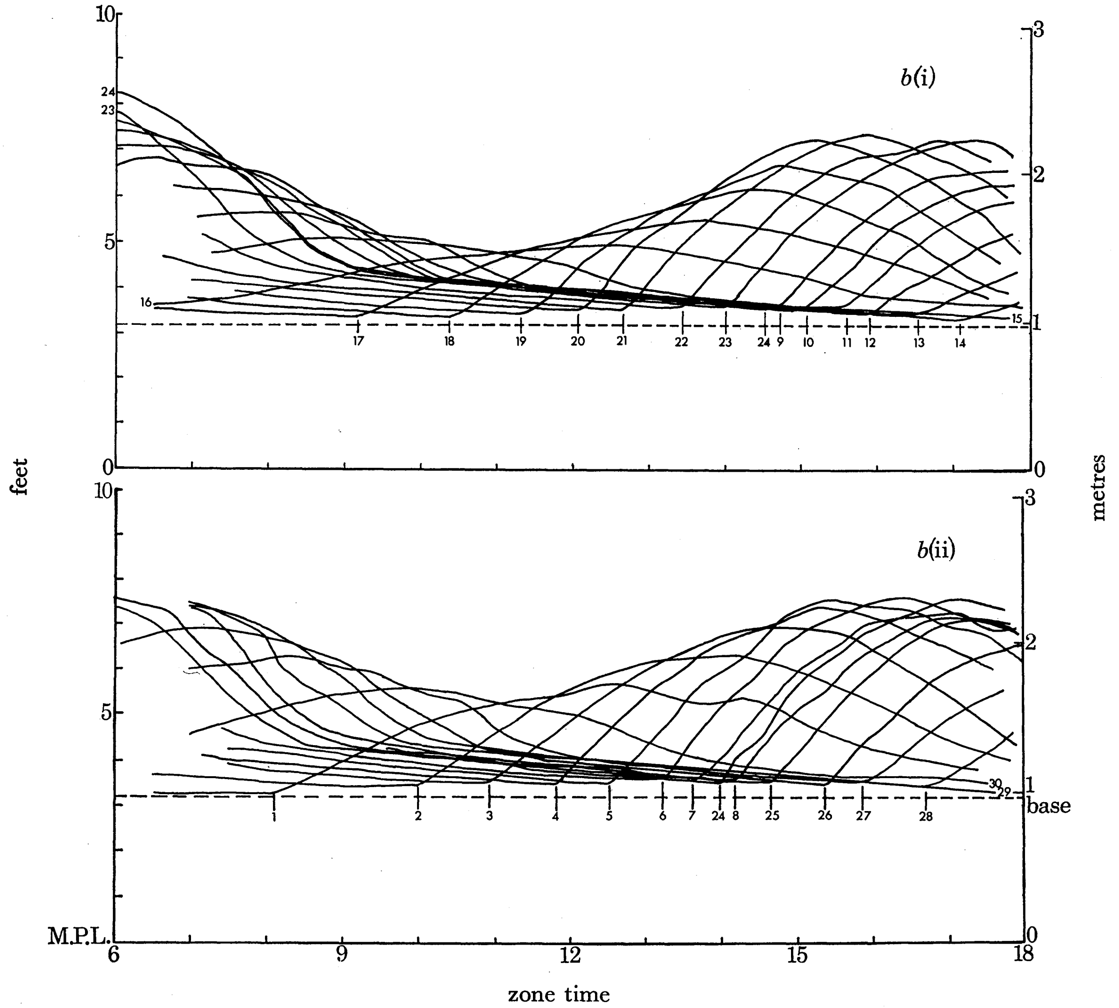

FIGURE 15(*b*). For legend see facing page.

Following high water in the lagoon the tide recedes past the Tide Race Point in a 'normal' sinusoidal fashion until the level of the oceanic tide approaches that of the platform base-level. At this stage water, which has been piling up in the embayment between Point Jarmen and Camp Frégates (figure 14), spills around the point and the level is lowered at a uniform rate of between 4 and 5 cm h^{-1}. Rather than being a true tide curve, the records are merely a plot of the emptying of a water-filled basin. The resulting asymmetry means that the tide is ebbing for $9\frac{1}{2}$ to 10 h out of the $12\frac{1}{2}$ h tidal cycle.

