The Lagoons of Nukuria and its Neighbour Atolls *

A Field Reconnaissance

By Sofus Christiansen

Abstract

The lagoon of Nukuria, an atoll east of the Bismarck Archipelago, was investigated in an attempt to find phenomena comparable to terraces previously observed in the archipelago. Specific levels were found to occur in echograms from Nukuria and its neighbour atolls Kilinailau, Taku and Nukumanu.

During the *Noona Dan expedition 1962* several traces of a relative movement of land/sea were observed in the Bismarck Archipelago. Very conspicuous was for instance a nearly ubiquitous notch in the coral-cliffs comparable to recent terraces in the 1,5 m (5 foot) level (*S. Christiansen* 1963). A series of higher as well as submerged terraces were furthermore observed. It was therefore natural that some interest developed in observations on the west-east line of atolls stretching more than 600 km from New Ireland towards the depths of the Pacific, atolls belonging to the Australian Territory of Papua and New Guinea (see fig. 1). The names of these atolls are often used in a confusing way, here the original local names will be consequently preferred. Thus Nukuria instead of Nuguria, Abgarris or Fead Group; Nukuria proposed by Prof. *S. H. Elbert* to be the proper spelling instead of the often used Nuguria. The names of the other atolls treated in this paper will then be Kilinailau (for Carteret), Taku** (for Tauu or Mortlock) and Nukumanu (for Tasman). A comparison between levels of phenomena like terraces could also be proposed to be of value in the determination of types of vertical movements in the region, interesting especially as the atolls are

*) Noona Dan Papers No. 12.

**) According to Prof. Elbert Takuu is more correct.

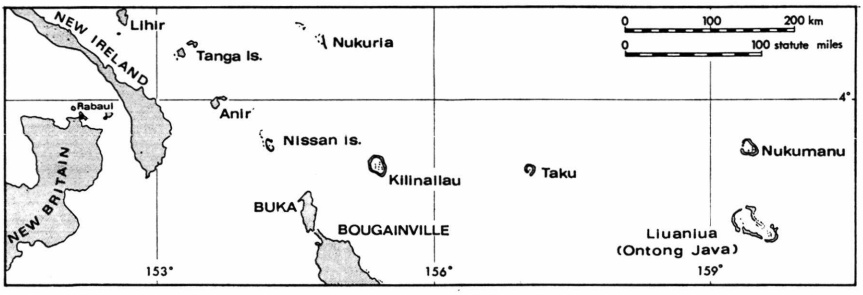

Fig. 1. Position of the four atolls, Nukuria, Kilinailau, Taku and Nukumanu. While Nissan is an elevated atoll, Lihir, Tanga and Anir are of volcanic origin.

Fig. 1. De fire atoller, Nukuria, Kilinailau, Taku og Nukumanu. Nissan er en hævet atoll, Lihir, Tanga og Anir er vulkanøer.

forming a line almost orthogonally to the Andesite-line, which separates the true oceanic from the continental type of ocean floor. It was decided to concentrate investigations to sounding of the lagoons. The regrettable short time available (9th–19th of May 1962) made, however, the sounded lines too few.

Methods of investigation

Soundings were all made by means of an Atlas Supergraph recording echosounder with a car-type battery as a power-source. The sounder was mounted on the ship's dinghy or on a hired outrigger canoe fitted with an outboard motor capable of giving a fairly constant speed. Between fixed landmarks – recognizable on aerial photographs – straight-lined courses were run. As variations in speed are inevitable, cross-bearings were taken underway as a means of controlling the larger deviations. (Methods were the same as used in Rennell Island, *S. Christiansen,* 1964). Of course determination of positions from land would have yielded a much higher accuracy, but such ones could not be accomplished. The crude method of fixing positions does not match the accuracy of depth determinations well, but as frequent soundings give a better impression of bottom topography these were not renounced from. Echograms from Kilinailau, Taku and Nukumanu were taken from the Noona Dan herself and kindly set at our disposal by the ship's captain *J. Narup.*

