Morphology of Some Coral-Cliffs, Bismarck Archipelago*

Indicators of the Eustatic 1,5 m (5 ft.) Level ?

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Abstract

Morphological elements of some double-notched coral cliffs in the Bismarck Archipelago are described. Origin of zonation is discussed. Upper notches of the cliffs are found to bear evidence of an emergence of about 1,5 m (5 ft.). Widespread occurrence of the 5-ft.-level in coast lines of the Pacific and the Indian Ocean often interpreted as an indication of eustatic origin allows no conclusive explanation. Other modes of origin are discussed.

During the *"Noona Dan" expedition* 1962 a number of coast-localities in the Bismarck Archipelago were visited. The investigation of these was especially interesting as their dispersal would make it possible for general features, if any, to show themselves clearly. Naturally many of the tropical types of coasts are found in the Archipelago — probably most of them — but most conspicuous by number are cliffs worked out in coralline material. The explanation for this is partly the situation of the islands in the center of the area of coral growth, partly the great tectonic movements they have been exposed to in tertiary and post-tertiary times. Occurrences of tertiary corals have thus been found in altitudes exceeding 1250 metres. Probably the entire Archipelago should be regarded as an island-arc related to the mountain-ranges found along the northern coast of New Guinea and continuing in the Indonesian arcs.

Morphological elements of cliffs

Various cliffs in the Bismarck Archipelago will here be treated with a brief discussion of the forming processes. In spite of a recognizable local variation the cliffs around Kalili Bay on the western coast of New Ireland will be regarded as representative types. The

* Noona Dan paper no. 5.

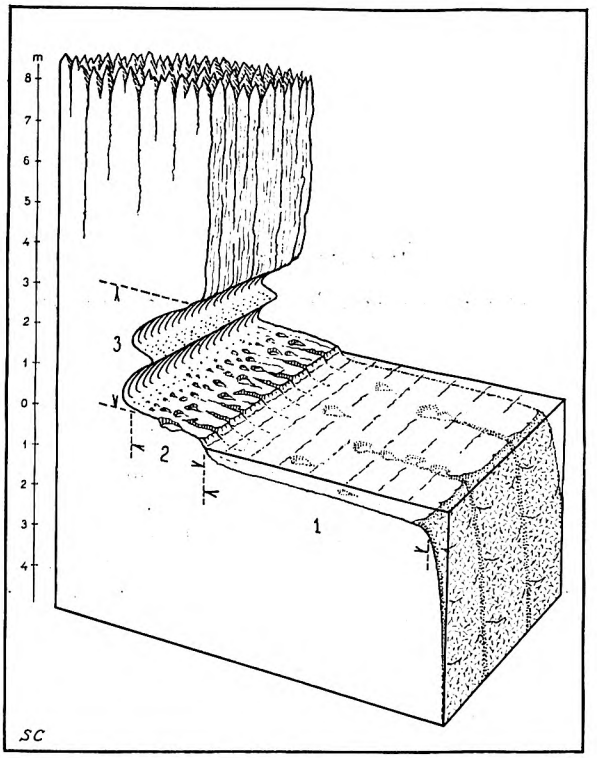

Fig. 1. Cliff of Pana Island near Kalili, New Ireland. 1) Reef-flat, mainly in dead coral-material. 2) Cliff-base with zonation seawards: pits, small basins near the wateredge developing into intricate channels. 3) Double notch. The upper notch often with some stalactites not found in the lower one. Both notches severely pitted. (Spray-effect allowing biological solution?).

Fig. 1. Klint i Pana Island, ved Kalili, New Ireland. 1) Revflade udviklet i dødt koralmateriale. 2) Klintfod med zonering: øverst småhuller, dernæst flade bassiner, der mod vandkanten udvikles til sammenhængende kanaler. 3) Dobbeltkehl. Den øvre kehl har ofte drypstenudvikling, den nedre ikke. Begge kehle stærkt præget af småhuller, der måske udvikles ved, at bølgesprøjtet giver mulighed for biologisk opløsning.

morphological elements characterizing the cliffs are — beginning from the seaward side — 1) the reef-flat, bearing a very conspicuous edge towards the deep, 2) the cliff-base with a marked zonation and 3) the notch — usually a double one — below a nearly vertical cliff-face (block-diagram, fig. 1).

The submarine slope at the edge of the reef-flat is very steep. Some echograms sounded at right angles to the coastline showed a sea-floor with an impressive inclination. Thus was a depth of more than 700 m found at a distance of a little over 2000 m from the coast — a feature which recalls the edges found at atolls (fig. 2). A further

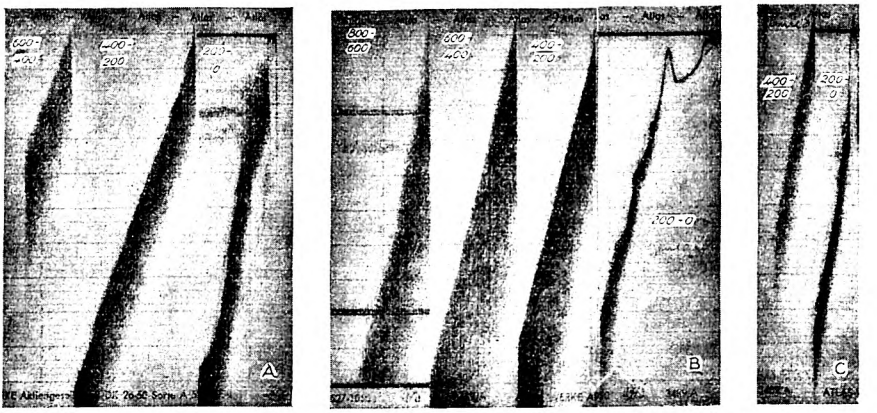

Fig. 2. Three echograms from the Kalili area (Location viz. fig. 7, sequence C - A - B). Vertical scale appr. 10 × horizontal.

Fig. 2. Tre ekkogrammer fra Kalili-området (lokalisering, se fig. 7, hvor rækkefølgen er C - A - B). Dybdeskala ca. 10 × vandret skala.

feature generally associated with atolls was a submarine terrace usually found at a depth of about 15—20 m (the 8—10 fathoms terrace also mentioned by *H. J. Wiens* (1962)?).