Ilot Marquoix, since it is situated towards the centre of the lagoon, is not influenced by any irregular configurations of the margins, and the curves do not therefore show such a sharply linear basinal effect. The effects are those larger basinal effects of the lagoon as a whole, and amongst them shallow-water harmonics play a more important part than at the Tide Race Point.

Because of the very low drainage rate off the Marquoix Platform it happens that at spring tides there is too much water in the lagoon to drain away completely before the next tide. Not only is there more water to drain at springs but there is also less time for it to do so than at neaps. This gives rise to the ponding effect visible on the two lagoonal sets of tide curves shown on figures 15*b*, *c*. The effect is greater at Ilot Marquoix than around Tide Race Peninsula, due to the damping influence of the wide expanse of intervening platform. Thus Ilot Marquoix dried to its base level of 89 cm on the neap tide of 1 October, but on subsequent days the low-water level gradually built up until on the spring of 6 October the Marquoix Platform carried 0.3 m of water at low tide. The water level continues to be impounded in the lagoon for several days after springs, which causes complications in the prediction of tidal heights at the eastern end of the lagoon, and accounts for the hysteresis seen in figure 18.

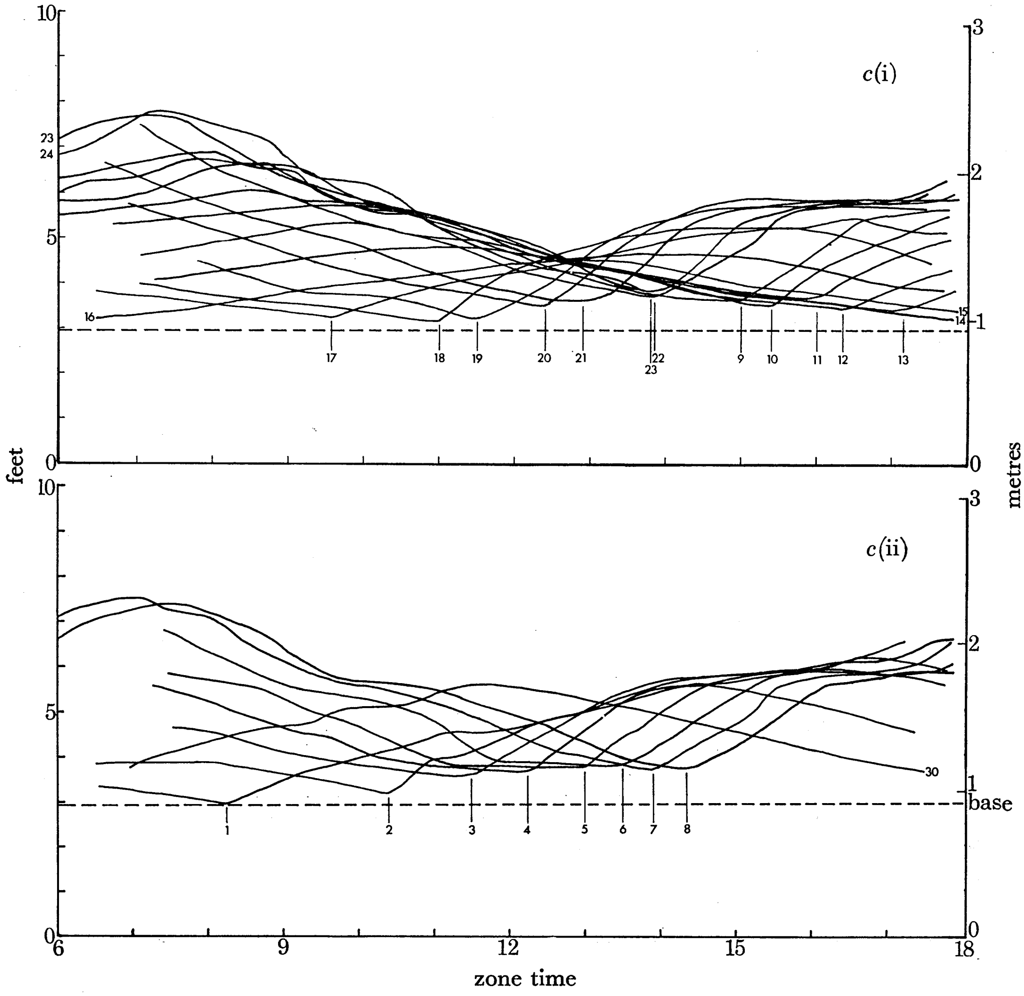

FIGURE 15 (*c*). For legend see p. 112.

