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GEOMORPHOLOGY AND CRUSTAL MOVEMENTS OF THE ARU ISLANDS IN RELATION TO THE PLEISTOCENE DRAINAGE OF THE SAHUL SHELF

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ABSTRACT. The Aru Islands form an oblong geanticlinal upwarp of the Sahul shelf to the west-northwest of Australia. Many contradictory opinions have been expressed so far concerning their lithological structure and their recent tectonics. The author's conclusions —based on field observations and on a study of photogrammetric maps—are preceded by a discussion of the work of former investigators.

Geomorphologically the archipelago is a low plateau with slight undulations. Structural terraces are common and have been wrongly attributed to Recent uplifting by several authors. Sunken coast lines and drowned abrasion platforms indicate subsidence of the outer zones in Recent times.

The most remarkable geomorphic phenomena of the group, i.e. the channels or "sungi" between the islands, are explained as a result of a pattern of diagonal shear joints. The youthful appearance of part of these joints points to a continued warping of the Aru rise in sub-Recent or even Recent times. Neither the channels nor the submarine relief of the Sahul shelf have any connection with the Pleistocene courses of New Guinea rivers, as has often been suggested.

The Aru Islands, situated in the eastern part of Indonesia, are located on the Sahul shelf near the Australian continental margin (fig. 1). Thus to the east of the group the sea floor does not exceed 20 meters, whereas approximately 30 kilometers to the west the depth suddenly increases, and it reaches 3650 meters in the central parts of the Aru basin. The islands form part of a gentle, east-west running submarine ridge, the continuation of the so-called Oriomo axis (Carey, 1938) of eastern New Guinea and the Merauke Ridge (Van Bemmelen, 1949) of western New Guinea. Roughly speaking the Aru group has the shape of a huge ellipse, the longer axis having an azimuth of approximately 0-10° and being about twice the shorter axis. H. A. Brouwer (1925) maintains that the Banda orogene influenced the neighboring shelf and thus caused the Aru rise. This explains, according to this author, why the axis is more or less parallel to the nearest island of the Banda outer arc, Key Major. The whole 8600 sq.km of the archipelago is a low plateau, with slight local undulations. The maximum height is about 240 meters, but the bulk of the region is much lower.

The islands are built up of Neogene and Quaternary marls, soft limestones and sandstones (Gregory, 1924). The beds are subhorizontal throughout the group, and only locally a few gentle dips are observed. Ph. H. Kuenen (1933) measured gentle westward dips at the west coast between the Manumbai and Workai channels, whereas R. Tayama (1936) mentions a northwestward dip of the island of Wamar in the northwestern part of the archipelago. Thus a geanticlinal uparching is suggested. The author's observations of southwestward dips near Cape Lelar in the extreme south western part of the group agree with this, although the gentle dips measured in the row of islands to the east of the Aru "mainland" point to a somewhat more complicated development there, i.e. a slight folding.

The sediments mentioned above form only a thin cover, and the basement rocks must be present at shallow depth, as appears from the occurrence

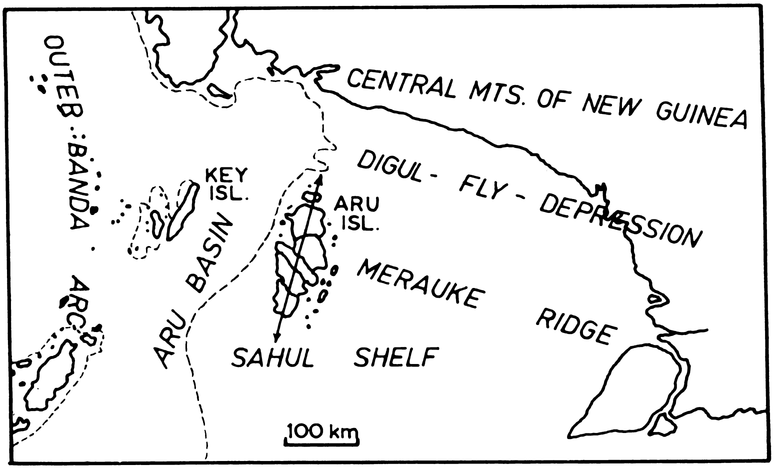


Fig. 1. Location map of the Aru islands showing the main geotectonic regions. The Australian continental margin is indicated by the 200 meters depth contour.

of coarse terrigenous minerals (quartz, feldspar, mica. etc.) (Fairbridge, 1951). Tissot van Patot (1908) observed an outcrop which he thought was probably granite, near the village of Sia in the southeast part of the group. This was not confirmed by A. Heim (van Bemmelen, 1949) nor by the present author who visited the spot at the end of 1956.

