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LATE PLEISTOCENE DEPOSITIONAL AND DENUDATIONAL HISTORY OF ARUBA, BONAIRE AND CURAÇAO (NETHERLANDS ANTILLES)

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ABSTRACT

Herweijer, J. P. & J. W. Focke (1978). Late Pleistocene depositional and denudational history of Aruba, Bonaire and Curaçao (Netherlands Antilles). *In:* H. J. Mac Gillavry & D. J. Beets (eds.): The 8th Caribbean Geological Conference (Willemstad, 1977). Geol. Mijnbouw, 57, p. 177-187.

A sequence of subaerial denudation benches, which are recognized as remnants of planation surfaces, has been found in the drainage basins of Aruba, Bonaire and Curaçao. The benches were formed during periods of relatively stable sea-level. This denudational sequence has been correlated with the late Pleistocene marine limestones of the islands. These limestone deposits represent eustatic sea-level maxima.

The correlation led to a revised stratigraphy of the marine strata. At least ten units, each representing an individual sea-level event, have been recognized. One of the units (presently + 10 m above sea-level) is correlated with the 125,000 B.P. highstand. The rate of tectonic uplift is estimated to be in the order of 0.05 m/1000 year.

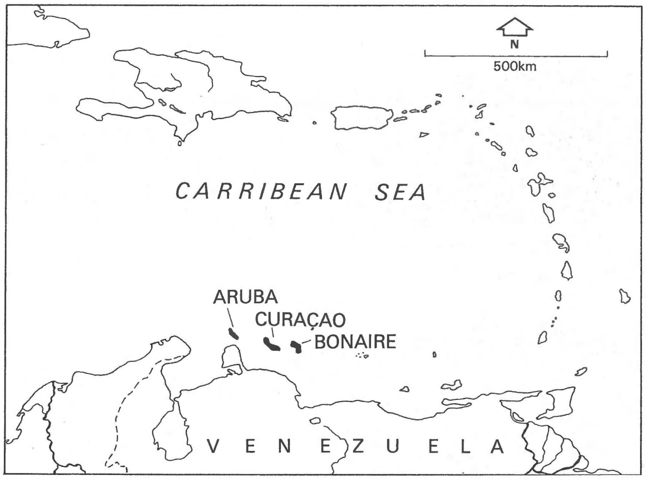

Fig. 1
Index map of Aruba, Bonaire and Curaçao.

INTRODUCTION

The islands of Aruba, Curaçao and Bonaire (southern Caribbean, Fig. 1) consist of a core of folded sedimentary and igneous rocks of Cretaceous and early Tertiary age (BEETS & MAC GILLAVRY, 1977) unconformably overlain by Neogene and Quaternary limestone deposits (DE BUISONJÉ, 1974). The Quaternary limestones occur as terraces mainly along the coast of the islands. The older rocks are deeply weathered and form generally low, undulating terrains; the Quaternary limestones, on the other hand, are more resistant to weathering and occur as a higher rim around the central part of the islands.

The terraces are mainly formed by in-situ deposition of coral reefs, although, locally, they may be present as marine denudational surfaces in the older rocks. Quaternary eustatic sea-level changes superimposed upon a slow regional tectonic uplift of the island created conditions favourable for the development of terraces. DE BUISONJÉ (1974) distinguished 5 terrace levels which were named from old to young (and from high to low): Highest Terrace, Higher Terrace, Middle Terrace II, Middle Terrace I and Lower Terrace (Figs. 2 and 3). Assuming that each of these terraces represented a more or less constant sea-level high, one of us

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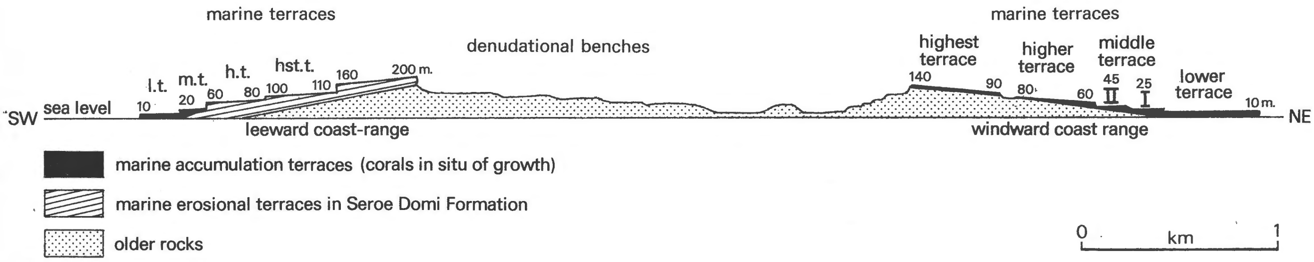

Fig. 2
Schematic cross-section of limestone terraces after De Buisonjé & Zonneveld (1976). Denudational benches are exaggerated.

(J.P.H.) did a geomorphological study of the interior of the islands, in order to see whether a highstand had a counterpart in the morphology of the river valleys and their divides in the form of planation surfaces. Relics of these planation surfaces, from now on called benches in this paper, are well preserved in the divides between river systems. In fact many more benches were found than the 5 predicted by the marine terraces. This meant that either there was no direct relation between benches and marine terraces, or that more sea-level stands were present within the terraces. Renewed study of the limestone terraces showed that the latter assumption was correct. As will be discussed in this paper, both the Lower Terrace and the Middle Terrace I are in fact amalgamated terraces consisting of a number of distinct limestone bodies separated by unconformities. No attempt will be made to correlate the higher situated marine terraces with planation surfaces, because of the scant number of good outcrops in the Higher and Highest Terraces and the ill-preserved nature of the benches at this height (above 60 m).