(ii) *Differential insolation phenomena in relation to marine communities*

On oceanic platforms extreme low water coincides with spring tides: greatest subaerial exposure occurs between 12h00 and 14h00. On lagoon platforms extreme low water coincides with neap tides: maximum subaerial exposure occurs between 06h00 and 08h00. Thus intertidal communities on the oceanic platforms are subjected to maximum midday insolation, while in the lagoon these effects are minimized, since exposure occurs in the early morning and evening. As a result of the ponding effect, lagoon platforms are always covered by at least 15 cm of water at midday, though never by more than 0.6 m (figures 15*b*, *c*). This provides throughout the tidal cycle the optimum conditions for the growth of many littoral invertebrates, especially those like *Tridacna* whose growth is strongly dependent upon sunlight penetration. Coupled with the absence of severe wave action and the presence of the regular circulation and interchange of water masses associated with channel areas, this makes the Marquoix Platform extremely rich in bottom fauna and flora.

In accord with the north–south trend of the co-tidal lines in the Aldabran sector of the Indian Ocean, the tide begins to flow earlier over the Grande Terre and Eastern Platforms than over the Malabar Platform. Within the Passe itself platform height is appreciably lower on the eastern than on the western flank. These two factors combine to produce a tidal overlap of up to 4½ h, with flowing tide to the east and ebbing tide to the west of the Passe. This gives the Eastern Platform a dominantly oceanic character, including a greater degree of wave action, while the Marquoix Platform is 'lagoonal'. Some of the densest *Tridacna maxima* populations on the atoll are found lagoonwards of Camp Frégates on the margins of the Marquoix Platform, including the largest specimens now living, over 46 cm in length. Along a 4 km stretch of the oceanic Malabar Platform west of Passe Houareau only four specimens were seen in boulders in the Nullipore Zone and two at the base of the champignon Cliff; none exceeding 7½ cm in length. *Tridacna* is also rare on the Eastern Platform, which may suggest that the effects of differential insolation play an important part in controlling its distribution around the atoll.

(iii) *Currents and bedding*

Currents in Passe Houareau are not known in the detail of Passes du Bois or Gionnet. As in the other channels slack high water occurs 1½ to 2 h after oceanic high. The maximum ebb current around the Tide Race Peninsula is attained from 3 to 4 h after. Early readings indicated values as high as 3 m s^{-1} (6 knots) at springs, when a head difference of 40 cm exists around the Point.

The transport of sediment through the Passe is effectively confined to the lower Eastern Platform, where megarippled sandbanks of sigmoidal outline are strung between Pointe Grande Terre and the islands off East Camp (figure 14). Figure 16, plate 10, shows the sandbank southeast of Ilot Elisabeth, with asymmetrical megaripples of average wavelength 1.65 m and 23½ cm amplitude. The sandbanks are transient structures. Although shown on the aerial photograph of Passe Houareau dated June 1960, and surveyed in mid-August 1968, the 400 m long sandbank north of Ilot Elisabeth had disappeared when the channel was next visited in mid-September. Whether the megaripples are of the reversing type formed on the floor of Passe du Bois has not been verified; nor is the destination of the coarse sand known. It may be deposited as a deltaic fan at the mouth of the channel, as off Passe du Bois. Certainly it would appear from the aerial photographs that the net transport is towards the ocean rather than the lagoon. The very limited fauna of these sandbanks is in keeping with their transitory nature. Isolated mole crabs (*Emerita* sp.), *Mitra mitra* and rare irregular echinoids comprise a deeply burrowing infauna showing much in common with the fauna of the oceanic sandbank off Anse Mais.

The importance of the strong tidal currents in moulding the structure of bottom facies becomes apparent on examining an aerial photograph from any part of the lagoon. Their effects are particularly striking lagoonwards of Passes Gionnet and Houareau (figure 14) where strongly lineated structures may be seen south of Ilot des Requins at the head of the Passe, and southwest of Camp Frégates, where the tide races through the narrow straits separating the many small islands.