All echograms have since been corrected as to recognized variations in speed and redrawn in constant scale with a vertical exaggeration of 20 times. Recorded depths very rarely exceeded 60 m, therefore no corrections were applied as to variations in temperature/salinity. Corrections fell by far short of the accuracy of ½ m

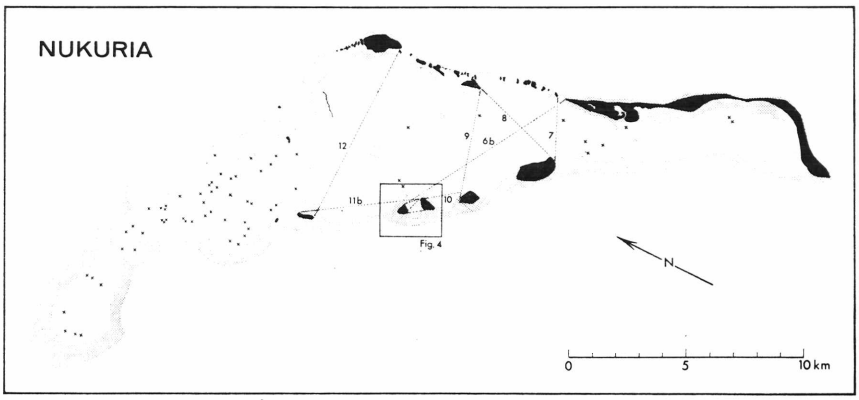

Fig. 2. Nukuria atoll (or Nukuria Central group. Further to the North Northern Nukuria or Malum group is found). Patch-reefs are marked with crosses.

Fig. 2. Nukuria atoll (eller Nukuria's hovedgruppe. Længere mod nord ligger Nordlige Nukuria eller Malumgruppen). Paddehatformede rev m. m. er markeret med kryds.

(1½ foot) aimed at in the soundings. To keep accuracy within this limit it was necessary to check the sounder before and after every half-day's cruise by comparison of recording to a known depth. Tidal variations were only slight being of the order of ⅓ m in the same time interval.

Basis-map for checking positions and comparing distances in Nukuria was derived from aerial photographs kindly delivered by Australian authorities. The map is shown in fig. 2. Its scale is approximate, derived from camera constant and flying altitude; time did not permit measurements of base-line and triangles. Maps from the three other atolls (fig. 5) are redrawn from small-scale official maps; they of course give only a crude impression of the island topography.

The Nukuria lagoon

It was necessary to concentrate on soundings of the central part of the Nukuria lagoon. The northern part seems, however, to be rather shallow and filled up with patch-reefs and coral-knolls (see fig. 2), whereas the southern part was said to show depths at about 10—15 m over sediment-covered bottom*). For an impression of distribution of lagoon depths we are forced to suffice with what can be obtained from sections 6b, 7, 8, 9 and 12, all from the central part (fig. 3). A section 13 was actually run, but depths were too

*) Much information on Nukuria was kindly contributed by its owner, Mr. Graham Carson, who generously assisted the expedition.

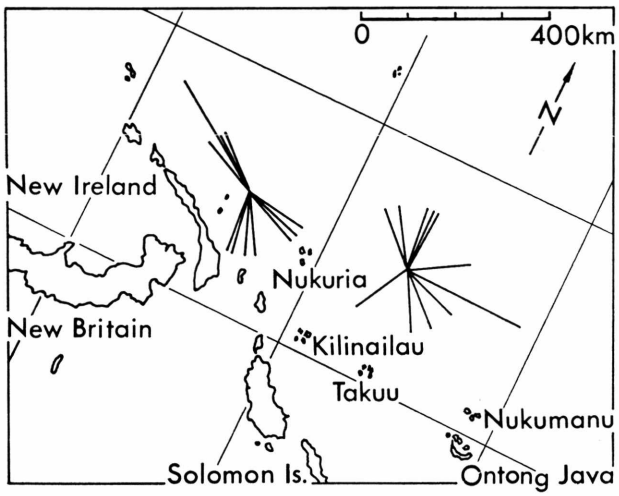

Fig. 2 a. Wind-regime in the area: prevailing wind pr. month is indicated by an arrow. Map is redrawn after *Wiens:* Atoll environment and ecology, and based on material from the Atlas of Climatic Charts of the Oceans, 1938.

