TOPOGRAPHIC LINEAMENTS IN NUSA BARUNG, EAST JAVA.

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ICHTISAR

Pengukuran kelurusan-kelurusan (lineaments) topografi pada karst batugamping di Nusa Barung menghasilkan tiga buah maksimum, jaitu jang terarah ke N 5°-10° E, N 35°-40° E dan N 335°-340° E. Kelurusan-kelurusan topografi itu dipengaruhi oleh rekah-rekah/sesar-sesar. Penjebaran dari maksimum-maksimum mengesankan bahwa rekah-rekah disebabkan oleh tekanan jang terarah N 10° E — S 10° W. Rekah-rekah jang sama arahnja dengan tekanan adalah rekah-rekah tarikan (extension fractures); jang membuat sudut 25° dengan arah tekanan adalah "shear fractures". Tekanan itu tidak menghasilkan perlipatan tetapi memiringkan seluruh Nusa Barung ke selatan sebesar 2°. Hal itu sesuai dengan posisi pulau tersebut pada sajap selatan Geantiklin Djawa.

INTRODUCTION

Several geomorphologists have noted in karst regions the linear arrangement of hills and depressions. Flint *et al.* (953) mentioned limestone walls in Okinawa. Meyerhoff (1938) and Kaye (1957) described rectilinear, topographic alignments in the limestone of Puerto Rico. Pannekoek (1948 *a* & *b*) pointed to the alignments in the limestone of Ajamaru in Irian (New Guinea); in the Karangbolong Mountains and Gunung Sewu, both in Java. These lineaments are all attributed to joints in the rock.

The typical planar as well as panoramic outlook of conical karst regions, i.e. consisting of cones of limestone, has invited several theories concerning their formation. Grund (1914) starts with a limestone plateau on which are isolated depressions (sinkholes); subsequent widening by solution results in the coalescence of these round depressions leaving hills with angular outlines, which also become rounded afterwards. According to this theory any linear arrangement in the topography is due to a casually statistical distribution of the primary sinkholes. Pannekoek (1938) in Indonesia and Meyerhoff (1938) in Puerto Rico attributed the rectangular river pattern in limestone regions to fracture systems. These fractures serve to localize and to accelerate solution, ultimately resulting in a landscape of coical hills interspersed by sinkholes. In this case the depressions have angular plans while the cones are rounded in outline. The typical map features of karst regions, i.e. rounded hillocks and angular sided depressions on the one hand the alignment of hill tops, depressions, and stream courses on the other hand are therefore simultaneously explained.

Flint *et al.* (1953) described linear, narrow limestone ridges in Okinawa. They ascribed these limestone walls to casehardening of friable limestone. Casehardening involves the deposition of secondary $CaCO_3$ by evaporation in the pore spaces of a porous limestone. This process takes place next to surfaces exposed to alternate wetting and drying, particularly on steeply inclined surfaces such as on the sides of enlarged fractures. This deposit of secondary lime forms a superficial crust of dense limestone. In places where residual soil can accumulate, as on the surface of a limestone plateau, evaporation is inhibited by the soil cover, and casehardening does not occur. In contrast to the casehardened limestone the flatter surfaces with soil blanket are reduced topographically at a faster rate. Narrow walls or ridges of casehardened limestone are progessively raised in relief as the upland surface is reduced.

On studying Nusa Barung (Fig. 1), East Java, from the topographic sheet 56/XLIV — A&B one is struck by the linear arrangements of hill tops and ridges, depressions, stream courses, and straight stretches of coast line. These map features clearly indicate the control of fractures on the morphology of the island.

This paper aims to present a case of geomorphic and structural analysis derived from a topographic map. A similar structural analysis was made from Sheet 30, a geologic map of Purwakarta, West Java (Tjia, 1962).