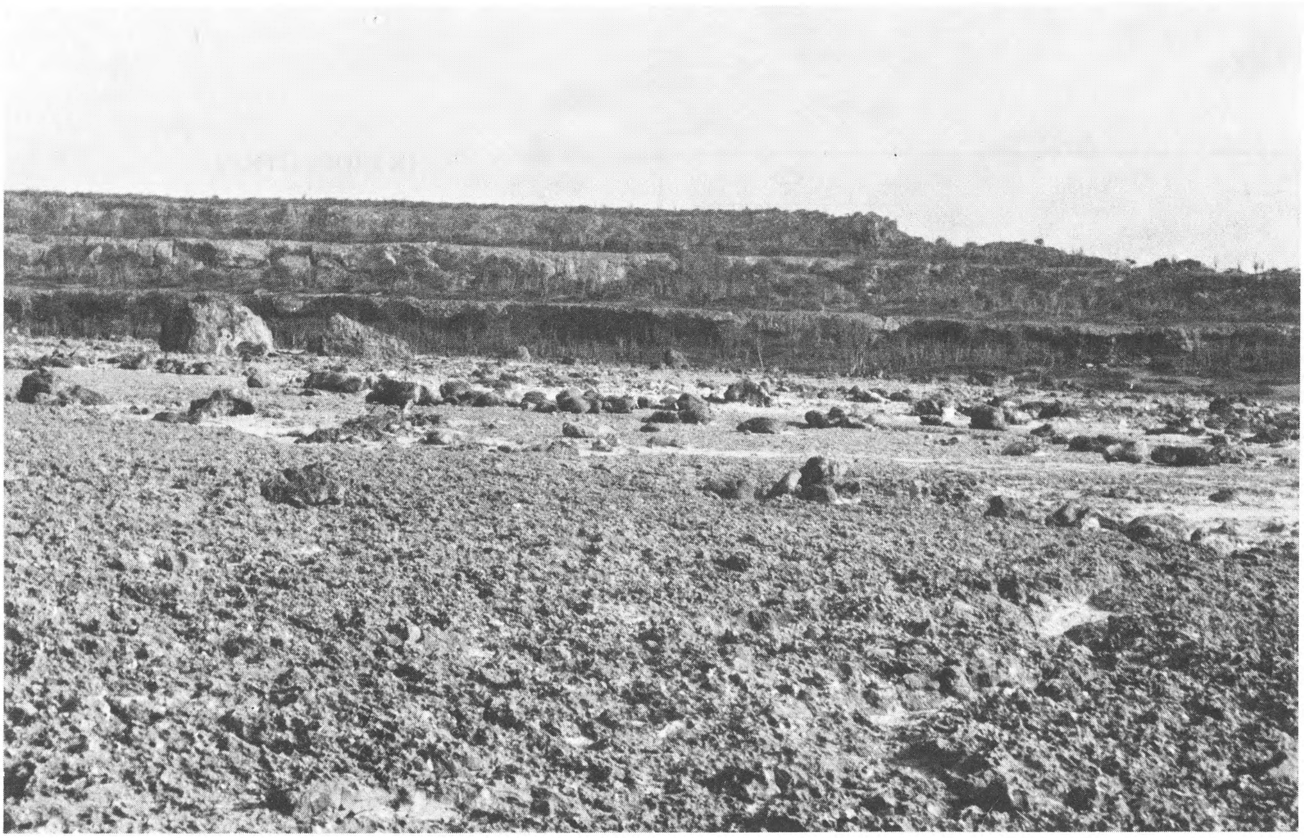

Fig. 3
Characteristic terrace sequence (N.E. Bonaire), showing Lower (foreground), Middle, Higher and Highest Terrace.

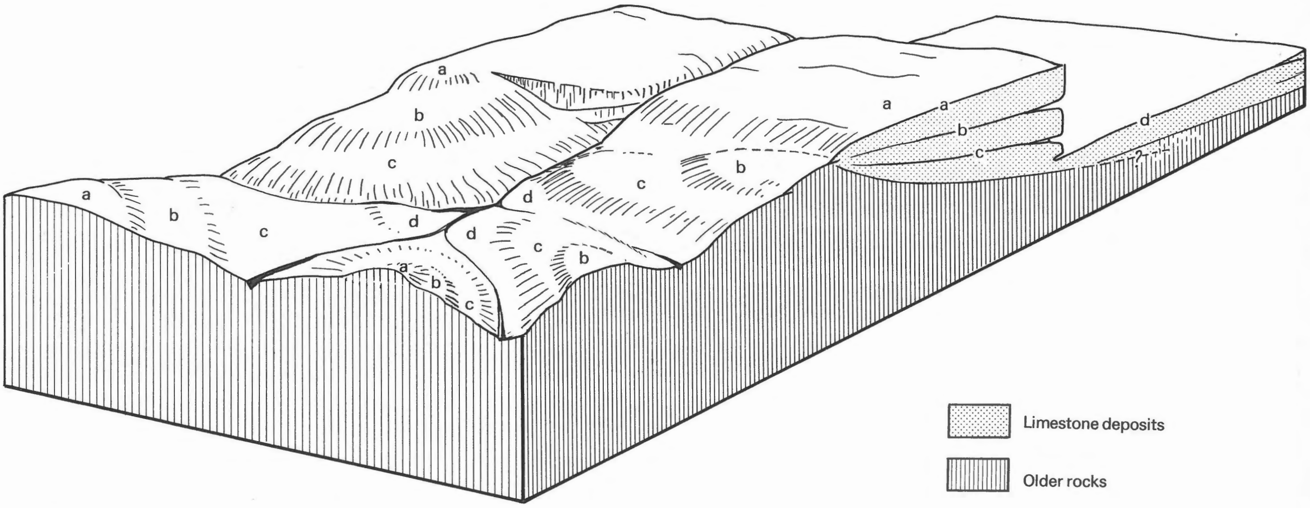

Fig. 4
Schematic block diagram showing benches (a-d) at different levels, and correlated limestone units (a-d).

Fig. 5
Stone pavement which covers the soil.