In most places the reef-edge was intersected by deep grooves. It could not be stated, if the grooves were spaced at regular intervals, though it looked so. Observations from canoe (no diving gear being available) indicate that erosion maybe is the main factor in the formation of the grooves, as previously mentioned by *Newell* (1961). In calm weather with a gentle swell, small moving clouds of material were seen following the grooves intermittently. The explanation of mechanical formation of grooves is supported by the evidence of correlation between wind exposure and occurrence of grooves *(Munk and Sargent* (1954) cited from *Wiens)*. However, it cannot be excluded that the subsistence of grooves partly is caused by the fact, that a deep shadow — prohibiting coral growth — usually is found in grooves. Sometimes traces were found of a sort of drainage system on the reef-flat in continuation of the head of grooves. It should be remarked that no Porolithon (or Lithothamnion) incrustations were found at the reef-flat edge — apparently supporting *Kuenens* (1956) statement, that this requires the heavy surf related to oceanic coasts.

The reef-flat — nearly dry at low water except for the inner part— varied very much in seaward extension. Near some cliffs (Delta 6 at Kalili) only few metres were found, at other places up to 250 m were measured (at the Island of Anir). Behind larger reef-flats usually no cliffs were found — presumably because the loss of wave

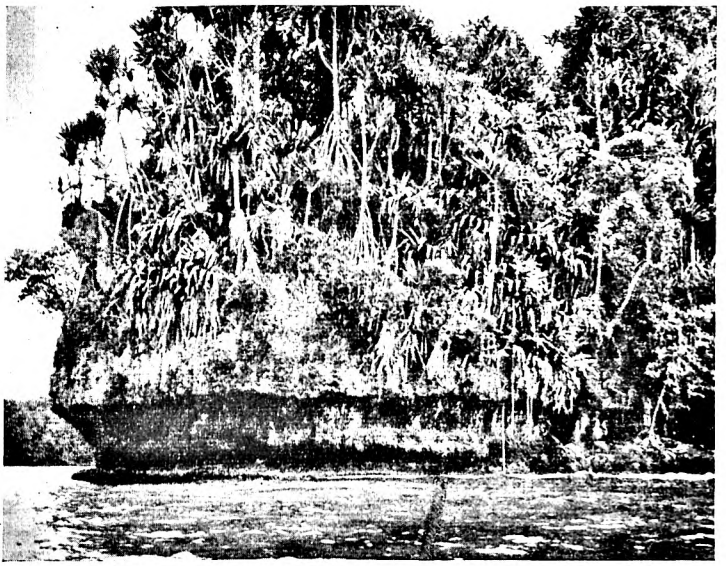

Fig. 3. Pana Island near Kalili. Below the dense vegetation (mainly Pandanus) the pitted surface and the notches are seen.

Fig. 3. Pana Island ved Kalili. Under den tætte vegetation (hovedsagelig af Pandanus) ses den småhullede overflade og dobbeltkehlen.

energy on a larger reef-flat finally do not enable a cliff to be cut. Thus was often found accumulation forms like mangroves along with broad reef-flats. The surface of the reef was rather uneven, holes and crevasses were found, but usually not more than 10—20 cm deep. Generally no living corals were seen on the flats, aside from occasionally some Acropora species of a dense, flattened form. Not easily seen, but unavoidable to be felt was the presence of rather coarse coral sand, usually finding its way into one's footwear, making wading a cumbersome affair. The sand was moved to and fro by waves, preferably close to the bottom. In the calmer waters of the wider reef-flats practically no sand was seen. Probably a lot of it is eaten by animals (Trepang f.i.) and thereby ground down to an unperceptible size. After all, the total amount of sand can be regarded as sufficient to furnish the returning water of the breaking waves with grinding tools for erosion of reef-edges. The development of reef-flats in the Kalili area gives the impression of erosion, while growth evidently is of lesser importance. The same can be said of solution, which is of paramount importance within the intermittently wet/dry zone of the tidal movement. This leaves us with the impression that the reef-flat is closely related to the low water level,

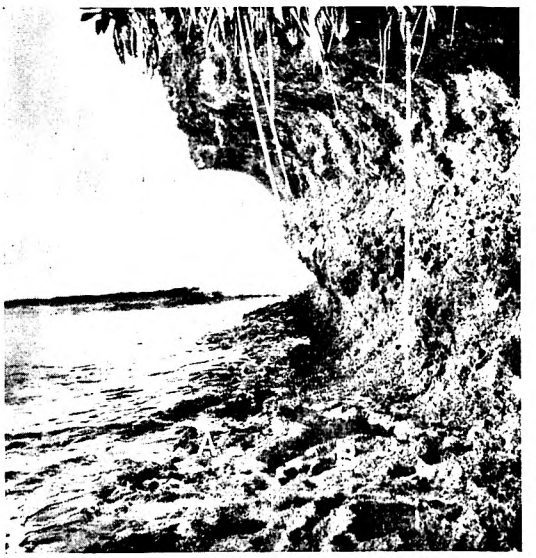

Fig. 4. Cliff-base with channels (A) and shallow bassins (B). Stick to the right is exactly 3 m.

Fig. 4. Klintfod med kanaler (A) og flædvandede bassiner (B). Målestokken t. h. er 3 m.

a fact which has earlier been pointed out by several authors (f. i. *H. J. Wiens* (1962)), and necessarily should be considered when levels of coastal features are to be compared.

The inner part of the reef-flat is generally a little lower than found further seawards. Often a "boat channel" is found with depths exceeding 1 m. This may give rise to some difficulties in determining the level of an ancient reef-flat. Apparently the level of the reef-flat also shows some variation as to exposure to waves. By Kalili we never saw the reef quite dry, while the Anir reef dayly lay completely exposed. Maybe the corals of the reef of Anir avoided being dried out on account of the heavy, spraying surf, so that much more living material could accumulate on top of the reef. The highlevel reef-flat of Anir may be due to a slight upheaval, although other features do not support this explanation. A zonation was found at the cliff-base, much like that demonstrated by *A. Guilcher* (1952 and 1955, summarized 1958).