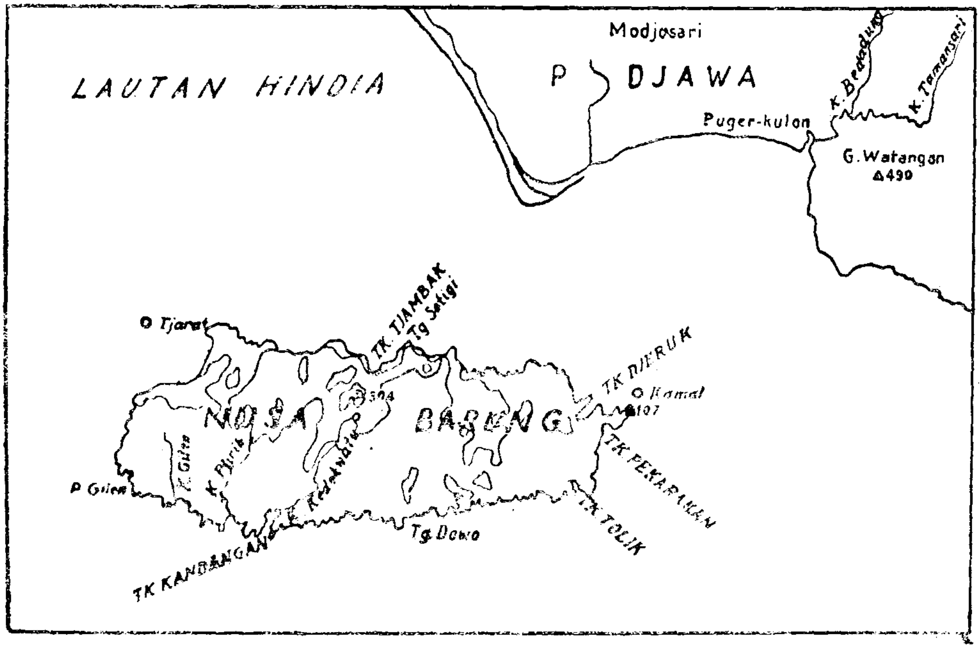

Fig. 1 scale 1 : 250.000

GEOLOGY OF NUSA BARUNG

Morphologically Nusa Barung belongs to the zone of Southern Mountains in Java. Its present position as an island off Puger, East Java, is caused by a small rise of sealevel relative to the land surface, as is indicated by the shallow depth of the sea bottom between the main island and Nusa Barung (Pannekoek, 1949) and the ria-coast features of the latter.

Verbeek and Fennema (1896) indicated on their geologic map the surface of Nusa Barung to be composed entirely of limestone. The topographic map at the scale of 1: 50.000 strengthens this conception by indicating the presence of karst features like isolated hills of conical shape, depressions, rectilinear stream courses, and the partly subterranean Kali Plirik. Although further geologic information is lacking from Nusa Barung, yet in analogy with the rather uniform development of the entire zone of Sounthern Mountains (Tjia, 1959) sevral geologic assumptions relevant to the subject of this paper can safely be made. We may suppose that the outcropping limestone is of young miocene age. Furthermore, pleistocene diastrophism has also tipped the surface of the island toward the south, as is indicated by the closer spacing of contour lines on the north coast than those on the south coast. The amount of tilt probably does not exceed 4° as is indicated in the Djampang region, West Java, where it amounts to 1.5°-4° (Pannekoek, 1946), and at the most 2° in the Karangbolong Mountains, Central Java (Tjia, 1962 *b*).

MEASUREMENT OF TOPOGRAPHIC LINEAMENTS

On the topographic sheet 50/XLIV — A&B alignments of hill tops and ridges are clearly indicated. It is assumed that these lineaments of topographic highs mark orientations of fractures in the island. Field observation may probably solve the problem whether these topographich highs are fractures proper which by casehardening, as explained by Flint *et al.* (1953) for the limestone walls of Okinawa, have become resistant to erosion, or whether the linear ridges and tops are representing non-fractured areas whereas the adjoining valleys are true fractures topographically reduced. A third possibility is that both types are represented in the island. In any case these lineaments are considered as strike orientations of fracture sets.

Figure 2 gives an example how hill tops and ridges are marked by straight lines. The resulting orientations are measured in classes of 5 degrees and plotted on a rosette or strike frequency diagram (Fig. 3). Table I represents more than 300 measurements of the strikes of lineaments.

The rosette indicates three major and two smaller maxima, namely as follows :

Maxima (major): N 5-10 E, N 35-40 E, and N 345-350 E ;

Maxima (smaller): N 25-30 E and N 325-330 E.

The distribution of the major maxima is such at to enable further elaboration on their nature and possible origin.