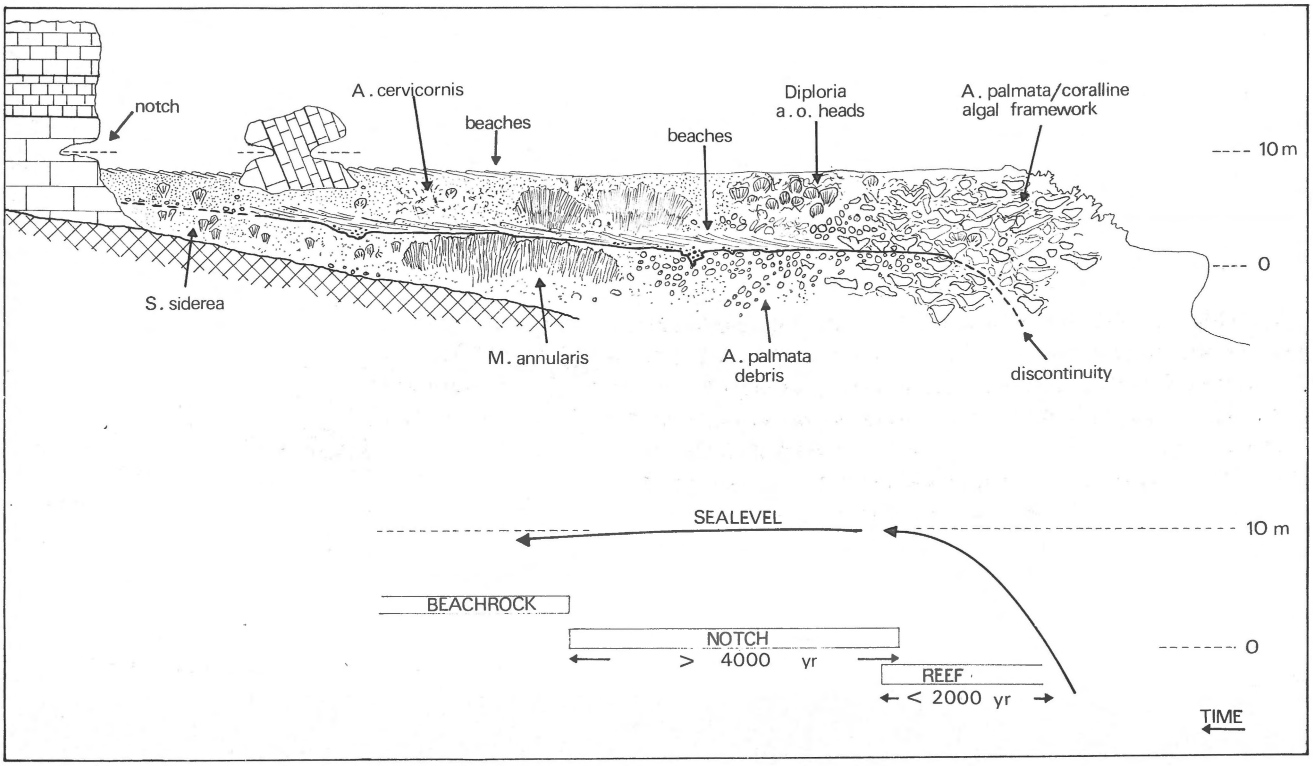

Fig. 6
Schematic cross-section through Lower Terrace deposits showing two superimposed units (Cortalein and Hato), and the sea-level interpretation of the upper unit.

DENUDATIONAL LANDFORMS IN THE CENTRAL PARTS OF THE ISLANDS

Most of the denudational slopes in the central parts of the islands have a stepped topography: relatively flat surfaces (benches), gently dipping towards the valley-floor alternate with narrow steeper slope segments (Fig. 4). The results of a slope profile survey (HERWEIJER, in prep.) show that the vertical sequence of benches is very regular in most of the slopes on Curaçao, Aruba and Bonaire (Fig. 13). The regularities of the bench-sequence concerns the number of benches as well as their elevation above the valley-floor (talweg).

Present-day geomorphological processes were analyzed to find explanations for the formation and preservation of the benches. On the arid to semi-arid islands transport of material only takes place during the scant heavy rain showers.

The regolith is made up of stones and weathered fine particles. Splash and surface wash during rainstorms tends to remove the fine particles, leaving behind a stone pavement (Fig. 5). This stone pavement forms a protection against further splash erosion and the high permeability of the pavement hinders superficial flow of water over longer distances and consequently sheetwash erosion. Even if the stone pavement is disturbed, surface wash and splash will not result in significant lowering of the terrain as a new stone pavement will be formed.

A different picture arises from the streams. Here during a rainstorm the streambed is occupied by relatively fast running water, eroding the rather loose fragile components of the bed (weathered stones, clay, sand etc.) in the streambed and streamflanks. Lateral erosion of the streamsides is probably as important as vertical erosion under conditions with a more or less stable base-level of erosion This lateral erosion produces 'floodplains' of varying dimensions and as such may be considered as 'planation'. The lateral extension of this planation will be slow as the erosion is concentrated in small areas and the processes which produce the planation are only temporarily active. However, during periods of rapid lowering of the base-level of erosion the vertical erosion may outweigh the lateral. Therefore, taking into account the position of the benches on different levels, it may be deduced that the benches are remnants of planation surfaces, which were formed during periods of different base-levels of erosion.

Another argument for this assumption of subsequent planation levels may be the fact that the occurrence of benches is not associated with differences in rocktype or lithological differences within one rocktype (HERWEIJER, in prep.).