Sometimes, as previosly mentioned, the lower part of the cliff-base a) is a steep slope, now and then with a slightly marked notch to the reef-flat. All the material in the zone directly around the low water mark is covered by red algae. b) Above the appr. 1 m high,

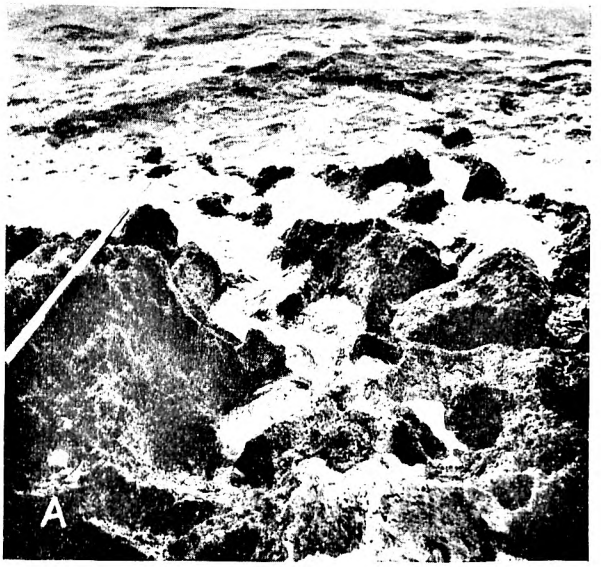

Fig. 5. Detail showing channel (A) from fig. 4.
Fig. 5. Detalje, der viser en kanal (A) fra fig. 4.

steep slope the cliff-base pass into a narrow platform with small shallow basins about 10 cm deep and with sharp sloping edges (fig. 3—6). At the edge against the steep slope the basins often meet forming channels of an intricate pattern (fig. 5). The upper part of the basin edges is often covered by the same algae growth as seen lower down the cliff-base; at the bottom of the basins, however, is often growth of green or bluish-green algae. The formation of the basins is most likely a biological phenomenon, perhaps combined with chemical solution. It seems that the algae during their growth mould hollows, which when deep enough continuously keep water. It looks like the ubiquitous snails then turn up rasping off the algae and the surrounding material. The biological effect depends on the level and the flat bottom arise. Big amounts of snails were present in this part of the Kalili area, at some places estimated to appr. 50 per m^2. The excavation, however, was not the work of snails only, but may be applied to numerous other animals such as bristle-worms.

In the upper part of the zone the basins are replaced by cm-deep holes in such numbers that their sharp edges form an intricate network (fig. 4). To these holes which most often remain dry are attributed spray-effects from the surf. Dissolving effects of the spray itself must, however, be very faint (as solubility of calcite in sea-

Fig. 6. Detail showing area around (B) in fig. 4. Some of the small basins are seen.

Fig. 6. Detalje, der viser området ved B i fig. 4. Nogle af de fladbundede bassiner ses.

water under circumstances like those mentioned is very low). Probably the small pits are partly due to biological activity, most likely from bacteria, if not solely by effects of salt-precipitation in crevasses as found by some authors.

The notch seems to lie around the high water mark; a great part of its surface is consequently covered by the "spray-pits" just mentioned. In the literature is often mentioned that the development of the notch chiefly is due to processes of dissolution (*A. Guilcher* 1958, *W. Panzer* 1933, *R. Revelle* and *K. O. Emery* 1957), an impression which was strengthened also at Kalili, as the depth of the notch practically was the same at sections exposed to strong wave washing as at sections more sheltered. Generally, however, the notch had not the same vertical extension, for which naturally the degree of exposure is of importance, as this determines how far up the coast can be washed by the waves (*Verstappen* 1962).

At Kalili the notch is a double one (fig. 1, 3 and 4) and completely similar to that at Patlangat farther to the north described by *Panzer* (1933). The vertical distance between the two notches is about 1,5 m. This seems to be correct, whether the measure is taken from low water mark to low water mark or from between the most deep-cut parts of the notches, a method, application of which can be neces-

sary as the upper low water mark is often missing. The placing of the notches in the cliff is varying along the coast at Kalili as shown at fig. 8. Unfortunately the two notches have developed so close to each other, that no zonation enable us to determine, if they belong to the same set of morphological element or are two sets, one superposed the other. The part of the cliff between the notches is at most places strongly pitted by spray and even stronger dissolved than seen at the below lying notch. This may be taken as an indication of an existing difference in age of the two notches, the upper being the elder. No definite signs are found in the two notches permitting a reliable decision concerning their relative age, apart from a rather marked development of stalactites — as will be mentioned later — which can be seen in the upper, but not in the lower notch.

By comparence of a series of profiles from Kalili it will be seen that the difference in height between the two notches is rather constant (fig. 8). The depth of the two notches, however, is naturally not the same. The map, fig. 7, shows, that the development of the depths of the notches seems to correspond to the differences in the wave attack they have been exposed to. As seen from the map, wave attack is at a minimum by profiles E and F, increasing towards A and H, which face the open sea only protected by a very narrow coast-reef. The profile C shows a so-called mushroom-rock. The wave washing seems here to be insignificant, but additionally the foot of the mushroom is exposed to the effects of an often rather considerable current moving in regular alternation in the small sound where the "mushroom" stands. Profile G shows the double notch worked far into the cliff, but nevertheless the profile is not just as advanced in development as profile H, of which the lower notch is completely dominating, whereas only two slight hollows are left of the upper part. The profiles B, C, E, F and G seem to show weak signs of these. It is not impossible that the development of the profiles in the Kalili area must be based on the perception of the notch as composed by three single units.

Without entering into details it shall be mentioned that at Kalili the cliff-face above the notches is rather different in heights. At the trigonometric point D6 close to profile A the height is 8,5 m, but the little island Pana shows heights up to 12 m. Both near D6 and other places at the height of about 6 m and 3 m are signs which may indicate a faded notch.

The development of the caves often found at these heights may be attributed to a waterlevel of the said size.