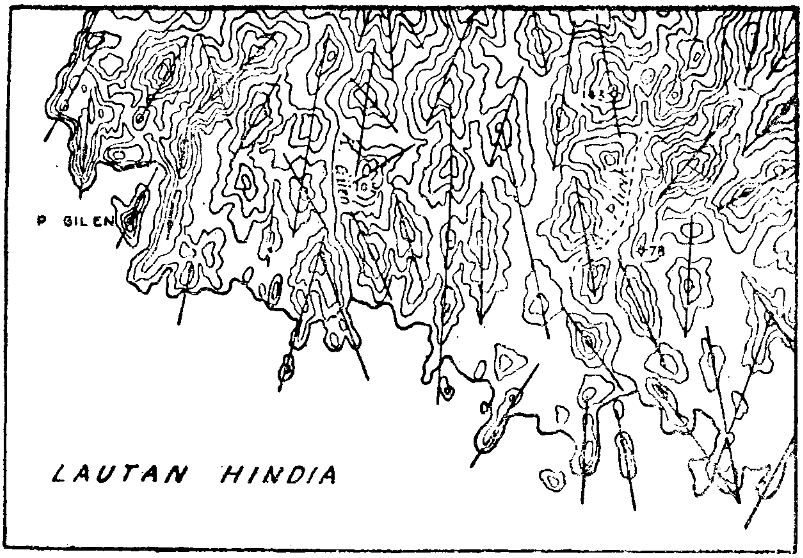

Fig. 2. scale 1 : 50.00

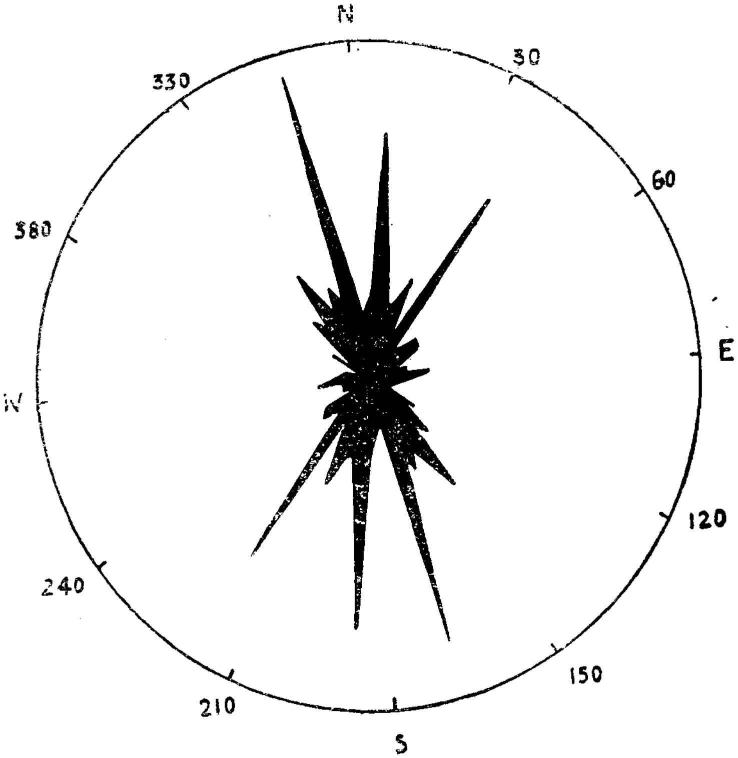

Fig. 3

FRACTURES IN ROCK

Fundamentally there exists two states of stresses in nature, that of tension and that of compression. Under tension rock will fail along planes of rupture perpendicular to the direction of tensile stress. Compression may result in three types of fractures. In the first place rock subjected to compression under confining pressure will fail along two intersecting planes (so called *shear planes)* of which the smaller intersecting angle faces the maximal principal stress (generally designated as P), the larger intersecting angle faces the minimal principal stress (R), whereas the intermediate principal stress (Q) parallels the intersection of both shear planes (Fig. 4a). Secondly compression is found to set up tensional forces in planes perpendicular to the direction of compression. In this case rupture takes place along planes parallel to P and including Q, while R is perpendicular to this plane. These are called *extension fractures.* (Fig. 4b). Lastly rock under compression may not fail directly because of insufficient stress applied to it. However, when the compression is aprreciably decreased, failure is seen to take place along planes perpendicular to the former. The fractures formed are *release fractures.*

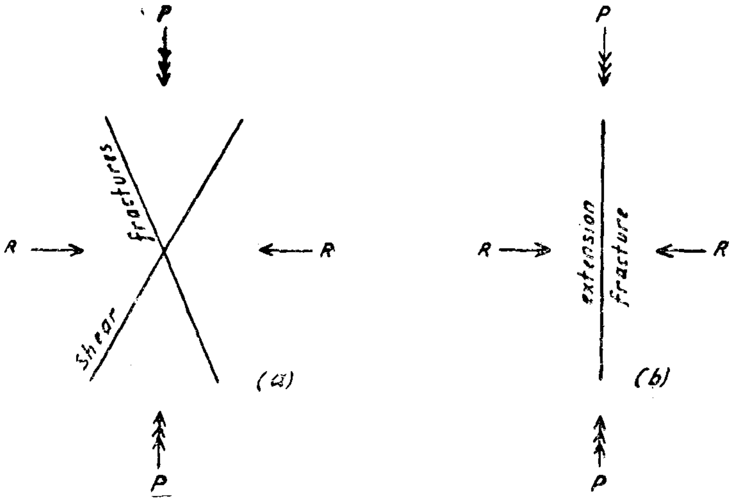

Fig. 4.