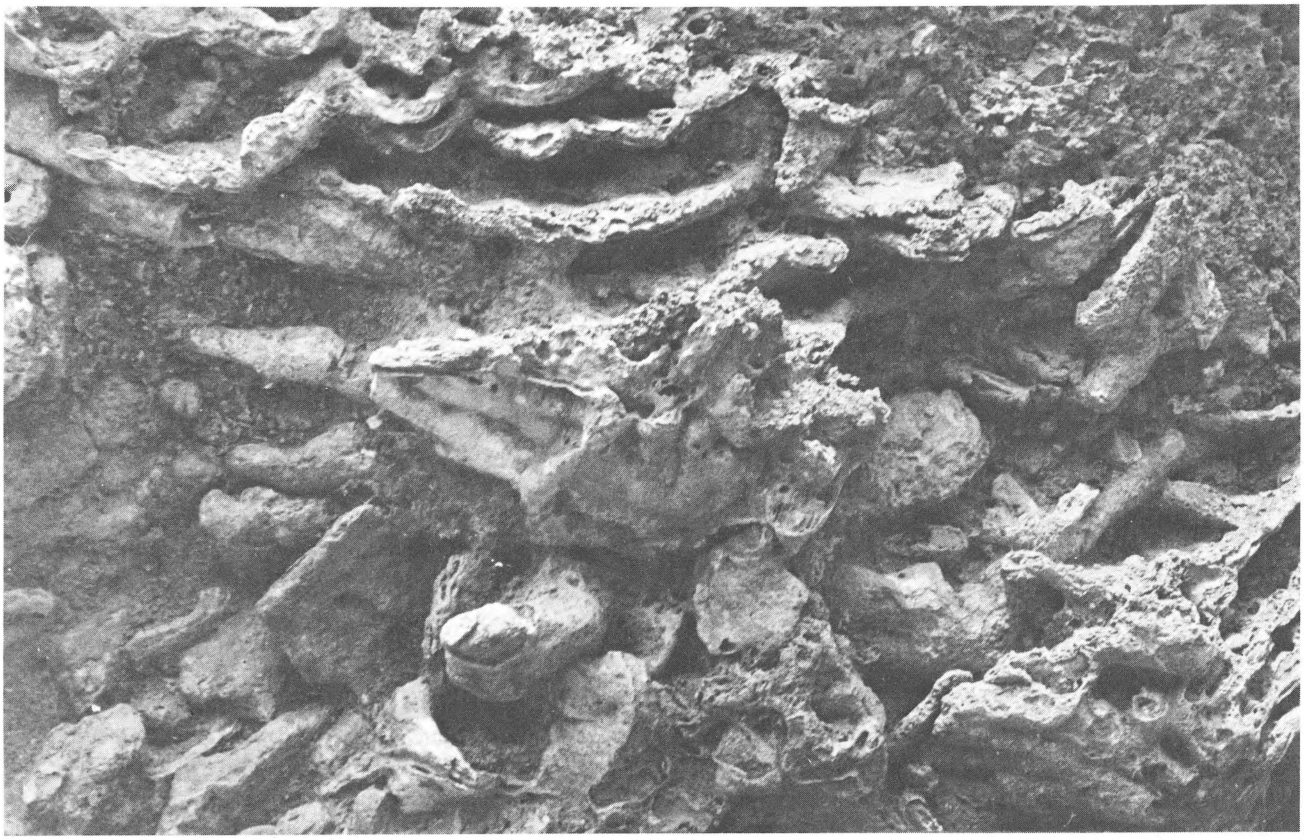

Fig. 7
Interlocking framework of *Acropora palmata* and *Porolithon pachydermum,* such as found in the barrier-reef zone.

The presence of stone pavements may protect (parts of) these planated surfaces during lower base-levels of erosion, while the planated valley-side slopes may be buried during eventual higher base-levels of erosion. In both cases the planation surfaces are probably preserved to some degree.

If the assumption that the benches are remnants of planation surfaces is correct, it may be anticipated that a correlation exists between these planation surfaces and palaeo-sea-levels which have been preserved as marine terraces and deposits. This prompted us to re-investigate the marine stratigraphy of the terraces of the Netherlands (Leeward) Antilles.

THE LIMESTONE DEPOSITS

Facies

The best preserved reef deposits from the Lower Terrace limestones (Fig. 2) consist of two zones (Fig. 6):
(1) A barrier-reef zone, made up almost exclusively of coral *(Acropora palmata)* and coralline algal *(Porolithon pachydermum)* framework (Fig. 7). Both frame builders are typical components of relatively exposed, shallow water reefs in the Caribbean.
(2) A back-reef zone, dominated by *Montastrea annularis* and a variety of other corals such as *Diploria sp., Acropora cervicornis* and *Siderastrea siderea.* Back-reef conditions are suggested by the composition of the sediments (mainly coral and coralline algal fragments, no calcareous green algae), the predominance of gastropods over bivalves in many areas, as well as the fact that the corals often form an interlocking framework. The diverse coral and mollusc assemblage, and the abundance of thick coralline algal crusts and massive rhodolites indicate open marine conditions and relatively high energies.

In the Caribbean *A. palmata* is the dominant coral frame builder in relatively exposed reefs, growing in water-depths of less than 10 m (GOREAU, 1959; ADEY & BURKE, 1976). The nature of the framework in the Lower Terrace reef, with thick coralline algal crusts, and the close lateral association with very shallow water indicators, such as the coralline alga *Lithophyllum congestum* (STENECK & ADEY, 1976), demonstrate that the *A. palmata* zone represents the former reefcrest with very shallow water or even emergent condi-

Fig. 8
Core drilled on South-Bonaire, showing a distinct break at approximately 1 metre below present sea-level (depth on core is in cm below landsurface). Note the well-lithified clasts in the upper unit. The δ 0^{18} are obtained at 1: –3,35‰ PDB; 2: –5,11‰ PDB; 3: –2,71‰ PDB.

tions. The upward growth rate of the reef can be approximated to on the basis of coral growth bands (KNUTSON ET AL., 1972; BUDDEMEIER ET AL., 1974). Measurements in *M. annularis* from Curaçao yield framework growth rates of 9 to 10 mm/year. Comparison of framework growth rate and net accumulation rate in a Holocene *M. annularis* reef (FOCKE, 1978-b) indicates that the net accumulation rate in such reefs is in the order of half the framework growth rate. The net accumulation rate of the Pleistocene reef is therefore estimated at approx. 5 mm/year. An equally rapid (relative) sea-level rise is concluded since the entire reef, laterally as well as vertically, has been deposited in very shallow water. Because the islands have been tectonically uplifted since early Quaternary time (DE BUISONJÉ, 1974), this sea-level rise must have been of a eustatic nature.

In the cliff of older limestones bordering these reef deposits on the land side (Fig. 6), a sea-level notch has been cut out at a level coinciding with the topographic top of these reefs. The profile of the notches, as well as erosion rates within a notch, vary with the degree of exposure. The profile of the notches occurring in the Middle Terrace cliffs suggests exposure conditions, whereby erosion rates have been 1.5 mm/year at the most (FOCKE, 1978-a; TRUDGILL, 1976). Because the notches are up to 3 m deep, they represent a minimum time-span of stable sea-level of 2000 years. The presence of collapsed blocks, with renewed notch development, in front of the cliff shows that the cliffs underwent at least 2 cycles of notch development, bringing the minimum time-span to 4000 years (Fig. 6).

Although periods of relatively stable sea-level may have occured between eustatic minima and maxima (at intermediate levels), these periods did not last as long as 4000 year or more (see δ 0^{18} curves of EMILIANI, 1978, and others).

Stratigraphic breaks

Several discontinuities have been recognized in the Lower and Middle Terrace deposits (Table I). The deepest was found in cores taken near the blue obelisk at the solar salt works of southwest Bonaire (FOCKE, 1978-b), at a depth of 9 m below mean sea-level. The discontinuity showed an irregular truncation surface, accompanied by caliche features (cf. HARRISON, 1977). Several other cores taken in the vicinity showed a very sharp break at –1 m (Fig. 8), with clasts of the lower, well lithified unit 'floating' in the upper unit, which is only friably lithified.

The limestone immediately below the break is significantly depleted in carbon-13, as compared with the limestone above the break and the limestone further down (Fig. 8). The unit above this –1 m break forms a prominent terrace at ca 2 m

Table I
Tentative stratigraphy of the Lower Terrace deposits. The two units underlying the Plenchi unit have been recognized in cores. The stratigraphic relation between the Cortalein unit and the Plenchi unit is uncertain. See also Fig. 12.

Elevation	Lower Terrace group
10 m	
	HATO unit
4 m	
	CORTALEIN unit
2 m	....
	PLENCHI unit
–1 m	
	SUB-PLENCHI unit I
–9 m	
	SUB-PLENCHI unit II ?