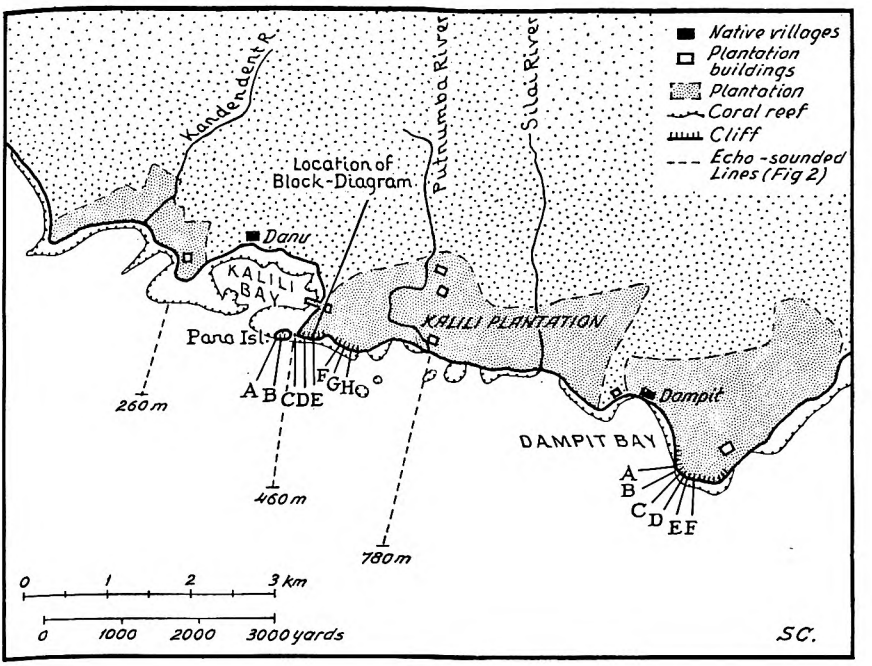

Fig. 7. The Kalili-area showing location of block-diagram (fig. 1), echo-sounded lines (fig. 2) and cliff-profiles (fig. 8).

Fig. 7. Kalili-området med lokalisering af blokdiagram (fig. 1), ekkogrammer (fig. 2) og klintprofiler (fig. 8).

As the described zonal arrangement of elements was also found at other localities visited in the Archipelago, no further reference will be given of this. The form and placing of the notch, however, seems to vary somewhat. For getting an idea of the forming of these notches and especially of the particular conditions which caused their development, it is necessary to examine a larger body of the coast profiles.

Distribution of double-notched cliffs

About 6 km southeast along the coast of the already mentioned cliffs at Dampit another system of cliffs, also developed in coral, is found. These cliffs, too, show the development of a double notch, as it will appear from fig. 9. By comparence of these profiles it will be seen, that the last cliff-profile in the series shows a higher lying notch than the preceding ones.

A main character of the profiles from Dampit is that the additional upper notch, which in the Kalili profiles only is shown by weak signs

in a common upper notch, in this area is more sharp-cut. This may be due to an occurrence of an upheaval of the area, strongest in the south, during the development of the notches. It can also be explained by the different exposure to the wave washing. Generally it must be said, that the Dampit coast is more exposed than that of Kalili. Here, too, are very big depths found close to the coast. It must be pointed out, that the profiles were measured at a regular spacing. The consequence of this is, that features of more casual nature happen to appear; on profile F for instance, the opening of a rather deep, dry cave. Possibly it marks the same water level as that usually indicated by the upper notch. Apart from this the profiles do not show many haphazard traits. Particularly surprising is, that the coral material seems to be so homogeneous that variations in the material can be left out. This told, it must be borne in mind that the notches at more places are destroyed by landslides. The cliff material is full of joints, most of them in the direction 230° N; it is certain that these joints besides the many in other not so marked directions play an important part for rock falls and landslides.

At the Island of Mussau more than 400 km away double notches were especially found at two visited localities, at Malakata on the northwestern coast and at Tasital on the east coast. The cliff at Tasital (fig. 10) is completely similar to the Kalili cliffs, only it has even more clearly-cut notches. A level corresponding to the bottom of the upper notch can be seen both behind the half mushroom-formed beach rock and very clearly at a plain along a great part of the coast.

Observations made from shipboard gave good reason to suppose, that the double notches without doubt were to be found at many places along the western coast of Mussau. At Malakata and at a section further north opportunity offered a more closely view of the cliffs. In the bay at Malakata's landing place were cliffs very similar to the Kalili type (fig. 10), only the notches had greater vertical extension. The profile C had an enormously developed notch, apparently of another height than seen at Kalili. The cliff-form of the surrounding areas motivate the presumption, that it is a notch of the same type as B, by which a new notch is now formed at sea level. The normal cliff types in the Malakata area are without doubt "A"-types very similar to the Kalili cliffs. A form as that of profile C seems to be very much diverging, at any rate on first view. This profile is like the "B"-profile found on the most exposed coast sections

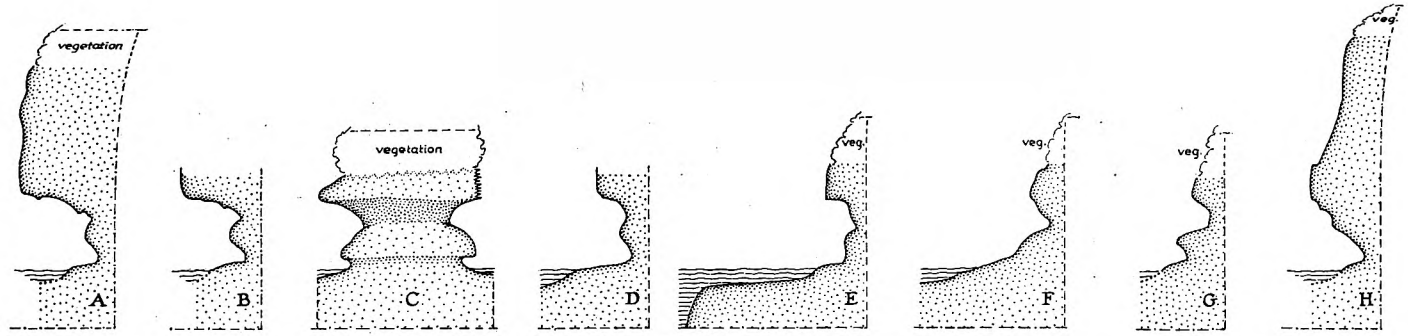

Fig. 8. A-H: Kalili, New Ireland.

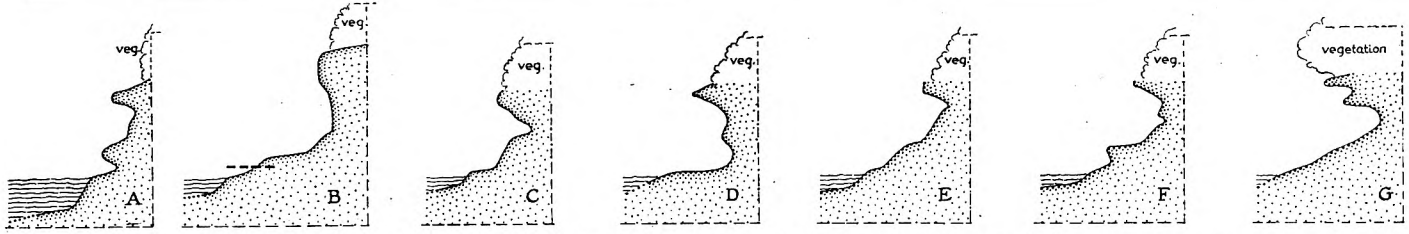

Fig. 9. A-G: Dampit, New Ireland. Dashed line on B: Water-level as shown at the other figures.
Fig. 9. Streget linie på fig. B: vandstand svarende til den angivne på øvrige figurer.