R. D. M. Verbeek (1908) considered the Aru Islands to be a raised coral reef, but this opinion is not in accordance with the present geological knowledge. Tayama, on the strength of a few coral remains found on the island of Wamar, still maintains that the archipelago is a raised plateau reef, but this evidence appears rather insufficient for such a conclusion.

The abundance of living reef has been mentioned as an argument in favor of the raised reef hypothesis. This theory being abandoned, Kuenen looked for an explanation of the lack of raised reefs in this uparched region surrounded by flourishing living reefs. He visited 60 kilometers of the west coast and found that the reef is not as abundant as usually assumed. A vast reef flat, 15-40 kilometers wide, is indicated, however, on the charts of the east coast and is also mentioned by Sperling (1936) and van Bemmelen. Kuenen therefore supposes that the islands have risen above the shelf during the Pleistocene regression or that the subsoil was unsuitable for coral growth. Fairbridge holds similar views, stating, on zoogeographical evidence, that the islands had not subsided after the Pleistocene and thus got no reef cap. Field observations of the present author on the shallow platform to the east of the Aru Islands revealed the interesting fact that marls, similar to those occurring on the islands, are predominant. Locally some scattered coral polyps are found, but shell accumulations—mostly oysters—are far more common. Thus the conditions for coral upgrowth nowadays seem to be as unfavorable as they were in the earlier stages of the uparching of the Aru Islands. The soft marls apparently are not a suitable environment for the polyps.

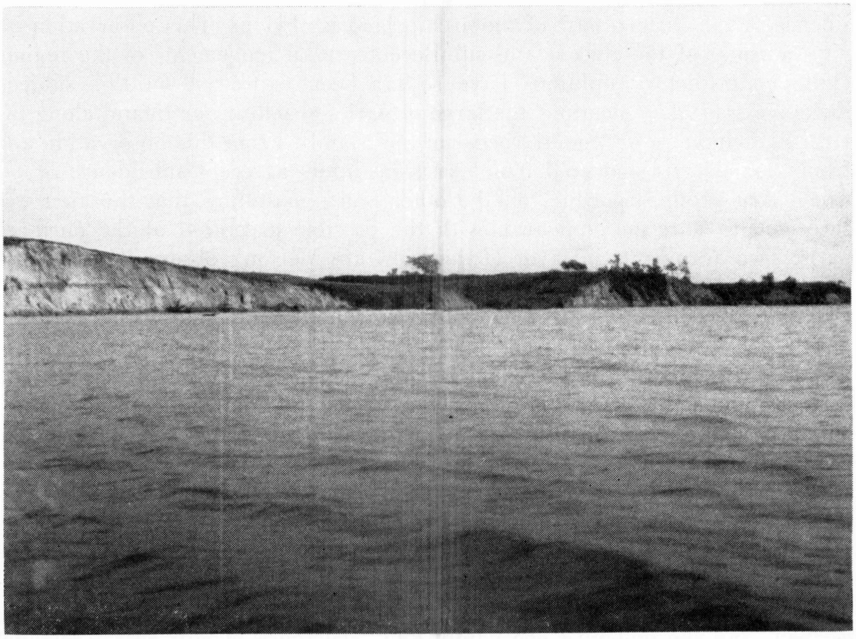
The flats can only be considered as an abrasion platform, and because the seaward parts now are situated several meters below mean sea level, recent subsidence of the eastern part of the archipelago is obvious. This observation invites a study of the Recent and sub-Recent crustal movements of the region. Quite contradictory opinions have so far been expressed on this subject. Zwierzycki (1927) mentions the large estuaries reaching far inland along the river-like channels or "sungi" between the islands. From this observation and from the mangrove-covered mud coasts he infers a recent subsidence of the whole Aru group. Sperling, on the other hand, maintains that the area was subjected to a recent upheaval, with the possible exception of the northern parts. Two arguments in favor of this view are Merton's observations (1910) of raised coast lines and notches in the interior of the islands and Tissot van Patot's observations of raised coast lines and notches on southwestern Terangan. Field observations showed, however, that these phenomena are the result of minor lithological differences of the subhorizontal beds and thus do not suggest regional uplift. In areas of dipping strata, the "notches" are also tilted. The very active recession of these small cliffs is another indication that selective erosion instead of wave action is their cause.