The mechanical principles involved in rock failure are more fully discussed in papers by geologists occupied with rock deformation like Hafner (1951), Hubbert (1951), and in a monograph by Jaeger (1956).

In laboratories for rock deformation it is found that half of the acute intersecting angle between shear fractures vary most commonly between 25° and 30° (Hubbert, 1951 ; Handin and Hager, 1957). These observed values correspond with those predicted by Mohr's theory of failure under compression. Graphically the Mohr's theory is depicted in the Mohr's stress circle (Fig. 5) according to the formula:

$$\theta = 45° - 0.5\ t°,$$

where θ = angle of failure
t = angle of internal friction of the rock, varying between 30° — 40°.

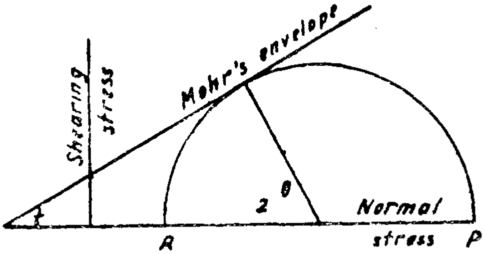

Fig. 5

STRUCTURAL AND GEOMORPHIC ANALYSIS.

Structural analysis of measured data. Focussing our attention again on the strike orientations of the fractures in Nusa Barung, we note the following.

In the first place the lineaments are straight lines indicating fracture planes vertical or almost vertical in attitude.

TABLE I

Number of measurements of topographic lineaments.

Orientation	Number	Orientation	Number
0 — 5	12	90 — 95	3
5 — 15	33	95 — 100	3
10 — 15	16	100 — 105	0
15 — 20	10	105 — 110	1
20 — 25	11	110 — 115	0
25 — 30	15	115 — 120	4
30 — 35	5	120 — 125	6
35 — 40	29	125 — 130	0
40 — 45	5	130 — 135	7
45 — 50	6	135 — 140	10
50 — 55	8	140 — 145	8
55 — 60	7	145 — 150	17
60 — 65	4	150 — 155	11
65 — 70	2	155 — 160	13
70 — 75	3	160 — 165	11
75 — 80	1	165 — 170	42
80 — 85	3	170 — 175	7
85 — 90	8	175 — 180	8

In studying the angles between the three major maxima it is found that the most extreme maxima are separated in plan by an angle of 50° (N 345-350° E and N35-40° E), while the other maximum is intermediate in position (N 5-10° E), and bisects this angle almost exactly. Furthermore the minima are most apparent in the sector between N 45° E and N 135° E, and their supplementary angles.

From the combination of the above mentioned evidence the conclusion can be drawn that the fractures represented by the three major maxima are the result of a compression directed in S 10° W — N 10° E. Those fractures oriented between N 345° E and N 350° E, and those between N 35° E and N 40° E are *shear fractures* making an angle of failure of 25° with the direction of compression (P). The fractures parallel to the derived direction of compression are the *extensional fractures*. The absence of other pronounced maxima seems to indicate that the direction of maximal principal stress has remained the same throughout the post-limestone history of Nusa Barung, or it may imply that the island was only subjected to one phase of diastrophism after the deposition of the limestone.

As a consequence of the compression one should also expect reverse faults/fractures and fold axes in N 80° W and S 80° E, i.e. prependicular to the direction of compression. The rosette (Fig. 3) definitely shows the near absence of fractures (reverse faults) in that direction. A possibility which may explain the nonexistence of the above said fractures will be discussed in the following paragraph. To study the probable existence of fold axes, to asymetrically inclined slopes, as are indicated by closer spaced contour lines on one side than on the other, were assigned dip and strike symbols on the topographic sheet. However, no fold axes of significance could be constructed. On the other hand considering Nusa Barung as a whole, the effect of the compression is also illustrated by the appearance of large scale tilting. This is evidenced by the sea scarps, particularly the one along the west coast where it diminishes in height toward the south. Secondly tilt is indicated by the distribution of peaks, being higher in the north (about 200 till over 300 meters) than in the south (of the order of 100 meters and lower). Thirdly tilt is also illustrated by the more pronounced ria-coast outlook of the south coast than that of the north coast. This latter evidence needs some explanation. The north coast being higher in relief is affected more severely by abrasion than the south coast which passes more gradually below sea level. Therefore promontories and bays on the north coast are straightened out at a faster rate than on the south coast, hence the difference in ruggedness. Still another evidence supporting the tilt is indicated by the directions of stream flows, which are southward.