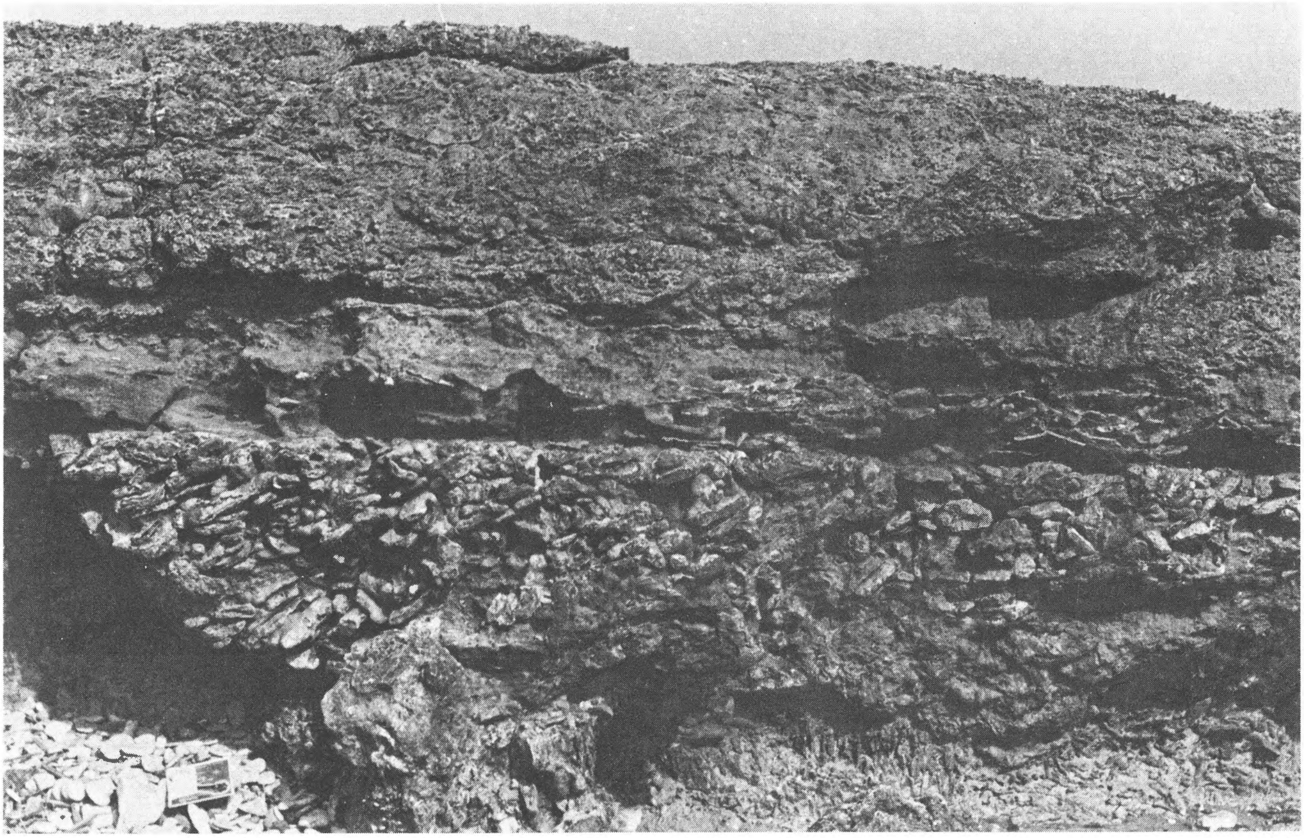

Fig. 9
Outcrop in Boca Cortalein (N.W. Curaçao) showing the Cortalein unit (below) and the Hato unit (above), separated by a distinct discontinuity (see Fig. 10).

above sea-level. A large part of South Bonaire and probably S.W. Aruba is made up of this terrace, and possibly part of the city of Willemstad on Curaçao is built on it. Where the unit is overlain by other deposits, the break is difficult to find because of its proximity to sea-level. A distinct break at 4 to 5 m above the present sea-level can be seen in outcrop in many of the coastal inlets ('boca's'). This break, which separates two well developed reef bodies (Fig. 9), is often associated with beachrocks, irregular truncation surfaces overlain by conglomerates (Fig. 10), and/or coral settlement immediately upon the discontinuity surface. The type section of this break is the outcrop in Boca Cortalein (N.W. Curaçao). The unit above the +4 m break forms a very prominent terrace at ca 10 m above sea-level, and is not overlain by younger marine deposits.

In the Middle Terrace deposits, against which the deposits described above are situated (Figs. 2, 6), breaks have been recognized at 13, 16, 21 (?), and 27 m above sea-level (Table II; Fig. 11) while the unit of this group, lying above the 27 m break, forms a terrace at approx. 35 metres. The type locality of these units is found near the Indian drawings (Boca Onima), N.E. Bonaire. Another terrace, at + 41 m, probably also belongs to the Middle Terrace group, but in this case the stratigraphic relations are not clear. As in the Lower Terrace group, the breaks are truncation surfaces with basal conglomerates, and/or beachrock deposits. The spatial relation between the units which are separated by these breaks is shown in Fig. 12 according to the data now available.

Table II
Tentative stratigraphy of the Middle Terrace deposits. The possible presence of a break within the Bolivia unit is indicated. See also Fig. 12.

Elevation	Middle Terrace group
35 m	————————
	HOENDOE unit (Middle Ter.I)
27 m	————————
21 m	................BOLIVIA unit ....
16 m	————————
	ONIMA unit
13 m	————————
	BACUNA unit
	?

Fig. 10
Detail of Fig. 9, showing the discontinuity as an irregular truncation surface, overlain by conglomerates and beachrocks.

DISCUSSION

The truncations in the marine limestones (indicating pre-lithification), caliches, negative δ C^{13} values (see also ALLAN & MATTHEWS, 1977) and other phenomena described above, show that the breaks in the deposits are sub-aerial exposure surfaces. As has been discussed (Fig. 6), the stratigraphic units represent eustatic sea-level maxima. The alternation of marine units and sub-aerial exposure surfaces therefore demonstrates the relation of each unit with individual sea-level events.