Fairbridge suggests an eastward tilt of the archipelago because of the predominance of mangrove swamps, isolated islands, etc., in the east, and the occurrence of low cliffs along the west coast. Subsidence of the east coast is evident from the features just described, but uplift of the west coast is less obvious and is in contradiction with both the westward dip of even the youngest beds and the embayed coast line. The occurrence of cliff coasts does not necessarily indicate emergence. On the contrary, subsidence will usually result in cliff coasts, whereas coastal plains are formed along emerging coasts. The red cliffs of the southeast coast of the island of Terangan are a good example of a subsiding coast that quickly reached old age in the feebly resistant rock (pl. 1). The differences between the east and the west coast are easily accounted for by the asymmetry of the geanticlinal upwarp. This asymmetry is also reflected in the relief, the greatest heights being observed near the west coast whereas the eastern part is a low plateau region.

A study of the numerous joints occurring on the islands enabled the author to conclude that the warping of the Aru rise continued to sub-Recent or even Recent times, thus resulting in a sinking of the coastal areas and possibly in a minor rise of the interior. To explain this the drainage pattern of the archipelago needs some further consideration.

The occurrence of a number of river-like channels running across the group and dividing it into islands is beyond doubt the most remarkable geomorphic phenomenon of the Aru Islands. Numerous branch channels are also encountered. There are several theories concerning the genesis of these channels. Wallace (1857, 1869) tried to explain them as the remainders of the Pleistocene lower courses of New Guinea rivers preserved here by subsequent uparching of the Aru region, whereas elsewhere the river courses gradually disappeared during the transgression of the shelf associated with the postglacial rise in sea level. Van Hoëvell (1890) discarded this river hypothesis because of the very irregular cross and longitudinal profiles of the "sungi". The great depth of the channels—locally even deeper than the surrrounding shelf—*is an-*

PLATE 1



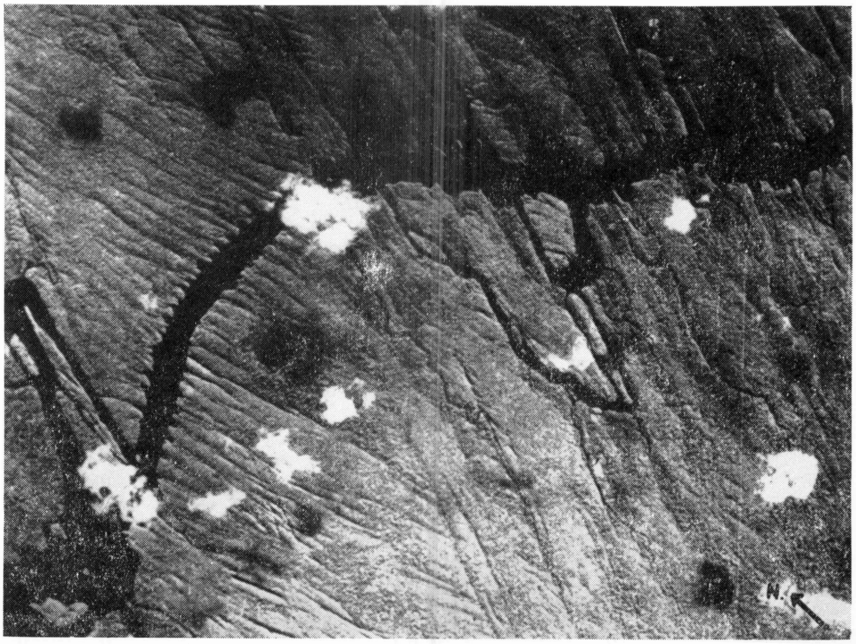
Cliffs on the old shore line of submergence in the SE part of the Aru islands (Terangan Island).

other argument. He maintains that faults resulting from the uplift of the area are the cause of the pattern of channels. Verbeek and Brouwer share this opinion.