The other fractures oriented as is indicated by the submaxima may be the manifestations of local reorientations of stresses. Still another conclusion may probably be drawn from the symmetrical distribution of the fracture sets about the axis of compression, i.e. none of these fractures is generated by a vertical compression. In this case we should expect a non statistical distribution of fracture orientations, at least of the submaxima. Therefore it seems that the tilting is the result of tangential rather than radial forces.

Geomorphic analysis.

Karst features of limestone regions are readily distinguishable on topographic maps. Such a landscape is shown by the presence of numerous conical hills displaying more or less linear trends, dry or water-filled sinkholes, few surface drainage, and usually also linear river courses. These streams may be partially subsurface drainage. It has also been noted that karst limestone regions in Java present a rugged topography and have fewer, scattered, and smaller settlements than is found in areas underlain by volcanics (Tjia, 1962 c).

Nusa Barung is a clear example of the karst features mentioned above. On figure 2 linear trends indicated by the distribution of hill tops and linear stream courses are easily discernible. The topographic map shows furthermore dry sinkholes with angular outlines, one of the streams being partially subsurface drainage, and the complete absence of settlements. A closer examination of the contour lines depicting hills in many cases indicates convex, sometimes straight, but also some concave slopes. The comparatively large contour interval, i.e. 25 meters, does not seem to warrant further speculation about the slope profiles. However, the mere indication of convex slopes has an appeal for field study concerning its origin as is pointed out by the author (Tjia, 1962 d).

The distribution of hill tops is such that along the north coast are found the highest summits, whereas the south coast is occupied by summits 100 or more meters lower than the former. Only the height of one hill north of Teluk Tolik in the southeast corner, being 242 meters, is anomalous in the general scheme of summit distribution. This hill may be a resistant (volcanic plug ?) rock of the underlying "Old Andesite" Formation (Tjia, 1959). North-south cross sections of the topography across the island generally imply a gradual southward sloping surface joining the summits. The average angle of tilt does not exceed 2°, which conforms to the order of inclination for the erosion surfaces in the Djampang region, West Java (Pannekoek, 1946) and in the Karangbolong Mountains, Central Java (Tjia 1962 b). However, it does not mean that the sloping surface containing summits of the Nusa Barung limestone also represents an erosion surface. The geologic history of the Southern Mountans indicates that it is more probable to assume the limestone of Nusa Barung to have been deposited on an erosion surface. Consequently the southward sloping summit elevations are also representing the tilt of the aquitanian (Tjia, 1962 b) erosion surface. Therefore the summit-plane of the limestone would only represent a structural plateau.

The difference in ruggedness of the ria-coast features of the north and south coasts has been ascribed to the difference in relief and intensity of abrasion, as is discussed in the former paragraph.

The rosette of Figure 3 does not shaw alignments in the topography and consequently no fractures in the direction perpendicular to the axis of compression. It has been concluded that this compressive force did not form revrse faults/fractures. However, ther is another possibility to explain the near absence of such faults/fractures. It may be that because of the southward tilt of the whole island, erosion has been more active in north-south direction and thus accentuating north-south lineaments rather than those in east-west direction. At the moment the author is not prepared to speculate further on this possibility.

CONCLUSION

All facts pointed out in the former section lead to the conclusion that the fracture pattern of Nusa Barung is primarily caused by a N 10° E — S 10° W directed compression acting in a horizontal plane or nearly horizontal plane. Its angle of shear lies in the range of shear angles found empirically to exist. This compression did not form folds in the limestone, but tilted the whole island toward the south. The southward tilt of the island conforms to its position on the south flank of the Java Geanticline which axis runs through the present volcanic zone of Java.

Erosion has been particularly active along the fractures formed by the compression and has carved out conical hills (with all possible slope profiles) arranged in linear sets reflecting the orientations of the fractures. Especially at the junction of fractures, depressions with angular plans are formed, whereas the linear valleys occupy the fractures proper.

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