The sequence of levels as revealed by this marine stratigraphy (Tables I and II) shows a remarkable similarity with the bench-sequence found in the interior parts of the islands (Fig. 13). This similarity suggests that the benches are also related to palaeo-sea-levels, and confirms the original assumption that the benches are remnants of planation surfaces, formed during periods of stable sea-level. Several radiometric age-datings have been obtained from material from the Middle and Lower Terrace deposits (Table III). All authors have sampled within the stratigraphic frame work of DE BUISONJÉ (1974), and it is not possible to determine which of the units as defined in the present paper have actually been dated. The age of the Middle Terrace group as a whole appears to be in the order of 500,000 years (Table III). Because the deposits represent eustatic sea-level maxima, and taking into account that eustatic maxima in this age-range have been more or less at the present sea-level (SHACKLETON & OPDYKE, 1974; EMILIANI & SHACKLETON, 1974), the present elevation of the Middle Terrace I group (up to + 27 m; Fig. 2, Table II) points to an *average* rate of tectonic uplift in the order of 0.05 m/1000 year, over the last 500,000 years. This rate is very low as compared to average uplift rates of well known raised-reef areas such as Barbados (0.43 m/1000 year: MATTHEWS, 1973), Kikai (1.5 m/1000 year: KONISHI ET AL., 1974), and New Guinea (3 m/1000 year: VEEH & CHAPPELL, 1970; CHAPPELL, 1974). This slow uplift rate explains why so many sea-level events are represented in relatively short vertical intervals.

The upper units of the Lower Terrace group (Table I) have ages between approx. 90,000 and 130,000 years (Table III). Raised reef terraces in this age-range are very abundant throughout the world *(inter alia:* BROECKER ET AL., 1968; MESOLELLA ET AL., 1969; KONISHI ET AL., 1974; FAIRBANKS & MATTHEWS, in ms.). Terraces of approx.

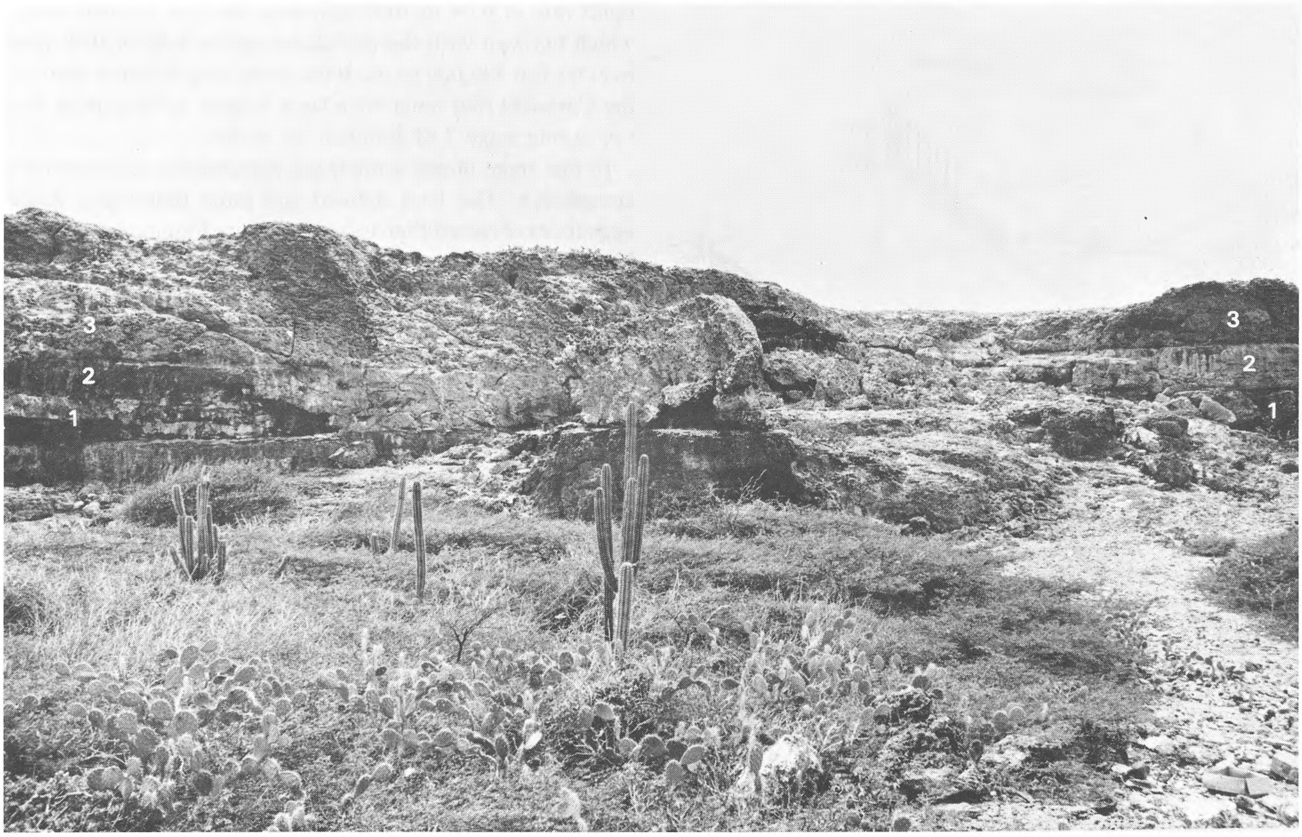

Fig. 11
Middle terrace cliffs (S.E. Aruba), showing Bacuna (1), Onima (2) and Bolivia (3) units.

Table III
Radiometric ages obtained from the Netherlands Antilles and the adjacent islands of La Blanquilla; references: 1: De Buisonjé, 1974; 2: Murray, 1969; 3: Schubert & Szabo, 1977; 4: R. K. Matthews, pers. comm., 1977. The radiocarbon dates were obtained from *Strombus* shells of unknown mineralogy; resampling by us on the original locations showed all collected shells to be strongly recrystallized or contaminated. These dates are therefore rejected. Studies by Chappell et al. (1974) indicate that for U-series dating techniques unaltered coral is to be preferred above mollusc shells. The 126,000 year age (ref. 4) is an average of 8 dates obtained from the same coral sample by different laboratories, with a range of 120,000 to 140,000 years B.P., and illuminates the present lack of calibration between results obtained by different laboratories (R. K. Matthews, pers. comm., 1977).

location	terrace	elevation of sample	method	age in years B.P.	material	ref.
Aruba (Andicouri)	Lower Terrace	+ 0.5 m	^{14}C	39,550	*Strombus*	1
Curaçao (Schottegat)	Lower Terrace	+ 0.5 m	^{14}C	31,300	*Strombus*	1
Curaçao (Boca Tabla)	Lower Terrace	+ 8 m	^{14}C	36,500	*Strombus*	1
Bonaire	Lower Terrace	< 5 m	U-series	93,000	*Strombus*	2
Bonaire	Lower Terrace	< 5 m	U-series	103,000	coral	2
La Blanquilla (Venezuela)	'Lower Terrace'	?	U-series	127,000	coral	3
Curaçao (airport)	Lower Terrace	< 10 m	^{230}Th	129,000	coral	3
Curaçao	Lower Terrace	?	^{230}Th	126,000	*A. palmata*	4
La Blanquilla	'Middle Terrace'	$\leq$ 15 m	U-series	> 410,000	coral	3
Curaçao (airport)	Middle Terrace	< 25 m	^{230}Th	> 400,000	coral	3
Curaçao (airport)	Middle Terrace	< 25 m	^{234}U	510,000	coral	3