Fairbridge, using air photographs, considers that jointing had some influence but, on the whole, he adheres to a modified river hypothesis. He maintains that the Merauke Ridge acted as a divide of the Pleistocene Sahul shelf and prevented the New Guinea rivers from flowing across the Aru region. Thus he supposes that comparatively short rivers, having their sources slightly east of the present archipelago, are the cause of the "sungi". Yet another view was expressed by Ribbe (1888), Tissot van Patot and Tayama, who suggested a submarine origin of the "sungi", i.e. as channels in the living reef, modified by the tidal currents. Sperling rejects this theory because the Aru Islands remained above sea level after the Pleistocene epoch; otherwise the faunal relationships are incomprehensible. This author, in fact, is not satisfied with any of the theories, but stresses the importance of tidal currents and further mentions depression zones as a primary cause, but without attempt at proof.

A series of Japanese photogrammetric war-time maps throws new light on the question. It reveals an abundance of criss-cross joints resulting in an angular pattern of the "sungi", narrow swamps, etc. It appears that the location and direction of the branch channels are fully imposed by these joints. The same can be ascertained for the greater portion of the main "sungi", the remaining part being uncertain due to changes and enlargements by tidal currents and

PLATE 2



Aerial view of the drainage pattern along the Maikur channel, showing strong influence of jointing. Scale 1:40,000.

solution. Beyond doubt the drainage pattern is the direct result of jointing (pl. 2).

A study of the frequency distribution of joint directions yielded results that give further insight into the crustal movements of the area. The azimuth and the length of every rectilinear drainage element was measured on the eight sheets of the 1:100,000 photogrammetric map. The azimuths were grouped together per 5°, whereas the lengths were indicated in map centimeters which equal kilometers in the field. In total, 527 directions were measured amounting to 2086 kilometers joint length. There are no photogrammetric maps of the southern extremity of the archipelago, so this area has not been considered. The data are given in table 1.

It would have been preferable to carry out the measurements on the air photographs. Unfortunately, however, the Japanese vertical air photographs were not at our disposal, whereas the available trimetrogon war photos are not suitable for our purpose due to their low quality and incomplete coverage. Measurement in the field of such a large number of joint directions and lengths would have been impossible because of the dense vegetation, the mangrove swamps bordering the coasts, etc. Thus only the possibility of map measurements remained, with the inevitable consequence that a certain number of rectilinear drainage features will be wrongly interpreted as joints and thus be included in the measurements. This is not a serious handicap, however, because their distribution will be at random and will not influence, therefore, the out-

TABLE 1

Frequency Distribution of the Joints per Map Sheet
(The lengths are indicated in map centimeters whereas the azimuths are grouped per 5 degrees).