(iv) *Variation in tide curves through the lunar cycle*

Comparison of the month's tide curves for the Tide Race Peninsula and Ilot Marquoix (figures 15*b*, *c*) demonstrates the remarkably suppressed nature of the afternoon high tide in the lagoon. All the tide curves flatten off at between 1.75 and 1.83 m to produce a plateau effect. This effect occurs at the other end of the lagoon at l'Aileron, but only at neap tides (figure 11). It is a much more prominent feature in the lagoon at Passe Houareau, and suggests the presence of stronger higher harmonics in the tide, but unfortunately no analysis has proved possible because nocturnal elements in the tide cannot be assessed. The Marquoix plateau effect is strongest at intermediate tides of about 3 m Kilindini height. On 20 October, for example, when other curves were perfectly symmetrical, the high-water level remained constant at Ilot Marquoix for more than 3 h (figure 17). On 3 October, when other curves were distorted after high water, the Marquoix curve shows a delayed high-water 'knoll', which is the most frequent pattern observed.

As has been shown for Passe du Bois, shallow-water distortion is greatest at neap tides. The masking effect described for l'Aileron is also present at Ilot Marquoix, and is likewise a monthly phenomenon, appearing in the neap of 15 October, but not on the previous neap of 1 October (figure 17). The high-tide plateau effect is lost at neaps in contrast to l'Aileron, but is present in the Ilot des Requins curve, which does not normally show it. The more oceanward stations show the effects of shallow-water distortion at neaps more prominently. On 1 October a double high tide was recorded at the Tide Race Peninsula. This correlated with the delayed high water at Ilot Marquoix and a corresponding flattening of the Pt Ile Malabar curve. This flattening was more pronounced on the following neap, especially at Pte Grande Terre.

Ebb-tide curves for the major spring of 24 October show an interesting interchange of water masses across the head of the Passe. Figure 17 shows the switch in the pattern of the ebbing tide between Ilot des Requins and Ilot Marquoix, where the former seems to 'capture' the faster rate of the latter which correspondingly assumes the slower rate previously observed at the eastern station. The rapid build-up of water in the embayment west of Middle Camp as measured by the height difference between the two stations on either side of the Tide Race Peninsula is shown on figure 17.

(v) *Tide prediction in the lagoon—hysteresis*

When observed tidal heights in Passe Houareau are plotted against the corresponding Kilindini prediction it becomes clear that high-water level is always greater when amplitudes are increasing (figure 18). This may be attributed to the gradual ponding up of water in the lagoon as explained in (i). This ponding affects the curves more strikingly at low water, however, and accounts for the hysteresis which must be taken into account when predicting low-water heights over the Marquoix Platform. Residual water from high-spring tides causes a pronounced flattening of the curve (c') for Kilindini values of 0 to 0.9 m, after which low-water heights fall rapidly to local base-level at a value 1.2 to 1.5 m. The effect, though present at the