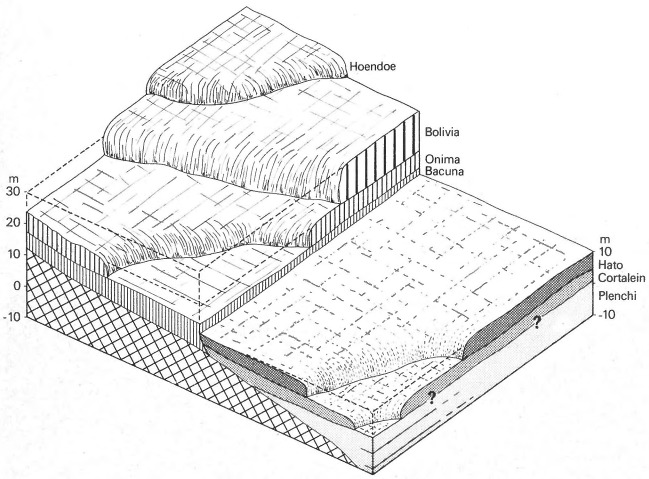

Fig. 12
Block diagram showing tentative stratigraphic division of Lower and Middle Terrace deposits; see Tables I and II; Note that the 'Lower Terrace' and 'Middle Terrace' are topographical surfaces, associated with several stratigraphic units.

125,000 years old are particularly abundant, and in areas of relative tectonic stability these terraces are found at elevations of 2 to 10 m (NEUMANN & MOORE, 1975; BOURROUILL, 1974; KU ET AL., 1974), indicating a eustatic maximum slightly above the present sea-level. The 0^{18} record, preserved in molluscs (SHACKLETON & MATTHEWS, 1977) and corals (FAIRBANKS & MATTHEWS, in ms.) in these terraces, also suggests that eustatic sea-level around 125,000 years ago has been a few meters above the present level (*i.e.* + 5 m, FAIRBANKS & MATTHEWS, in ms.). This provides evidence (SHACKLETON & MATTHEWS, 1977) to correlate these terraces, including Rendezvous Hill Terrace on Barbados (Barb. 3), with the most prominent peak (*i.e.* peak 5-e) in the last major interglacial period, as recorded by $\delta\ 0^{18}$ variations in deep-sea sediments (EMILIANI, 1971, 1978; EMILIANI & SHACKLETON, 1974). Considering the age-range of the upper units of the Lower Terrace group, the most obvious procedure is to correlate the uppermost unit, that is the Hato unit, at an elevation of + 10 m, with this 125,000 years old eustatic event (Barb. 3; peak 5-e). If one of the units underlying the Hato unit is correlated with this event, the Hato unit cannot be related to any of the remaining (younger) sea-level events, because the maximum levels reached by these events have been much too low (EMILIANI, 1978; FAIRBANKS & MATTHEWS, in ms.). The younger peaks from stage 5, represented on Barbados by terraces of 105,000 and 82,000 year B.P. (among others MATTHEWS, 1973), may be represented on the Netherlands Antilles by one of the submarine terraces which have been preserved (FOCKE, 1978-b, 1978-c). Correlation of the Hato unit with the 125,000 years old event points to an average uplift rate of 0.04 m/1000 year over the last 125,000 years, which fits well with the calculated rate of 0.05 m/1000 year over the last 500,000 years. If this basic correlation is correct, the Cortalein unit must have been formed prior to peak 5-e, *i.e.* during stage 7 of Emiliani, or earlier.

In this stage of our knowledge correlations are extremely speculative. The best defined and most thoroughly dated sequences of raised Pleistocene reefs are found on areas with high uplift rates, such as Barbados, New Guinea, and the Ruykyu Archipelago, while tectonically more stable areas such as Bermuda, Florida, the Bahamas, Hawai, and the Netherlands Antilles have yielded fewer dates which are often of uncertain stratigraphic affinity (*cf.* NEUMANN & MOORE, 1975). Yet it may be advantageous to solve and date the stratigraphy in these stable areas. As pointed out by STEARNS (1976), the assumption of constant uplift rate, which is basic to many of the eustatic calculations, may be severely critisized. The errors resulting from this assumption are much smaller in stable areas. Continued efforts to unravel the terrace stratigraphy of the Netherlands Antilles may therefore well be of more than just local importance.

CONCLUSIONS

The benches occurring in the interior parts of the islands are directly related to Pleistocene marine terraces and eustatic sea-level stands. Limestone terraces, which have formerly been regarded as single stratigraphic units, are in fact groups of terraces, or terraces underlain by more than one stratigraphic unit, each represanting different sea-level events. In the Lower Terrace deposits 5 units have been recognized at elevations of + 10, + 5, + 2, – 1, and – 9 m, relative to present sea-level. In the Middle Terrace deposits, units have been recognized at elevations of 13, 16, 21, 27, 35 and 41 m above present sea-level.

The + 10 m unit of the Lower Terrace group is tentatively correlated with Rendezvous Hill Terrace (Barbados 3, 125,000 year B.P.) and stage 5-e in deep-sea stratigraphy. The presence of units belonging to stage 7 in deep-sea stratigraphy (180,000 to 220,000 year B.P.) can at present only be assumed. The age of the Middle Terrace deposits as a whole is in the order of 500,000 years.

Other correlations can not be made reliably until further fieldwork, coring, and renewed radiometric dating have produced a much more refined stratigraphic framework.

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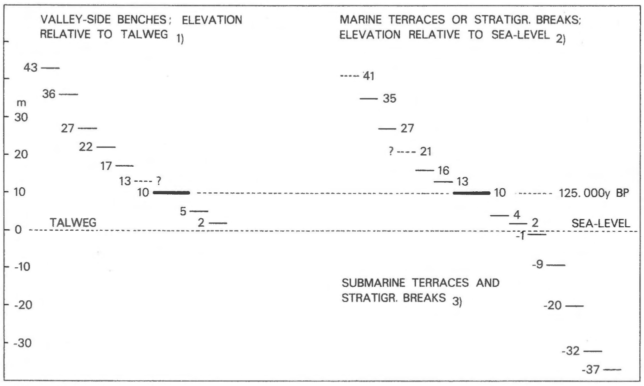

Fig. 13
The sequence of denudational benches (left) compared with marine terraces and stratigraphic breaks within the marine limestones. 1: Herweijer (in prep.); 2: this paper and Herweijer (in prep.); 3: Focke (1978-b, c).