Mapsheet	I	II	III	IV	V	VI	VII	VIII	I/VIII
Azimuth									
05	6	0	3	4	0	0	1	0	14
10	0	1	2	3	1	0	5	10	22
15	0	9	0	12	1	0	6	5	33
20	4	34	11	0	13	5	2	9	78
25	2	59	1	5	11	4	143	27	252
30	11	4	19	41	35	4	22	0	136
35	2	15	29	76	3	3	8	7	143
40	13	23	17	19	32	3	40	4	151
45	7	12	9	75	45	15	38	0	201
50	9	0	6	8	21	0	0	0	44
55	0	10	21	15	16	0	0	0	62
60	0	3	16	0	3	9	4	0	35
65	13	0	7	15	0	0	0	0	35
70	7	0	0	4	6	0	0	0	17
75	0	0	0	0	0	0	0	0	0
80	2	4	0	0	0	0	0	0	6
85	0	0	0	0	0	0	0	0	0
90	0	0	0	4	0	0	0	0	4
95	0	6	6	0	0	0	2	0	14
100	0	0	2	0	0	0	0	0	2
105	0	3	0	0	2	0	0	0	5
110	0	0	1	0	0	0	0	0	1
115	2	0	7	0	0	0	0	0	9
120	7	22	7	3	0	3	0	0	49
125	4	5	4	10	1	0	0	0	24
130	2	21	19	13	6	4	0	0	65
135	2	21	5	4	3	0	12	0	47
140	6	4	10	10	9	7	0	3	49
145	0	12	15	23	31	11	8	3	103
150	5	36	13	18	48	2	8	13	143
155	17	10	12	40	14	0	7	4	104
160	0	20	8	12	4	4	23	16	87
165	5	0	6	0	13	0	33	0	57
170	13	0	2	9	0	1	0	0	25
175	0	0	0	10	0	2	0	1	13
180	5	2	13	16	13	7	0	0	56
Total length	144	336	278	449	331	81	365	102	2086

come of the joint study. It is likely that a few pseudo-joints will be measured in every direction and thus the minima will be less pronounced. The maxima also will be broader and flatter. To eliminate the influence of meaningless local irregularities and to abstract only the general picture, the running averages were computed for every five 5°-group; this smoothing was carried out twice.

The results per map sheet are indicated by the 8 graphs of figure 2. Because the number of joints varies widely for the several map sheets, these 8 graphs were all reduced to the same superficies in order to make them more easily compared.

Finally the measurements for the whole archipelago were used to construct the strike frequency diagram of figure 3 (frequency is measured in map centi-