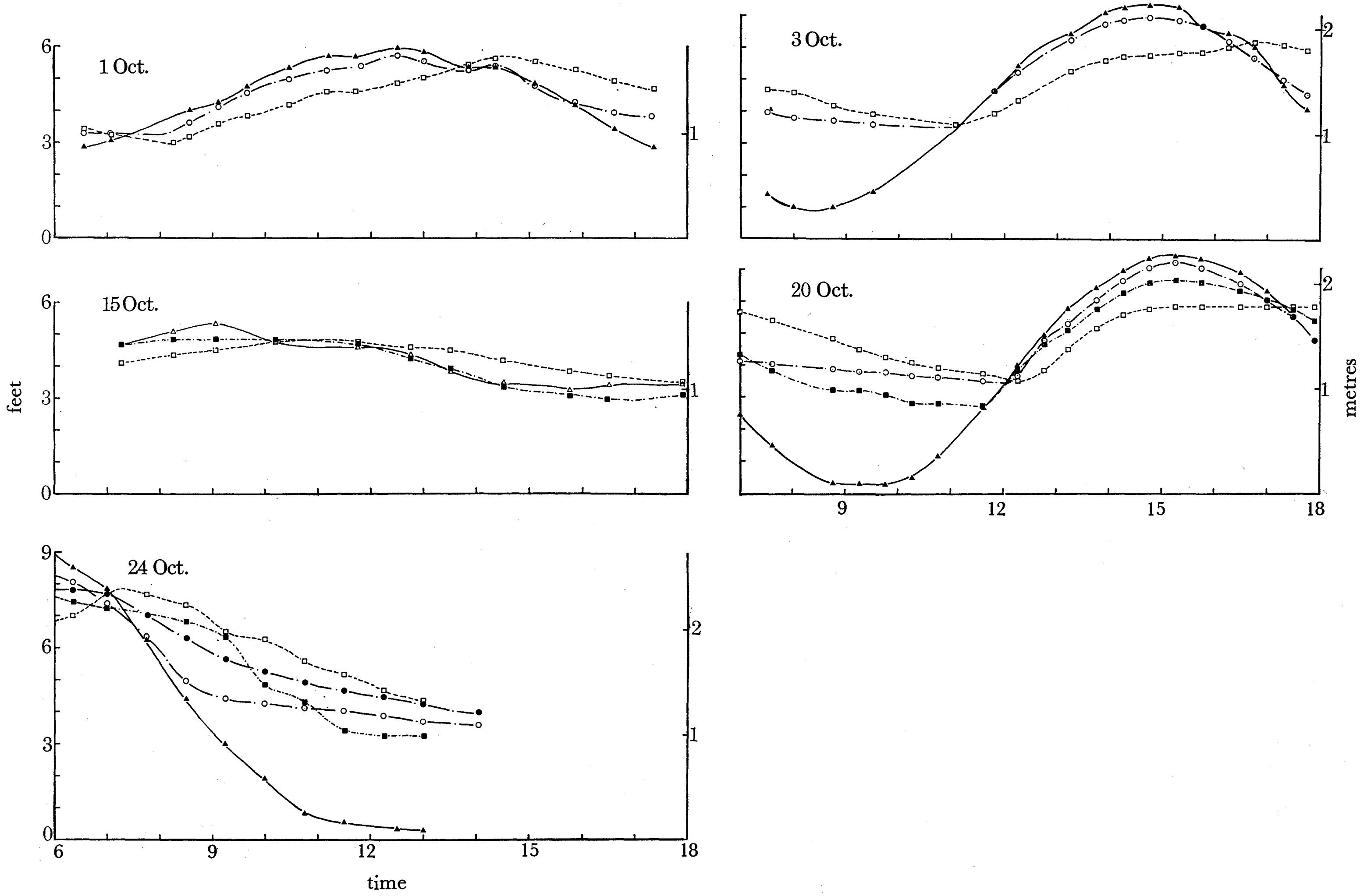

FIGURE 17. Visual tide records for Passe Houareau showing the changing profiles at different stages in the tidal cycle. 1 October and 15 October—neap tides, with shallow-water harmonics appearing in Malabar and Grande Terre Platform curves, though no 'plateau' on the Marquoix curve. 3 October and 20 October—intermediate tides: Marquoix 'plateau' very strong, other curves symmetrical: 24 October—high spring tide: showing differential run-off rates on either side of Tide Race Point, and change in water masses at the head of the Passe. —▲—, Pt Malabar; —△—, Pt Grande Terre; —·○·—, Tide Race Point; —·●·—, Tide gauge; –·–■–·–, Ilot des Requins; ---□---, Ilot Marquoix.

Tide Race Point, is not sufficiently pronounced to be shown on the prediction curve, but rather surprisingly it has to be allowed for on the Malabar Platform. The importance of taking the ponding hysteresis into account when planning littoral collecting will be discussed in §5.