Fig. 2 a. Retningen af den dominerende vind pr. måned efter retning. (Efter Wiens: *Atoll environment and ecology, baseret på materiale fra Atlas of Climatic Charts of the Ocean, 1938.*

faintly recorded, the battery being nearly exhausted. The scarcity and unequal distribution of information does not justify any statistical treatment of depth-recordings like for instance calculation of a "roughness-coefficient" (*Emery, Tracey and Ladd* 1949). Only a general interpretation of bottom-profiles may thus serve the purpose of finding signs of former stands of sea-level at the atoll coasts.

In fig. 3 some features usually found in atoll-lagoons are recognizable: 1) the eastern part shows to be fairly even, relative shallow, 2) the central part is still shallow, but has a more complex relief and 3) a jagged relief with deep-cut sections is found in the western part, where passages are present. It can be noted that the main profiles 6b, 9 and 12 all fit nicely into the said scheme. Their eastern parts all show very uniform depths of about 15 m, the western parts show depths exceeding 30 m. Profiles 7 and 8 are at variance with the proposed distribution of bottom-forms. In 7 the eastern part has the usual depth, but the western one is still shallower. Profile 8 shows depths in accordance with other profiles except for its eastern parts, of which the relief is very broken. Worth noticing is that in the profiles very jagged forms are found in the depth interval 15—20 m, but rarely in other intervals.

Profiles 10 and 11b (see fig. 3) depict depth variations along the

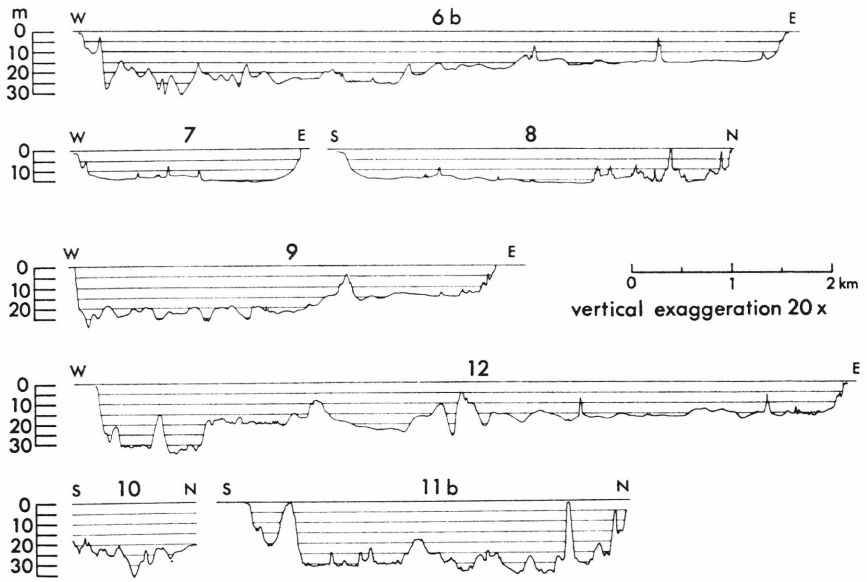

Fig. 3. Echo-sounded profiles from the lagoon of Nukuria. Vertical distance between lines = 5 m (15 ft.) For positions: see fig. 2.

Fig. 3. Ekkoloddede profiler fra Nukuria's lagune. Højdeforskellen mellem vandrette linier = 5 m. Profilernes placering fremgår af fig. 2.

inner side of the western atoll-rim. Depths usually vary in the range of 30—35 m, maxima found in interspaces between islands. Further details on bottom forms in an interisland passage can be found in fig. 4, profiles 1–6 and 11 a. Crosssection-area is nearly constant. Usually an outgoing current is met with in the passages, apparently depending on the magnitude of the breakers on the reefs.