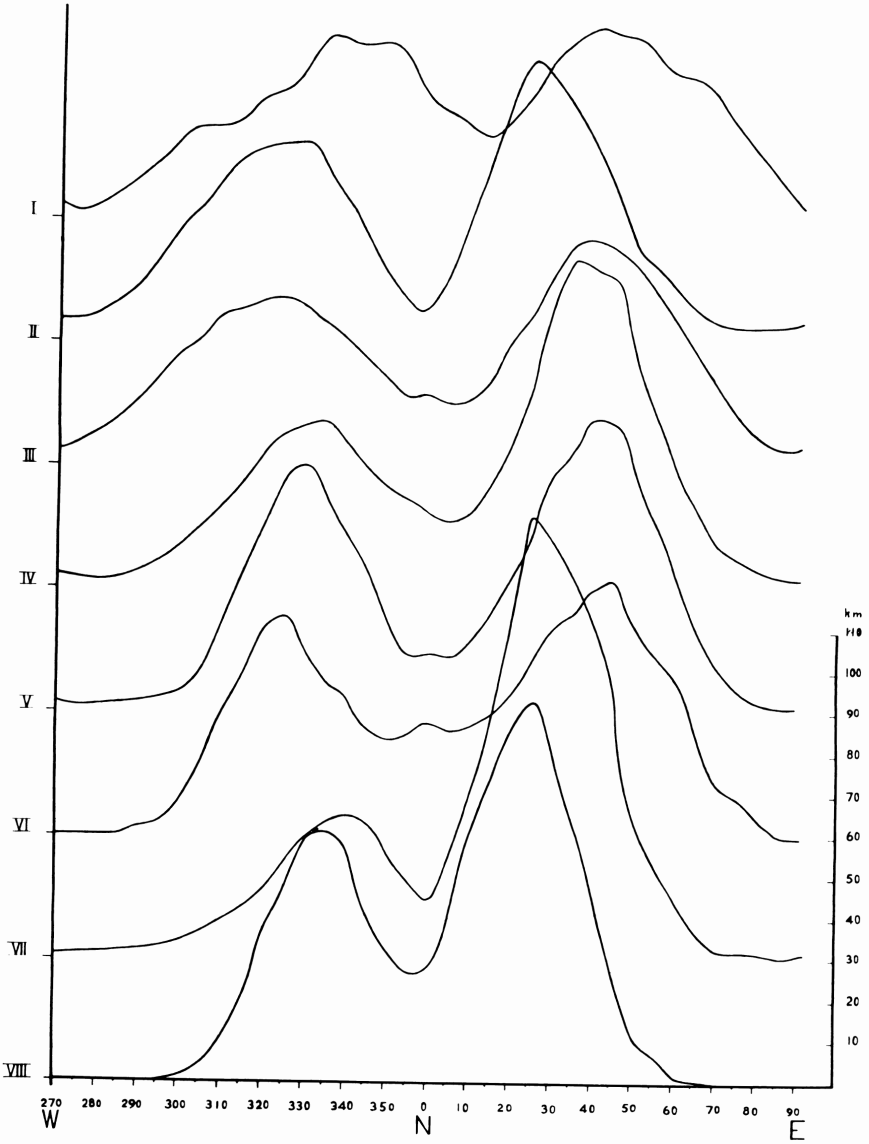


Fig. 2. Doubly smoothed graphs of the joint frequency of the Aru islands, for every map sheet. For location of the map sheets see fig. 4.

meters, not numbers of joints). The double smoothing is indicated around the diagram and pointing inward. It is evident that the maxima and minima of the direct observations are not shifted in the double smoothing, but that the whole curve is flattened out whereas secondary maxima and minima have disappeared. The number of observations was considered insufficient to allow for the construction of such a strike frequency diagram for every map sheet, but the doubly smoothed graphs of figure 2 nevertheless enable a fairly accurate determination of the predominant joint directions.