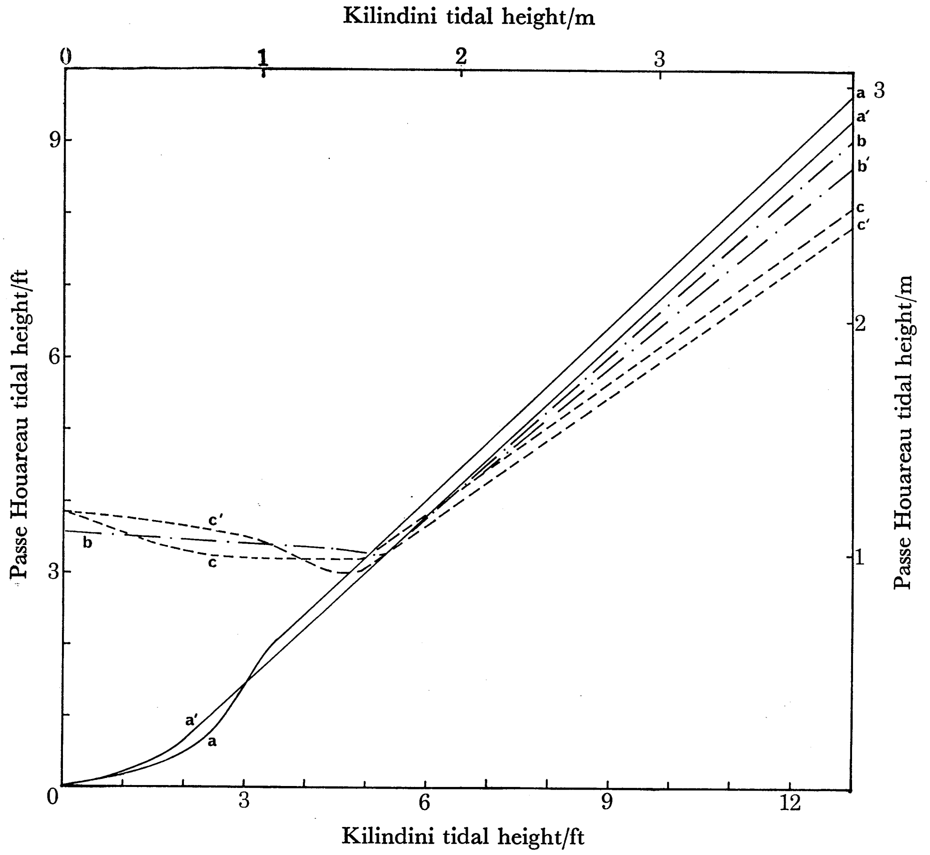

FIGURE 18. Graph used to predict tidal heights in Passe Houareau from Kilindini data.

amplitude increasing	a	Pt Malabar	a'	amplitude decreasing
	b	Tide Race Point	b'	
	c	Ilot Marquoix	c'	

(vi) *Calculated tide graphs for oceanic and lagoon platforms*

Using the prediction curve (figure 18) tidal heights for Pt Ile Malabar, Tide Race Point and Ilot Marquoix have been calculated from Kilindini predictions for the period 9 March to 20 May 1968. This season of the year possesses both the largest and smallest tides, and these are plotted on figure 19, which effectively summarizes the major lagoonal effects described above. The flattening of the low-tide profile for the most oceanic station at spring tides (figure 19*a*) demonstrates a marked platform effect at Point Ile Malabar. The asymmetrical nature of the tidal cycle is also apparent, the cycle containing the major spring tides being more contracted than that embracing the minor springs, where amplitudes diminish more gradually. Comparison of figure 19*b* and *c* demonstrates the reduced tidal range at the lagoon end of the Marquoix Platform, and the significance there of the delayed ponding effect at spring tides which causes the low-water profile to be sharply asymmetrical.

The coincidence in the lagoon of extreme low water with neap tides is well seen from figure 19, though on the very small tides of 9 March and 7 April (with oceanic ranges of less than 0.3 m) this rule was broken owing to the predicted height being 12½ cm above local base-level. In fact, if allowance is made for a masking effect similar to that found at l'Aileron on such very small tides (figure 11), then it is doubtful if any tide would be detected in the lagoon at all. However, there were only two occasions in 1968 when this correlation broke down: in some years such small tides do not occur.