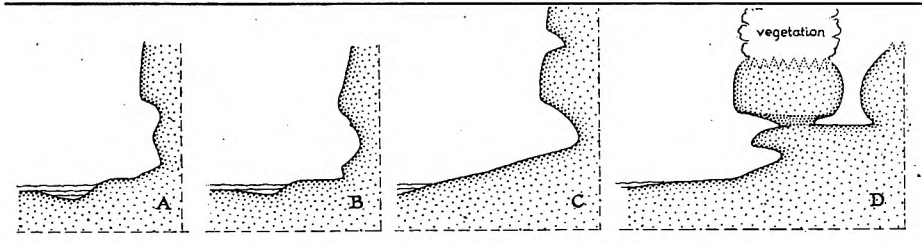

Fig. 10. A-C: Malakata and D: Tasital, Mussau.

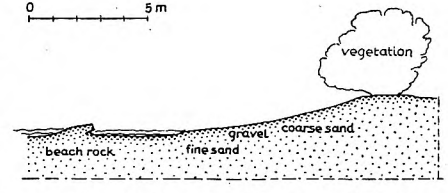

Fig. 11. Beach-plain near Kalili.
Fig. 11. Strandslette ved Kalili.

at Eia near Leegakinai, which forms a point at the corner of Mussau towards northwest (Cape Forsin). There is only a single notch corresponding to the usual double one. Perhaps the low-level notch has not been developed because of an unusually large accumulation of cobbles, yielding a sort of coastal protection. Above the very big notch, at a height of about 6 m is one more notch, the enormously developed stalactites of which indicate older age than those previously examined may be supposed to have. It may be pointed out, too, that a rather strong notch development was seen at various places slightly above the upper notch, i.e. about 3 m. This level was also found in a terrace at more places along the coast.

The previously mentioned double notched cliffs are only those which have been carefully investigated. There is, however, every reason to believe that such cliffs are widely distributed in the Bismarck Archipelago. From the sea for instance they were also observed at the Island of Dyaul. At a visited place, Sumuna, on this island no double notches were seen, but a cliff standing on a beach-plain about 1,5 m high has at this height a notch. This must at any rate be said to be an interesting parallel to the ordinary cliffs.

From the Island of Manus there are no cliff-profiles, but during the sailing along the north coast it was noticed from a distance, that the cliffs had quite the same look as the previously described. This was the case at Drampat and near Tulu more westwards. A level of 1,5 m was abundantly represented in the vast areas of sago swamp.

At New Britain the character of a great part of the coast prevents the formation of a double notch. The visited area around Cape Hoskins for instance had no notches in the coast material consisting of pumice and tuff extremely easy to destroy. In the southern part of New Britain near Kandrian no double notch was seen, but the 1,5 m level seemed nevertheless to be represented in the rather pronounced plains, at Analo for instance, directly west of Kandrian.

During a few hours visit of the eastern side of New Ireland no cliffs with double notches were measured. It was noted, however, that the coast road at various places runs on a natural plain lying at the mentioned level (f.i. at Karu) and that distant cliffs had the "usual look".

The Island of Anir (Feni) in the sea east of New Ireland has an immensely developed fringing reef to the ocean. From half-way between the beach and the sea and inward on the nearly 300 m wide reef are found a great number of 3 m high mushroomformed beach-

Fig. 12. Beach-pillar from Anir with notch in the 1,5 m-level. Stick is 3 m, appr. total height of pillar.

Fig. 12. Strandpille fra Anir, der viser kehl i 1,5 m-niveauet. Stadiet på 3 m svarer omtrent til pillens højde.

pillars and an impressive amount of 0,5 m high negro-heads, apparently remnants of an earlier reef-flat (fig. 12). It is certain that the "mushrooms" are not remainings of rocks torn off from the edge of the reef and washed ashore, as it is usually explaind about such occurrences when speaking about atolls. Not few crossings were seen between the beach-pillars and the unbroken coast, and it was moreover noted that at great number of the beach-pillars not only were of the same height, but also plane at the top, which incidentally quite often was overgrown. It seems that the coast of Anir greatly supports *Wiens'* points of view (1961) concerning a higher level for the coral reefs of the atolls. *Spender's* analysis of Low Isles (1930) also tells about a 5-ft. level on "promenades", perhaps quite corresponding. The negro-heads are may be equal to *Newell's* 2 ft. (0,6 m) level of Raroia.

A cliff form from Rennell Island, an "emerged atoll" in the southernmost part of the Solomon group, must be considered interesting. Though it is here a question of a cliff from Hutuna by Lake Tenggano, a lagoon with fresh or slightly brackish water, it looks very much like the Kalili type. The lake seems to maintain a level very close to the sea level, but the washing of the waves has,

though in no way negligible, by no means the same intensity as that of the sea. The notch in Lake Tenggano has the same height as usually seen, but it must be noted, that the cutting-up in two separated notches is more indistinct. This may among other things be due to the fact, that the coral lime here shows rather strong traces of percolating water-action, which perhaps again may be seen as a consequence of the character of the coralline material, which at the lagoon side is more loosely built than that built to the open sea. The sea-coast at f.i. Kanggava Bay had the usual double notches but as a part of a more complicated system.

Merely according to my own observations the distribution of the double notch in the Bismarck Archipelago must be said to be considerable, as shown on the map (fig. 13), where also occurrences mentioned in the literature are indicated. *K. Sapper* (1910) thus comments on a cliff at Nemasalang, where a slope side from a terrace falls directly to the sea or to a narrow sand beach. "The slope side shows here and there 2—3 m high, deeply cut notches which evidently the high tide for the time being cannot reach as shown by canoes kept here". Furthermore, *Sapper* mentions that by the Island of Awaruat near Lemau mushroomformed stacks have been developed from the lime rocks. In the Duke of York group by the coast of the Island of Ulu near the mission of the place is also a mushroomformed rock. *R. Pöch* (1907) gives a picture of a mushroom of the well-known form located as indicated on fig. 13. Better known is the comment on the mushromcliff at Patlangat made by *W.Panzer* (1933).