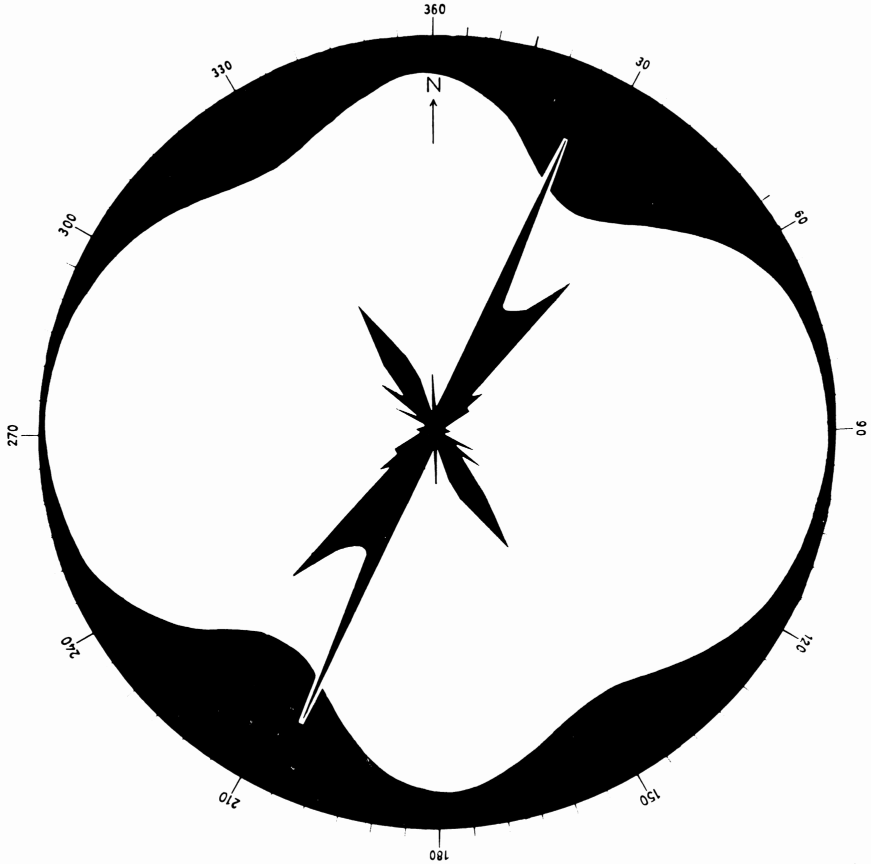


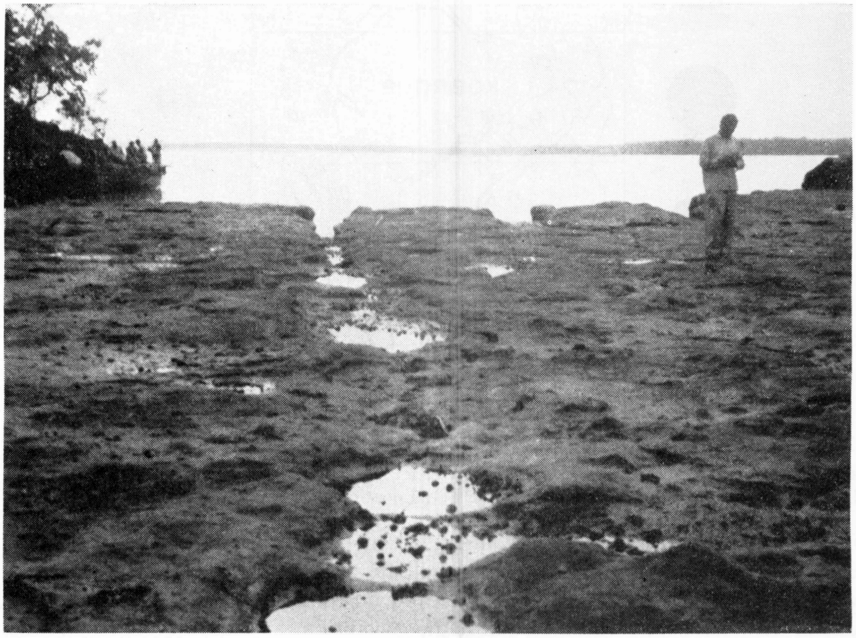
Fig. 3. Joint frequency diagram of the Aru group. The joint system is symmetric with respect to the longer axis of the archipelago, which runs approx. N-S.

As is clearly shown by the graphs, there exists a system of two diagonal joint directions making an acute angle (approx. 65°) in the north and south, and being symmetrical with respect to the axis of the islands. The northeast-southwest joints are more frequent than the other predominant direction. In between these maxima the number of joints decreases to very low values, and from this it follows that only a very limited amount of the measured drainage features has no relation to jointing and therefore should not have been included. The results thus seem to be fairly reliable.

Further consideration of the graphs reveals a number of local differences. The location of the maxima and minima is not exactly the same on all eight map sheets. The symmetry with regard to the axis of the archipelago remains, the only change being in the acute angle between the predominant directions. Especially on the northern and southern map sheets this angle becomes more acute. The minimum in between also underwent minor changes with the general tendency of being slightly shifted westward in the western part of the group and eastward in the eastern part. Sometimes an unimportant small maximum occurs in the direction of the axis. The explanation of these minor irregularities is hard to give, but certainly they result from local causes.

As a whole the phenomena observed strongly resemble a pattern of shear joints on a geanticlinal upwarp. The youthful appearance of a large number of the joints points to their rather recent formation, in view of the quick solution of the marls. It therefore seems clear that the warping continued until recently or is even still active. Plate 3 depicts a minor joint. As stated earlier, these tectonic movements resulted in a subsidence of the coast line and possibly in a minor uplift in the interior.

PLATE 3



Bowl-shaped solution features along a minor joint in the Aru islands.

The number of joints varies widely for the individual map sheets. Even if we allow for the different percentages of the areas covered by sea, sheet 1 in the northwest portion of the group contains more than five times as many kilometers joint length as sheet 6. The northern extremity is by far the most disrupted part of the Aru group, and the southeast part is the least (fig. 4).

Doubtless these differences are caused by variations in the lime content of the sediments. There is less jointing in the sandy southeast part, especially the island of Terangan. Moreover, joints once formed, will develop less quickly because of the lower rate of solution due to the lesser lime content. The relation between the number of joints and the lime content is only a qualitative one. In the areas of high lime content, channels will develop easiest, and because of their surroundings, solution will be most advanced and more joints will be visible there. Thus the picture induced by the differences in lime content is strongly exaggerated by subsequent solution, and the number of joints therefore bears no quantitative relation to the percentage of lime.