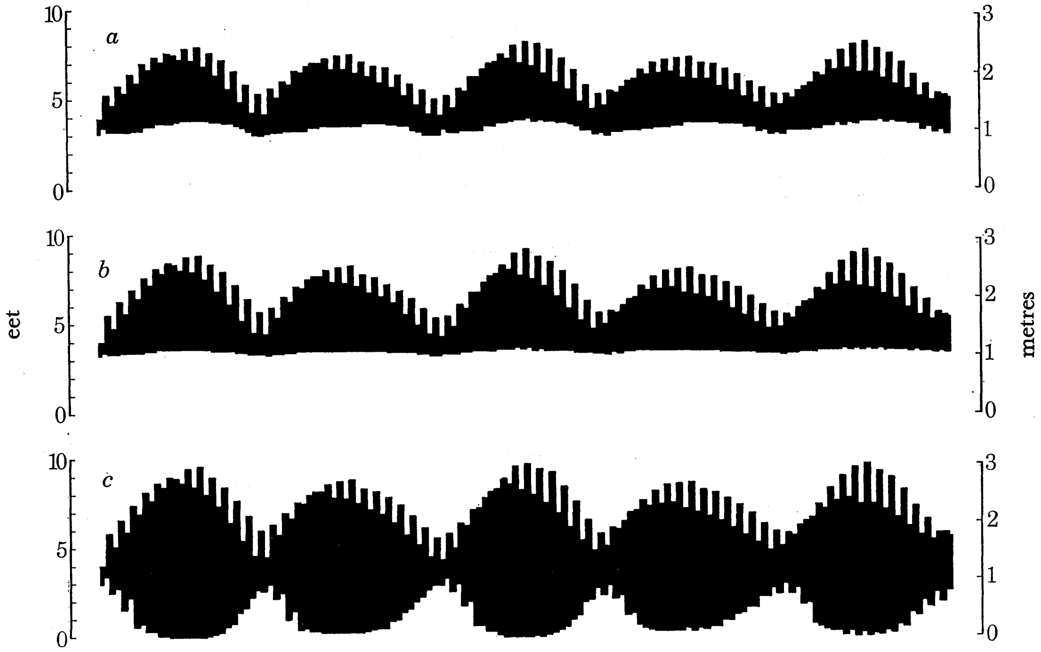

Figure 19. Predicted tide curves for Passe Houareau, 9 March to 20 May 1968, derived from Kilindini values in Admiralty Tide Tables and figure 18; showing delayed ponding effect at Ilot Marquoix and the coincidence of neap tides and extreme low water in the Aldabra lagoon. (*a*) Pt Malabar; (*b*) Tide Race Point; (*c*) Ilot Marquoix.

5. Logistic considerations

(*a*) *The planning of boat trips in the lagoon*

The navigability of the lagoon depends upon an interplay of three main factors:

(i) Height of platform, which determines the minimum possible water depth over critical 'watershed' regions.

(ii) Reduction in tidal range, which means that areas of the lagoon most distant from the open ocean can only be reached at spring tides.

(iii) Time lag at high water, which governs departure time.

Some areas in the lagoon, notably at the western end, can be reached on any high water from the Settlement, even at neaps. In this region reduction in amplitude and phase lag are not sufficient to restrict movement severely, though between Chalen and Passe du Bois platform height is a major factor in curtailing journeys from the eastern end of the lagoon. The coral fields between Esprit and Grande Poche or Gionnet are navigable on Kilindini 2.4 m tides, on which tides Esprit can also be reached from Settlement.

Journeys from channel areas into the more distant parts of the lagoon are easily accomplished at spring tides, but in the reverse direction, because of the time lag, they are extremely difficult. Cinq Cases, for example, cannot be reached on tides of less than Kilindini 3.35 m, but at this height lag amounts to 4 h, so that when journeying westwards a start is not possible until at least 2 h after oceanic high. It is on journeys of this kind that areas of high base-level in the lagoon reveal themselves. The region between Bras Anse du Bois and the Dune d'Messe landing is critical, for in the other direction it also prohibits any early departure from Settlement, when travelling to Cinq Cases or Passe Houareau. When travelling westwards with a well-laden boat, the platform lagoonwards of Passe du Bois may even be exposed by the time Chalen can be reached. It is thus necessary to wait for the next tide on Sylvestre, or to leave the lagoon via Grande Passe and pursue an oceanic course to Picard. Navigation outside the atoll is however hazardous off the major Passes. Grande Passe is particularly dangerous to cross on ebbing spring tides if travelling between Picard and Passe Houareau around the northern coast. Interference waves build up for a long way out to sea where the tide race meets the westward trending ocean swell, and even on calm days precipitous seas appear.