To a modern concept of morphology all above mentioned lagoon-features must be understood in the light of the dynamic milieu. No doubt *Ph. Kuenen* (1950) is right in stating that the existence of an atoll must be conceived as being a sort of balance-act between destroying forces (foremost the surf, perpetually hammering the reefs, but also the act of solution from the waters) and the up-building of reefs by billions of tiny coral-polyps. In accordance with this a.o. *Emery, Tracey and Ladd* (1954) have shown how the distribution of many atoll-features are related to wind-regime: reefs, islands ("motu"s), grooves, passes etc. From the Nukuria area wind-data are very scarce. Fig. 2a shows duration of prevailing winds pr. month related to direction. It is easily seen that the landmasses of Nukuria are preponderantly found on the reefs facing the winds of longest endurance. Also the passes are found leewards with the

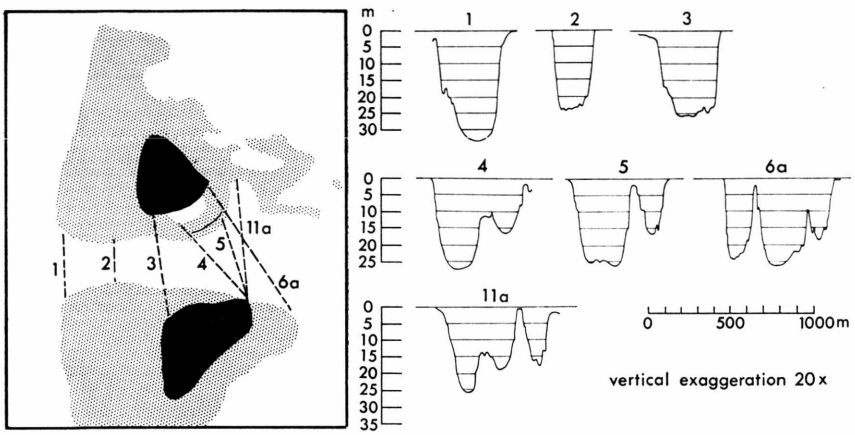

Fig. 4. Profiles of pass between the islands Ranau (in upper part of fig.) and Tehani (below) as seen from ingoing ship.

Fig. 4. Tværprofiler af passagen mellem øerne Ranau (øverst i fig.) og Tehani (nederst i fig.) som set fra indgående skib.

exception of one in the northern rim (of tectonic origin?). The "dynamic field", however, should also take distant storms into account, as these often rise a terrific swell capable of travelling hundreds of miles and releasing a considerable amount of energy on the reefs of Nukuria. The waves make the exposed reefs grow well, but tear again fragments off them, which are transported longshore. Part of the fragments is used to build up the islands. It looks like the initial islands (motus) can be equalled to the well-known off-shore bars familiar to coastal-researchers in all parts of the world. Such islands are usually further developed by addition of systems of recurved spits evt. combined with aeolic landform. Recurved spit-morphology can be recognized from fig. 2 especially conspicuous in the northern end of the main island, Nukuria. As demonstrated by *Wiens* (1962) also forms derived by storm-waves breaching through islands are usually found. The larger islands always show this tendency to break up in smaller, crescent-shaped ones. The breaches can usually be traced by their ensuing "tidal-fans", often quite regular half-cones protruding from the inner reef-edge into the quiet waters of the lagoon. Perhaps it should be doubted if the name "tidal-fans" is the appropriate one to these forms. On the reefs, often located windward to the island, are found parallel couples of narrow strips of dry land orientated orthogonally to the reef-edges. They closely remind of levées so well-known from fluvial morphology, and are probably developed in an analo-