A water level, the effects of which result in the formation of a notch, must also in other ways manifest itself in the coastal morphology. Here the attention is drawn to the fact that the development of plains at and around the level of the notches must be expected. It must be noted, however, that plains are less surely referable up to a certain sea level. Probably certain types of accumulation coasts like f.i. mangrove and sagopalm swamps represent the level of the notches, whereas the beach ridge plains developed at the same water level as a rule will lie somewhat higher, among other things depending on the height of the waves, which the beach concerned is exposed to. The abrasion plains, however, will lie lower than the sea level, at which they have been developed. Furthermore, it should be borne in mind, that it is nearly impossible to judge from a coral flat — especially an older one — if it is developed by abrasion or, much simpler, by the growth of corals to a sea level.

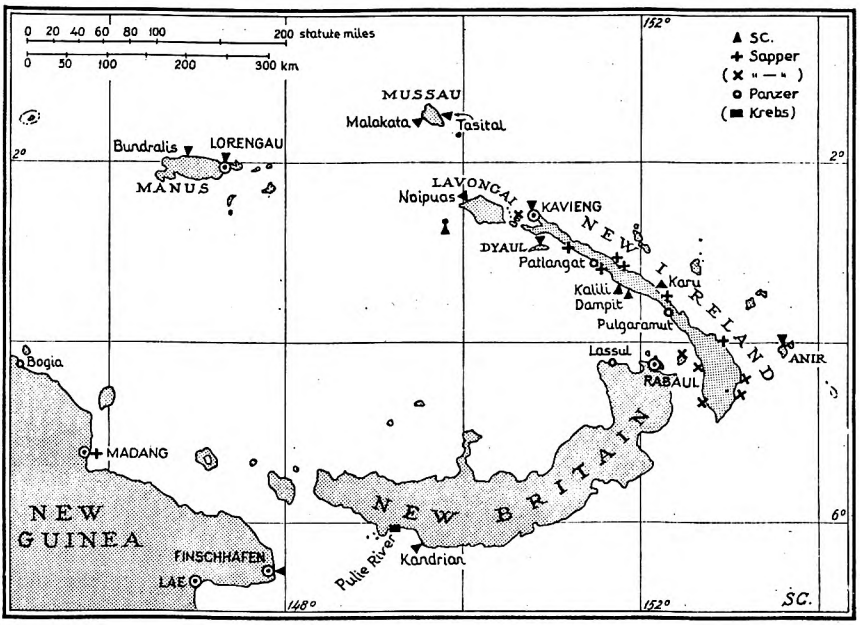

Fig. 13. Occurrences of double-notched cliffs and 1,5 m terraces according to literature — Sapper, Panzer and Krebs — and own finds — marked S.C. Signatures in brackets designate finds with uncertain information of either niveau or nature of locality.

Fig. 13. Forekomst af dobbelthulkehle eller 1,5 m-terrasser efter litteratur — Sapper, Panzer og Krebs — eller egne angivelser, mrk. s.C. Signaturer i parantes angiver forekomster, om hvilke oplysningerne er ufuldstændige med hensyn til enten niveau eller lokalitetens art.

Nevertheless it must here be mentioned, that there at many places in the Bismarck Archipelago are plains lying in the same heights as the notches. It may thus be mentioned that there, corresponding to the level of the upper notch in the Kalili area is a particularly wide plain. Between Kalili and Dampit this has the character of a beach-ridge plain; farther north it is a plain of a former mangrove swamp. A plain at the same level is found at Kavieng, in nature almost like an abrasion plain formed in front of a cliff, which the fact that most of the plain consists of firm coral-lime seems to indicate. On the east coast is also a plain of nearly the same height; it was observed at Karu during a short visit there. This plain, however, is built of loose material and consequently only with great uncertainty reveals the sea level when formed. Plains of similar character were found at the coasts of Mussau, greatly extended at both the west- and the east coast. Moreover, at Lavongai around Three Islands Harbour was a rather wide plain, partly mangrove, partly

sago swamp, marking the said height. Also Manus has, as said before, a strongly developed plain in level with the previously mentioned. The same goes for the little island Tingwon.

Fig. 13 gives a more complete account of the frequency of this level. Especially *Sapper* has shown terraces of the said height on a very great number of localities. Unfortunately he does not always give information about the nature of the material in his otherwise detailed report from his journeys, so it is not possible in every single case to make out, which sort of plain the discussion is about. Neither does *Sapper* explain whether the lower edge of the terrace or the upper one indicates the height. Moreover, it must be added, that *Sapper's* observations are not based upon measurements, but as to the low-lying terraces upon judgment, which can be treacherous, especially when — as during a journey — it is not possible in every single case to compare the height of the terrace with sea-level. It can even then be very difficult to pay due regard to possible changes of the water level caused by the tide. The tidal amplitude is in the area about 0,5 m; assuming that *Sapper* hardly has considered this fluctuation (which he himself points out in his report) it may be justified to represent his observations of more "Flachterrassen", save 0,3 m and 0,5 m terraces, under one signature in fig. 13. In his original work *Sapper* himself has divided his observations in 1,5 m, 1,5—2 m and 2 m terraces. From New Britain *Panzer* mentions a 1,5 m terrace from Lassul.

Leaving the Bismarck Archipelago one finds already at New Guinea the 1,5 m level represented at more places. Also the author of this article has found this level strongly developed at Lae and Finschhafen, especially at the last mentioned place. These observations can be supplemented with those of *Panzer's* (1933), also from the north coast of New Guinea, at Bogia and Madang. It must be mentioned, however, that other of *Panzer's* profiles from the same area of New Guinea do not indicate this level clearly, but instead show a level of 0,5 m and one of 3 m. (These heights are often seen in the Bismarck Archipelago at the same localities as the 1,5 m level.