(*b*) *Littoral collecting*

Figure 19 shows that extreme low water in the lagoon occurs at neaps rather than at springs, as on oceanic platforms. The corresponding times of low water are shown in figure 15. Because of this it is possible in channel areas such as Passe Houareau to collect through most of the tidal cycle. Low-tide heights of less than about 0.6 m Kilindini are required to work oceanic platforms along the western and northern coasts, but since the platform height would appear to be at least 0.3 m lower on the southeastern coast, the platform around Cinq Cases, for example, is best visited on the major springs with Kilindini heights of less than 0.2 m. Figures 7 and 18 enable a prediction to be made of height at low tide. In the lagoon, as well as allowing for the ponding hysteresis (p. 118), it is desirable to make a reasonably accurate forecast of the time of low water (figures 9, 10). This is especially necessary in Passe Houareau, where very wide expanses of platform are uncovered. Black tipped sharks invariably approach the Marquoix Platform within 5 min of slack low water at the Tide Race Point and advance across the platform with the tide in water no more than 0.3 m deep.

(*c*) *Diving in channels*

At high-water spring tides current reversal in the channels is so rapid that there is virtually no slack water (figure 13). Up to 20 min of slack high water may occur at neaps when the clarity of the water is always best. Because of the long duration of slack low water, this is the most satisfactory time to sample quadrats or otherwise investigate the channel biota. As an adjunct to maintaining station on the bottom of channels when currents reach above 0.5 m s^{-1} (1 knot) a wire-mesh shark cage may prove satisfactory.

6. Future studies

Before steps are taken to establish any further tide-recording stations in the lagoon it will be necessary first to level accurately the height of the lagoon platform. The ensuing records will then be related meaningfully to chart datum. For the present the channel areas and the western end of the lagoon have been adequately covered, though it would be of great interest to obtain tide-gauge records and an harmonic analysis for Ilot Marquoix, where fascinating shallow-water effects have become apparent from visual records. Details of amplitude reduction and phase lag in the central region of the lagoon, especially along the northern shore, are needed before the co-tidal and isorange maps for the atoll can be completed. The lagoon islets of Table Ronde, Ile Verte, Mentor, Cézanne, Ilot Deder and Champignon des Os, though unsatisfactory on grounds of subaerial exposure and remoteness for servicing, would provide a useful network of stations.

One important factor which has not been evaluated in the lagoon is the effect on the tidal régime of the seasonal change in the wind pattern. The results presented in this paper were all obtained during the Trades, when strong southeasterly winds blow across the lagoon. These could reasonably be expected to have accentuated the asymmetry of the lagoonal tide curves, by reinforcing the ebbing tide and delaying the flow. Only an analysis of long-term records from one of the existing stations for the period December to March will serve to demonstrate any effect caused by slight northwesterly winds.

In the longer term, the Aldabra lagoon represents an ideal subject for a mathematical model using limited boundary conditions. Following the accurate surveying of cross-sections of the lagoon at regular intervals along its length, and the determination of coefficients of friction of the dominant substrates, a computer program is in existence which will be used to predict the likely 'catchment' of each of the channels and the extent of any 'stagnant' water which may exist between them. Similarly, the period of any seiche will be obtained, and the results put to the test with a detailed hydrological survey in the lagoon itself, involving extensive current float experiments.

A great deal of time has been spent by expedition members in attempts to establish and service the Foxboro–Yoxall tide gauges. We are particularly grateful to Dr J. D. Taylor and Mr H. S. Stickley for making records from phase II available to us, and to Messrs A. A. Q. R. McLeod and W. Humphries for assistance in our work during phase V. The loan of a Carruthers totalizing current meter from the National Institute of Oceanography and of Foxboro–Yoxall tide gauges from the Hydrographic Department, Ministry of Defence, is gratefully acknowledged.

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FIGURE 3. Foxboro–Yoxall tide gauge on l'Aileron, collapsed champignon islet east of Passe du Bois.

FIGURE 4. Foxboro–Yoxall tide gauge on champignon overhang in creek leading to the Dune Jean-Louis landing, Bras Anse du Bois. The low tidal range is evident from the low amplitude of the solution notch.

FIGURE 16. Megarippled sandbank, southwest of Ilot Elisabeth, Passe Houareau, formed by ebb tidal currents.