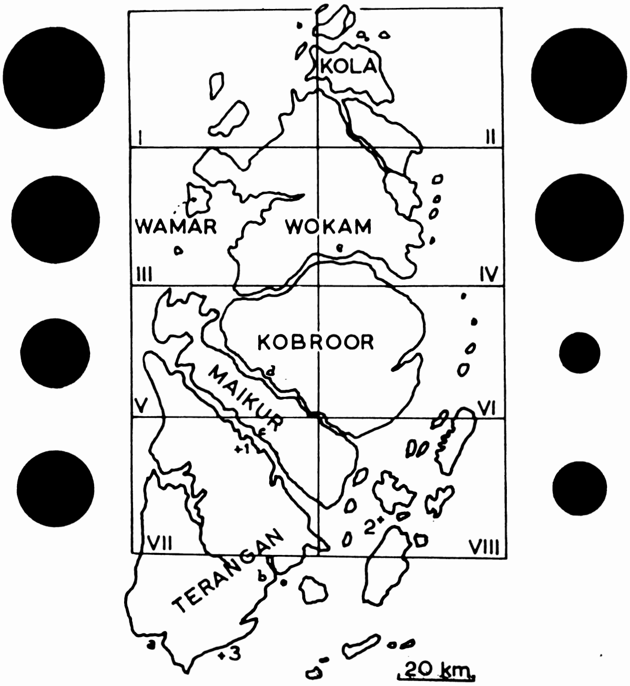


Fig. 4. Map indicating the number of joints for every map sheet. The sandy SE area is the least disrupted part of the islands. Key: a. Cape Lelar; b. Sia; c. Maikur Channel; d. Workai channel; e. Manumbai channel. 1-3: Location of the photographs.

After this explanation of the channel pattern as imposed by a joint system, invoked by uparching, the Pleistocene drainage pattern of the Sahul shelf deserves some further consideration. Fairbridge rejects Wallace's theory and maintains that the Merauke Ridge already existed in Pleistocene times. Thus the New Guinea rivers at that time were forced to flow westward in the Digul-Fly depression. The rivers now debouching to the east of Frederik Hendrik Island took in the Pleistocene a course to the south of the Aru group.

The Digul-Fly depression is still subsiding, as indicated by the well-known drowned forests of southern New Guinea. Though this zone existed already in the Pleistocene, there is no definite proof that it formed, topographically, a depression. This, of course, depends on the equilibrium at the time, between subsidence and sedimentation. Zoogeographic evidence points to the existence of the Merauke Ridge at the time of the postglacial transgression of the Sahul shelf, but its presence during the older Pleistocene is uncertain. Fairbridge's view, however, is supported by recent echo soundings. Though the number of soundings is not yet sufficient to allow for the construction of the Pleistocene drainage pattern, it is clear from the northwest-southeast directed sections that no former river valleys cross the Merauke ridge.

The sudden increase in depth recorded off the south coast of New Guinea shows that the recent sedimentation of the New Guinea rivers is restricted to a narrow zone along the coast and thus the Pleistocene river courses in the Digul-Fly depression will still be discernable, provided that a sufficient number of soundings is available. The edge of the continental shelf to the north of the Aru Islands appears to be rather irregular. A submarine ridge, running from east to west, occurs between two deeper belts, the latter probably being two Pleistocene river courses. The southernmost submarine valley can be traced as a valley, 100 meters deep and running north-northeast as far as approximately 25 kilometers northeast of the Aru group.

On the whole not much remains of Wallace's river theory on the peculiar "sungi" of the Aru Islands. There is no reason to assume the existence of short east-west directed Pleistocene rivers either. If rivers ever have occupied the main "sungi", it was only an incidental result of the solution along the joints, and they were not the cause of the channels. The geomorphology of the islands, especially the coastal development and the drainage pattern, is strongly influenced by young crustal movements, i.e. a continued warping of the Aru rise.

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