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REFERENCES

Adey, W.H. & R. Burke 1976 Holocene bioherms (algal ridges and bank-barrier reefs) of the eastern Caribbean - Geol. Soc. Amer. Bull. 87: 95-109.

Allen, J.R. & R.K. Matthews 1977 Carbon and oxygen isotopes as diagenetic and stratigraphic tools: Surface and sub-surface data, Barbados, West Indies - Geology 5: 16-20.

Bandoian, C.A. & R.C. Murray 1974 Pliocene-Pleistocene carbonate rocks of Bonaire, Netherlands Antilles - Geol. Soc. Amer. Bull. 85: 1243-1252.

Beets, D.J. & H.J. Mac Gillavry 1977 Outline of the Cretaceous and Early Tertiary history of Curaçao, Bonaire and Aruba - Guide to field excursions on Curaçao, Bonaire and Aruba; 8th Caribbean Geol. Conf. (Curaçao, 1977): 1-6.

Bourrouill, F. 1974 Sédimentologie, géochimie et petrographie sédimentaire Bahamien, région de Fresh Creek, Ile Andros, Bahama - VII Conf. Géol. Caraibes (Guadaloupe): 12.

Broecker, W.S., D.L. Thurber, J. Goddard, T.L. Ku, R.K. Matthews & K.J. Mesolella 1968 Milankovich hypothesis supported by precise dating of coral reefs and deep sea sediments - Science 159 (3812): 297-300.

Buddemeier, R.W., J.E. Maragos & D.W. Knutson 1974 Radiographic studies of reef coral exoskeletons: rates and patterns of coral growth - J. Exp. Mar. Biol. Ec. 14: 179-200.

Chappell, J. 1974 Geology of coral terraces, Huon Peninsula, New Guinea: a study of Quaternary tectonic movements and sea-level changes - Geol. Soc. Amer. Bull. 85: 553-570.

De Buisonjé, P.H. 1974 Neogene and Quaternary geology of Aruba, Curaçao and Bonaire (Netherlands Antilles) - Uitg. Natuurwet. Studiekring Suriname Nederlandse Antillen (Utrecht) 78: 291.

De Buisonjé, P.H. & J.I.S. Zonneveld 1976 Caracasbaai: A submarine slide of a huge coastal fragment in Curaçao - Nieuwe West-Indische gids 5: 55-88.

Emiliani, C. 1971 The last interglacial: paleotemperatures and chronology - Science 171: 571-573.

—— 1978 The cause of the Ice Ages - Earth Planet. Sci. Letters 37: 349-352.

Emiliani, C. & N.J. Shackleton 1974 The Brunhes Epoch: isotopic paleotemperatures and geochronology - Science 183: 511-514.

Fairbanks, R.G. & R.K. Matthews (in ms.) The marine oxygen isotope record in Pleistocene coral, Barbados, West Indies - Quat. Res.

Focke, J.W. 1978-a Limestone cliff morphology and organism distribution on Curaçao (Netherlands Antilles) - Leidse Geol. Meded.

—— 1978-b Holocene development of coral fringing reefs, leeward off Curaçao and Bonaire - Marine Geol.

—— 1978-c Subsea (0-40 m) terraces and benches, windward off Curaçao, Netherlands Antilles - Leidse Geol. Meded.

Goreau, T.F. 1959 The ecology of Jamaican coral reefs. I. Species composition and zonation - Ecology 40: 67-90.

Harrison, R.S. 1977 Subaerial versus submarine discontinuity surfaces in a Pleistocene reef complex, Barbados, West Indies - Proc. 3rd Int. Coral Reef Symp. (Miami) 2: 143-147.

Herweijer, J.P. (in prep.) Denudational slopes and the correlation with Pleistocene marine terraces on Curaçao, Aruba and Bonaire (Netherlands Antilles) - Ph. D. Thesis Univ. Utrecht.

Knutson, D.W., R.W. Buddemeier & S.V. Smith 1972 Coral chronometers: seasonal growth bands in reef corals - Science 177: 270-272.

Konishi, K., A. Omura & O. Nakamichi 1974 Radiometric coral ages and sealevel records from the late Quaternary reef complexes of the Ryukyu Islands – Proc. 2nd Int. Coral Reef Symp. (Brisbane) 2: 595-613.

Ku, T.L., M.A. Kimmel, W.H. Easton & T.J. O'Neil 1974 Eustatic sea level 120,000 years ago on Oahu, Hawaii - Science 183: 959-962.

Matthews, R.K. 1973 Relative elevation of Late Pleistocene high sea level stands: Barbados uplift rates and their implications - J. Quat. Res. 3: 147-153.

Murray, R.C. 1969 Hydrology of South Bonaire, N.A., a rock selective dolomitization model - J. Sed. Petr. 39: 1007-1013.

Neumann, A.C. & W.S. Moore 1975 Sea level events and Pleistocene coral ages in the northern Bahamas - Quat. Res. 5: 15-225.

Schubert, C. & B.J. Szabo 1977 Radiometric ages of Pleistocene marine terraces of La Blanquilla Island (Venezuela) and Curaçao (Netherlands Antilles) - Abstr. 8th Caribbean Geol. Conf. (Curaçao): 178-179.

Shackleton, N.J. & R.K. Matthews 1977 Oxygen isotope stratigraphy of Late Pleistocene coral terraces in Barbados - Nature 268: 618-619.

Shackleton, N.J. & N.D. Opdyke 1973 Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V 28-238: Oxygen isotope temperatures and ice volumes on a 10^5 and 10^6 year scale - Quat. Res. 3: 39-55.

Stearns, C.E. 1976 Estimates of the position of sea level between 140,000 and 75,000 years ago - Quat. Res. 6: 445-450.

Steneck, R.S. & W.H. Adey 1976 The role of environment in control of morphology in *Lithophyllum congestum*, a Caribbean algal ridge builder - Bot. Marina 19: 197-215.

Trudgill, S.T. 1976 The marine erosion of limestones on Aldabra Atoll, Indian Ocean - Zeitschr. Geomorph. Suppl. Band 26: 164-200.

Veeh. H.H. & J. Chappell 1970 Astronomical theory of climatic change: Support from New Guinea - Science 167: 862-865.