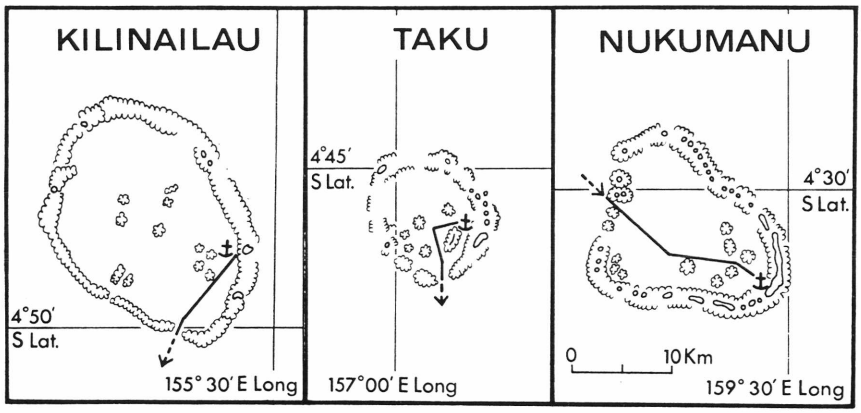

Fig. 5. Positions and sailed courses from the atolls Kilinailau, Taku and Nukumanu. Redrawn from official small-scale maps.

Fig. 5. Beliggenhed af øerne Kilinailau, Taku og Nukumanu med indtegnede kurser. Tegnet efter officielle kort i lille målestok.

gous way by the to-and-fro streams of water passing the reef. They deserve some mention because they apparently act like a sort of groins and thus play a part in development of new land. The lagoon has an effect like a sediment trap where not only the finer fragments of the reef-débris are sedimented, but where foremost remains of pelagic organisms form a large part of the bottom-sediment. Although no data may be given it cannot be doubted, however, that the rate of sedimentation is by far lower in the central part of the sheltered lagoon than in other parts, especially where little or none local coral-growth is found. It may be suggested that the bulk of the sediment-fill of sheltered parts of the lagoon was deposited when conditions of sedimentation were different from the present. If so, the level of the lagoon- bottom has relation to former relative stands of the sea, but it is difficult to know when such lagoon-areas were effectively barred off by the development of islands from receiving sediments from the reefs. This question cannot be answered at present, but it may be noticed that the interior parts of the island – showing signs of being consolidated – reach a level of abt. 1,5 m (5 ft), strikingly corresponding to the before mentioned leve lof notches cut in cliffs of the nearby islands. The 1,5 m level has been demonstrated by *R. W. Fairbridge* (1961) in the Abrolhos-islands. He postulates on their evidence combined with C_{14}-datings, that the 1,5 m terrace level is of quite recent origin and is caused by a subrecent sinking of oceanic sea-level. Supposing only slight vertical movements of Nukuria itself in recent times, the 15–20 m bottom