It is interesting to notice that various tropical coasts seem to show the same development of double-notched cliffs or corresponding terraces. Especially coasts with 1,5 m (= 5 ft.) terraces seem to be widely distributed in the Pacific. The value of the informations may differ, as for instance the examination from Mauritius seem to show (*McIntire* 1961); a valuation will not be tried here. The said

low terrace has already for long been a subject in the literature. It is rather fully treated by *Guppy* as to the Solomon Islands (1887) and later by *J. C. Grover* (1955), who i.a. brings a nice plate of double-notched cliffs from the islands of Ugi and a profile from Nanambolu. *A. Agassiz* has seen the phenomenon at Tonga, which appears from a picture by *K. André* (1920). *W. M. Davis* describes cliffs and plains from Fiji (1928) and — in the same work — from Palawan and the Philippines, the last mentioned without any information concerning the heights, however. Tahiti has a very important 2 m-terrace according to *N. D. Newell* (1961). *Stearns* (1935 and 1961) mentions the 5-ft. terrace from Hawaii and an emergence of same amount from Midway. From King Island, Southeast Australia, *Jennings* (1961) gives a description of 6—9 ft. terraces, perhaps being of the same sort as the 5-ft. terrace. It should be noted, that this seems to be the only occurrence from latitudes exceeding appr. 20°. Especially well known is perhaps *Fairbridge's* and *Teichert's* description of the 5-ft. terrace at the Houtman-Abrolhos-group outside the western coast of Australia. *Fairbridge* (1961 a) even brings a dating of the terrace. In the comprehensive literature about The Great Barrier Reef one can at more places find the development of plains of 8,5 and 2 ft. mentioned (*Steers* 1929, *Spender* 1930, *Steers* 1937). *Stanley Gardiner* declares about the upper of the said terraces "It is a structure found on nearly every reef". *Verstappen* (1962) speaks about a series of emerged reefs from Indonesia, but does not especially emphasize the 1,5 m level as the area is subject to heavy tectonic movements.

A. Guilcher (1952) has from an expedition to the Red Sea reported an erosion-level in cliffs with a double notch at exactly the same height and of the same character as in the Bismarck Archipelago. By the Red Sea double notches were observed already by *McFadyen* (1930). *Guilcher* gives a very careful analysis of the phenomenon and also mentions some of the here cited literature. A picture from Daressalam seem to show quite a similar phenomenon (shown in *André* 1908). According to *G. Schott* (1937) this is typical for the African coasts of the Indian Ocean. Informations from the tropical coasts of America are so scarce that it is not possible from these to draw conclusions.

Summing up, it seems to be stated from available sources that the majority of tropical coasts shows a rather uniform picture of double-notched cliffs and corresponding terraces not refound in some of the best investigated areas in the world; especially the

Dutch coasts and the coasts at the Mexican Golf must here be mentioned. *Fairbridge* (1961) compares the 1,5 m level to the "Dunkerquian" (Dunkirk I beds) of Flanders, citing *Tavernier* and *Moormann.*

Origin of double-notched cliffs

A conclusive explanation of the origin of the double notches cannot be given at present. A safe explanation will demand an answer to the following questions:

1. Are the two notches comprising the double one formed simultaneously or non-simultaneously?

If the upper notch is the elder, the next problem to be solved is:

2. Are the upper notches and corresponding levels of different regions formed simultaneously?

Untill a dating has been made for at large number of dispersed 1,5 m terrace localities, it can only be estimated which of the explanations briefly discussed below will be valid. It should here be noted, that unfortunately many difficulties arise from C_{14}-dating of coralline material; this seems to be almost impossible to use for a valid dating — and is the sort of material one usually must deal with investigating the not even biohermic but often even sedimental terraces. Erosional features like notches are of course still more difficult to date.

Simultaneous development of the twin-notches shall first be considered. *N. D. Newell* (1961) mentions that higher beach-lines in the Pacific can be related to wave-action during storms and tsunamis. A beach line formed during storms will, however, show a tendency to vary in height of level and in degree of development after exposure to storm waves. Beach-lines and notches seem generally not to be of varying height in the Bismarck Archipelago, where furthermore the development of the upper and lower notch is analogous to a remarkable degree. Development of the upper notch must have required a considerable time-especially as solution seems to be the major agent. It is worth noting that as a rule notches are developed in the same vertical plane, the upper notch without connection to a reef-flat. One cannot look aside from a possible relation of both notches to the same reef-flat. In consequence of this, an explanation referring to the seasonal change in predominant winds has been looked for by the present writer. From the eastern coast of Africa *G. Dietrich* (1957) has stated that a regular change of sea level oc-

curs as an effect of the seasonal winds — in the Somali-region setting up very strong surface-currents. However, it cannot from the available literature be seen, if this change bears any relationship to the present double notches. The careful analysis by *McFadyen* (1930) in the region around the entrance of the Red Sea discovered no connection between the phenomena. Our stay in the Bismarck Archipelago was too short for observing seasonal changes in the sea level. Local people from Mussau told us in the "North-Wester Season" that the upper notch was reached by the waves, when the Trades started blowing. Below that level was, however, important roads and populated villages indicating that such rises could at least not be of any length. Furthermore, generally a seasonal change in sea-level of a magnitude of 1,5 m cannot be expected at oceanic islands, where that level is reported quite common, too. Summing up, it seems not to be very probable that the upper level is as recent developed as the lower one.

Non-simultaneous origin, which is supported by the marked development of stalactites in the upper notch, will bring explanations concerning tectonic or eustatic movements into interest. As in fact the 1,5—2 m level is just a single one in a series of terraces, such explanations must be considered even more natural.

Both *Sapper* and *Panzer* regarded tectonic movements as the most plausible causes for the raised notches and other beach lines of the Bismarck Archipelago. This finds support in quite recent tectonic movements and active volcanism in the Archipelago. But here the difference between New Britain and small neighbouring islands and the rest of the Archipelago should be emphasized. While New Britain shows tectonic activity especially in the northern part, the other islands seem to be at rest. Maybe f.i. the low terraces around Kokopo described by *Panzer* (1933) are identical to the usual 1,5 m terraces, but for a recent dislocation. It should at least be noted, that the intricate system of landrising and -falling supposed by *Panzer* to explain the terraces of the Bismarck Archipelago probably can be considerably reduced, if not all movements are considered as being tectonic. At least the majority of faults in New Ireland does not disturb the alignment of the notches, even if the double-notched cliffs at some places can be followed for miles. The same seems to be the case of the other islands, which are not affected by active volcanism. The tectonic explanation has, however, the advantage of solving the problem of the many small notches involved in the two bigger ones.

If tectonic movements are responsible for the 1,5 m level, these must have comprised an enormous block, which should have omitted any tilting in the large area. This looks very strange as older beach lines in the territory indicate several differential movements.

Taking the occurrences of the 1,5 m level outside the Bismarck Archipelago into consideration, the question about the comparability of age and development arises. If the origin of all occurrences can be related to the same time, the origin must by definition be due to an eustatic movement.

Already 1887 *R. Langenbeck* wrote, after an examination of a large body of coral-reefs and -islands all showing a young raised beach line of small elevation: "Wir müssen daher für die jüngste geologische Vergangenheit ein Sinken des Meeresspiegel im Gebiet aller drei Ozeane annehmen." (quoted after *K. Andrè* (1920)). Especially in the last decade much attention has been drawn to these theories of eustasy (particularly the large-scale glacio-eustatic changes proposed by *R. A. Daly)*. *R. W. Fairbridge* (1961 a) has advocated at least two pronounced post-glacial maxima of sea-level: the Rottnest submergence (0,5 m stage dating to 1000 B.P.) and the Abrolhos submergence (1,5 m stage dating to 2300 B.P.). A difficulty arises from the reported almost exclusively tropical distribution of the said levels. *Fairbridge* (1961 b) citing *W. Munk* mentions that geoidal changes affecting near-equatorial sea-level must be considered. The geoidal change should be an effect of a change in the earth's rotational speed, this again being caused by a change in mass distribution when icecaps are subjects to major changes in volume. According to this hypothesis water-levels in polar regions should show transgression corresponding to equatorial regressions. This has at present still not been demonstrated to any extent.

Although the hypothesis of eustatic changes can explain the development of double notches of the Bismarck Archipelago, it shall be stated that this explanation of their origin until now is too poorly founded. Investigations of the total lenght of coastline in the Archipelago seem to be inevitable to arrive at final conclusions.

DANSK RESUMÉ

Klintekyster i Bismarck Archipelet udformet i hævet koralkalk fremviser sædvanligvis 3 morfologiske hovedelementer: 1) en foranliggende revflade, 2) en klintfod og 3) en hulkehl, der i regelen er dobbelt (fig. 1, 3 og 4).

Kanten af *revfladen* fremviser furer, der synes udformet ved erosion i forbindelse med korallernes vanskelighed ved genopvækst i skygge. Revfladens skrænt mod dybet er forbavsende stejl og de udenfor liggende dybder meget store (fig. 2). Revfladen selv viser meget få spor af koralvækst, men synes dannet ved erosion eller måske snarere ved opløsning. Dens niveau synes at være nøje knyttet til lavvandsstanden, idet dog den indre del, der ligger lidt dybere, er udformet som en svagt markeret »boat channel«.

Klintfoden viste en opdeling i zoner (fig. 4–6) svarende til den af *A. Guilcher* demonstrerede: nederst en rødalgeklædt stejlkant, derover en lille flade med ca. 10 cm dybe småbassiner. Mod kanten af revfladen er bassinerne ofte i forbindelse med hinanden, dannende indviklede kanaler. Bassinerne må formodes i hvert fald delvis at være dannet ved levende organismers virke, her bemærkes særlig den livlige virksomhed af snegle, som (i et antal af indtil 50 pr. m^2) raspede alger ud af deres smågruber i kalken. Hele klintens overflade viste huller af varierende størrelse af et udseende, som om de var frembragt ved syrestænk. Hullerne var særligt fremtrædende i den del af klinten, der vædedes af stænk fra bølgeslaget, og skyldes sikkert også biologisk opløsning.

Hulkehlen skyldes uden tvivl (som nævnt i litteraturen) i højere grad opløsende processer end egentlig abrasion. Ved Kalili er hulkehlen dobbelt. Kehlens dybde synes at variere noget med exponering for bølgeslag (fig. 7 og 8). Nærmere analyse af profilerne tyder på, at den øvre hulkehl måske består af to tætliggende, som oftest er sammensmeltede. Dobbeltkehle af type som ved Kalili, New Ireland, fandtes mange steder i Archipelet i omtrent tilsvarende udformning. Eksempler fra Dampit (fig. 7 og 9) og Mussau (fig. 10) viser dette. Fig. 12 viser en strandpille fra Anir, der også har en højere liggende kehl. I Bismarck Archipelet findes en lang række lokaliteter med terrasser, der i niveau svarer til kehlene. Disse kan undertiden med sikkerhed korreleres til kehle (Kalili fig. 11). I almindelighed lader det sig dog næppe gøre.

I litteraturen er omtalt flere lokaliteter med dobbeltkehle eller lokaliteter med gamle strandlinier i 0,5 og 1,5 m niveauet, svarende til de to kehle. Lokaliteter i Bismarck Archipelet er angivet på fig. 13. Strandlinier i det omtalte niveau synes almindelige på øerne i Stillehavet, ligesom de er konstateret langs den afrikanske østkyst – specielt i Rødehavet. Derimod synes de ikke at forekomme i Amerika (måske undtagen Bahamas), ligesom niveauet ikke kendes fra godt undersøgte kystområder i Europa. Forklaringen af niveauets tilstedeværelse må vente på en løsning af spørgsmål om: 1) de to kehles samtidige eller ikke samtidige dannelse og evt. 2) om de øvre kehle fra forskellige regioner er dannet samtidig, forudsat at øvre kehl er af ældre dato. Før datering af et stort antal kehle fra spredte lokaliteter kan en sikker løsning af problemet næppe gives.

Går man ud fra, at havniveauet har været som nu under den øvre kehls dannelse, kan den tilskrives tektoniske bevægelser. Dette er sandsynligt i det behandlede område, men støder dog på den vanskelighed, at de tektoniske bevægelser da må have været ensartede og have omfattet uhyre landmasser samtidigt. Muligheden for, at øvre kehl kunne være

dannet ved ekstraordinære højvande (evt. i forbindelse med de sæsonmæssige vindskifte) må sandsynligvis udelukkes, da vigtige veje og bebyggelser er anbragt i niveau under øvre kehl, og ingen udsagn om regelmæssige oversvømmelser af disse foreligger. Derefter synes det rimeligt at antage, at 1,5 m strandlinien er dannet ved en tidligere, højere vandstand. En sådan antagelse er fremsat af *R. W. Fairbridge*, først i 1947. Vanskelighederne ved den er, at det omtalte niveau ikke er sikkert dateret ret mange steder. (Fra Vestaustralien til 2300 før nu; et 0,5 m niveau, der falder sammen med nedre kehl, er dateret til ca. 1000 før nu). Dertil kommer, at de omtalte niveauer især synes at forekomme i en afstand fra ækvator på mindre end 20° (på grund af koralkysternes udbredelse?) Fairbridge antager, at de nævnte vandstandsændringer hidrører fra ændringer i Jordens geoideform, der må antages at variere med omdrejningshastigheden, som igen påvirkes af variationer i de polare iskapper.

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