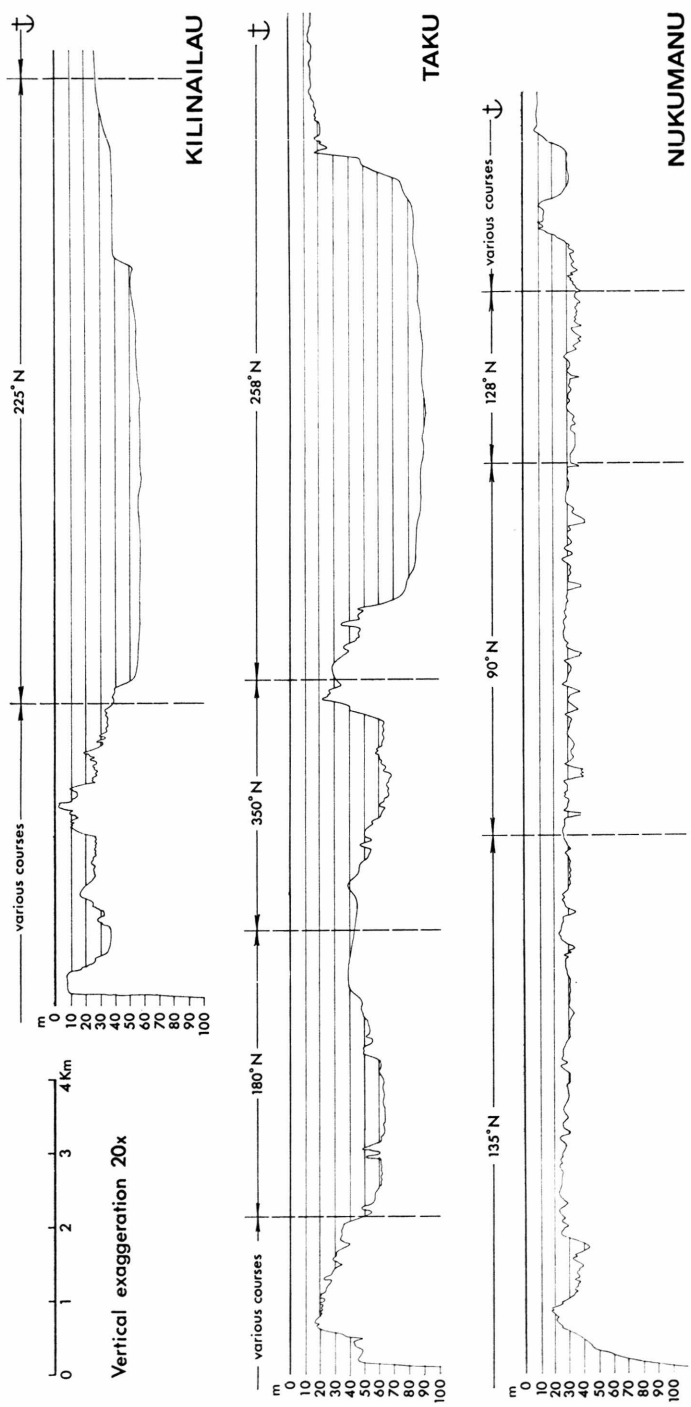

Fig. 6. Echosounded profiles from Kilinailau, Taku and Nukumanu.

Fig. 6. Ekkoloddede profiler fra Kilinailau, Taku og Nukumanu.

level of the southern and central lagoon must be related to a former lower sea-level. Be it as it may, but it is noteworthy that the "8–10 fathom terrace" has been found in many atolls (*Emery, Tracy and Ladd* 1954, *Wiens* 1962). If this line of thought is followed, the deeper level of 30–35 m of the Nukuria lagoon may also be taken as a former terrace-level. It is interesting in this context to note that large areas lying deeper than 30–35 m have an appearance like a "makatea" surface, a terrestric developed karst-surface. If it is so, the 30–35 m level was followed by an emergence. To determine this will, however, require detailed investigation.

The tides combined with water-masses spilled over the reefs by the almost perpetual breakers send a stream of water through the great openings in the reefs — the passes. Although such a constant supply tends to reinforce coral-growth, the passes are usually relatively constant features. *Ph. Kuenen* explains the origin of deep passes as placed where coral-growth has been hampered during the (latest) rise of sea-level. The maximum depths of passes are the indicators of the former level. In Nukuria the passes best suited for navigation (fig. 4) by sounding were found to reach a maximum depth of abt. 35 m, which corresponds to the deepest parts of the lagoon (fig. 3, profiles 10, 11 b and 12). Maybe this corresponds to the–40 m– level often found in soundings elsewhere in the area (see for instance *S. Christiansen*, 1964).

Comparison with neighbour atolls

The soundings of Kilinailau, Taku and Nukumanu were made during normal navigation, hence the shifting courses (see fig. 5). Only very cautious interpretation of these soundings is therefore permissible.

The first very striking impression of the profiles (fig. 6) is the lacking correlation between atoll-size and lagoon-depths, Taku, the smallest of the three, having the deepest lagoon. If lagoon-depths solely depended on modern dynamic conditions, such a correlation should be expected. *Wiens* (1963) finds thus from a large body of charts a certain correlation between maxima of lagoon-depths and atoll diameter. This does not exclude, however, that a further inspection of distribution of lagoon-depths can reveal a lot of "fossil" plateaus in many of them.

In Kilinailau the larger part of the lagoon-bottom lies in a depth of 50—60 m. To judge from echograms this bottom is covered by soft deposits. Another interesting feature is a steplike terrace be-

tween –30 and –40 m. Maybe it is important that much of the area above that level shows signs of being a "makatea"-surface – though such ones are very hard to discern from surfaces with actual coral-growth. The – 15 –20 m level of Nukuria is not or only to be found in a vague form.

Taku lagoon has a bottom plateau in depths around 90 m. Aside from this, distinctly discernible "terrace-levels" are absent exept for two: one in about – 40 – 50 m, which is especially sharp-cut in the outer part of the entrance to the atoll and repeated near the anchorage, and another one in – 15–20 m. In the atoll of Nuku-manu a lagoon bottom which is very like a "makatea"-surface was revealed by the sounding. This surface could have been developed at a relative sea-stand at abt. – 40 m. The – 15–20 m level is also marked especially in the entrance and near the anchorage.

If the presented material of the four atolls is compared, it is evident that common features exist. Although uncertain in Kilinailau, the presence of the – 15–20 m "terrace" seems to be over all. Below that another marked level is found in abt. – 40 m. Maybe the level at abt. – 50–60 m demonstrated by the main plain in Kilinailau lagoon is represented by the uneven plateau seen in the left half of the Taku-profile (fig. 6). Furthermore there are doubtful occurrences of two more levels in Taku namely one in – 75–80 m marked by a shelf encircling the deepest section of the lagoon and another one in a little over 90 m's depth formed by the central lagoon.

By the present state of knowledge it would be very uncautious to state a causal connection between terrace-levels of equal depth; this cannot be established before a dating of these phenomena has been carried out. The "terraces" are maybe developed individually from island to island, but they can also be the engraving of changing sea-level only slightly influenced by local vertical movements of the fundament of the islands.

DANSK RESUMÉ

På Noona Dan expeditionen 1962 observeredes der i Bismarck Arkipelet adskillige tegn på relative bevægelser af hav og land. Meget iøjnefaldende var således en hulkehl i klinter, svarende til terasser i 1,5 m højde (*S. Christiansen*, 1963). Også undersøiske terasser opdagedes, og det var derfor naturligt på et kort togt til atollerne Nukuria, Kilinailau, Taku og Nukumanu at prøve at undersøge, om atollernes laguner viste bundforhold svarende til sådanne terrasseudviklinger. En særlig interesse knyttede sig

til netop de nævnte atoller, fordi de fra New Ireland ligger i en linie næsten vinkelret på Andesitlinien, der adskiller egentlig oceaniske fra kontinentale jordskorpetyper.

Undersøgelsesmetoden var den samme som ved undersøgelsen af Tegano, Rennell Island (se Geografisk Tidsskrift 1964, 1. bd.). Ekkogrammerne korrigeredes på samme måde. Det må nævnes, at profilerne fig. 6 er opmålt af Noona Dan, hvis mandskab ydede enhver tænkelig hjælp ved undersøgelserne. For Nukuria's vedkommende leverede australske myndigheder luftfotos til udarbejdelsen af et basiskort. Kortene over de øvrige atoller er omtegnet efter officielle kort i lille målestok.

Nukuria's lagune er for den nordlige dels vedkommende opfyldt med paddehatformede koraldannelser (fig. 2) og er ligesom den sydlige del ret lavvandet (i syd ca. 15 m). Fig. 3 viser (profiler 6b, 7, 8, 9 og 12) forholdene i den centrale del. Det ses, at den østlige del af profilerne har jævn bund i ret ringe dybde. Midterpartiet er ret ujævnt, men stadig lavvandet, mens den vestlige del er dyb og med sønderskåret relief. Profilerne 7 og 8 afviger lidt fra denne beskrivelse. I profil 7 har den østlige del den sædvanlige dybe på ca. 15 m, men den vestlige er mere lavvandet. Den østlige del af profil 8 afviger ved at være mere urolig end sædvanligt. Vestsiden af lagunen viser ofte dybder på omkr. 35 m, dybest ud for mellemrummene mellem øerne (profiler 10 og 11b, fig. 4). Tværsnit gennem en passage er vist i fig. 4, profiler 1–6a samt 11a. Passagen, der har temmelig ensartet tværsnit, har tit stærk strøm, oftest udadgående, afhængig især af brændingens styrke.

Der er næppe tvivl om, at den antagelse er holdbar, som *Emery, Tracey and Ladd* (1948) og andre har fremsat, og efter hvilken et overvejende antal af en atolls former må ses i lyset af de øjeblikkeligt virkende kræfter. Også Nukuria synes at bekræfte dette. Af fig. 2 ses således, at revenes øer synes at være at finde på de stærkest vindpåvirkede kyster, mens passagerne med en enkelt (tektonisk betinget?) undtagelse er at finde på læsiderne. Endvidere viser atolløer (motus) sig ofte at være formet som barreøer, hvis tilvækst sker ved krumoddedannelse (se således Nukuria's hovedøs nordlige del). På revene ses iøvrigt ofte ud for øerne nogle interessante levée-lignende dannelser, der ofte er koloniseret af plantevækst. Disse virker muligvis som høfder og tjener derved til opbygning af atoll-land.

Mellem øerne findes ofte »tidal-fans«, aflejringskegler af materiale fra gennembrud gennem øer. (I de større øer findes på samme måde former, der ligner de fra Danmark velkendte havrendinger). Lagunebundens udvikling er således afhængig af adgangen for sedimenttransport tværs over revene. På denne baggrund er den næsten konstante dybde i den østlige del af lagunen, hvor denne er afskærmet ved øer, ret bemærkelsesværdig. Tilstedeværelsen af denne 15–20 m terrasse ("10-fathom terrace") kan måske tages som udtryk for en tidligere, relativt lavere beliggende kystlinie på atollen. På samme måde er det muligt, at øernes indre, med deres undertiden fastcementerede materiale ofte dannende en flade i ca. 1,5 m højde (svarende til observerede strandlinier i Bismarck Arkipelet), repræsenterer et andet relativt havniveua, senere end lagunens terrassebund. Den ujævne flade i lagunens vestlige del er måske

ligeledes udviklet ved en anden lavere vandstand. Dersom den "makatea"-agtige flade over –40 m niveauet virkelig er terrestrisk udviklet karst, må det antages, at –40 m vandstanden har efterfulgt en periode med tørt land, ældre end –15–20 m vandstanden. Observationerne er dog endnu for usikre til, at man kan sige noget sådant med sikkerhed, men meget tyder på, at de nævnte forhold i hvert fald er udbredte i store dele af Stillehavet. Især mangler en datering af forholdene, medmindre niveau-korrelationen til *Fairbridge's* (1961) undersøgelsesområde er holdbar, hvad man dog ikke umiddelbart kan antage.

En sammenligning med naboatollerne Kilinailau, Taku og Nukumanu er vanskelig på det foreliggende materiale (se fig. 5 og 6). Det er iøjnefaldende, at der ikke synes at være nogen korrelation mellem atollstørrelse og lagunedybde (som nogle forfattere har antaget). Lagunernes udformning synes i højere grad at have en "fossil" end en recent udformning.

Kilinailau's lagune synes at vise to veludformede »terasse-niveauer«, et i –50–60 m og et andet i –30–40 m. I –15–20 m niveauet konstateredes ingen terrasseudvikling som på Nukuria. Taku's lagune har et bundplateau i omkring 90 m's dybde, derudover findes ét i –40–50 m (særlig tydeligt ved indsejlingen og lige ved ankerpladsen) samt den sædvanlige –15–20 terrasse.

Nukumanu's bund ligner en "makatea"flade. Den kan være udviklet ved den vandstand på ca. –40 m, som også er markeret. En sådan storflades udvikling må evt. ses på baggrund af Nukumanu's størrelse. –15–20 m terrassen findes også tydeligt markeret.

På grundlag af den nuværende viden er det endnu ikke muligt at give en blot nogenlunde sikker forklaring på de her omtalte atollers udformning. »Terrasserne« kan være træk, der er udviklet individuelt fra ø til ø ved tektoniske bevægelser eller ved svingninger i havspejlet. Det foreliggende materiale ser dog nærmest ud til at tyde på, at små vertikalbevægelser er foregået samtidig med havspejlsvingninger.

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