Geology. — *"Fractures and Faults near the Surface of Moving Geanticlines. II. Abnormal Strikes near the Bending-points of the horizontal projection of the Geanticlinal axis."* By Prof. H. A. Brouwer.

(Communicated at the meeting of September 30, 1922).

In a previous paper [1]) we have pointed to the occurrence of considerable transverse fractures near the bending points of the horizontal projection of the geanticlinal axis, which phenomenon has been explained by velocity differences on either side of these bending points.

Another phenomenon that may be observed near the bending points is the occurrence of older strikes, inclined or normal to the horizontal projection of the axis [2]). This may be seen in rows of islands if the strikes in some islands do not coincide with the main trend of the islands. It is of great interest for determining the precise movements of the rows of islands, as will be shown in the following discussion.

The row of Islands Sermata-Islands, Babber, Tenimber-Islands.

In the islands Letti, Moa, Luang and Sermata the principal strikes are sometimes more or less parallel to the direction of the row, e.g. in Letti.

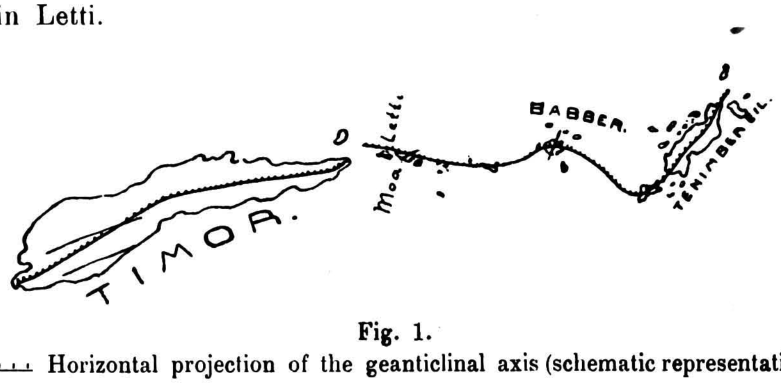

Fig. 1.

. . . . . . Horizontal projection of the geanticlinal axis (schematic representation).

——— Older strikes and coastlines.

In Moa some strikes are N.N.E. to N.E., so these are different from the direction of the row; in Luang the permian strata are

[1]) These Proceedings XXIII, p. 570,

[2]) H. A. Brouwer, The horizontal movement of geanticlines and the fractures near their surface. Journ. of Geology. XXIX, 1921, p. 560–577.

intensely folded, with strong differences in strike and dip. If we construct the geanticlinal axis, as is generally done, with right angled bends, near Babber and near the southmost island Selaru of the Ténimber-Islands, so that the geanticlinal axis between these two islands is below the surface of the sea, the Tertiary strike in Babber (N.N.E.) is *about normal to the direction of the row.*

The connection of Halmaheira with the Pelew Islands.

The soundings between these islands do not go against the assumption that the prolongation of the Northern Peninsula of Halmaheira via Morotai towards the Helena-reef has a more or less east-western direction and bends in a more or less north-eastern direction towards the Pelew Islands. Even if considerable depths

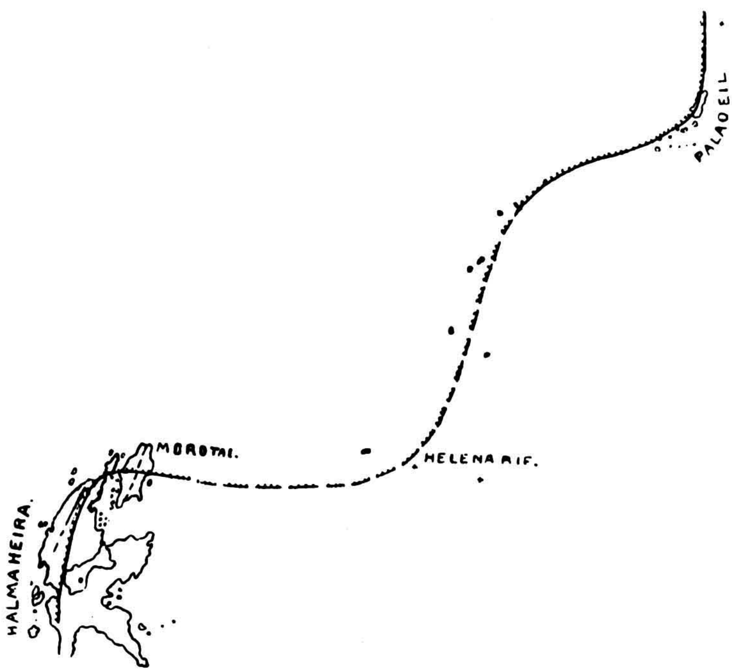

Fig. 2.

Horizontal projection of the geanticlinal axis (partly hypothetic).

Older strikes and coast-lines.

should exist where the E-W. prolongation of Halmaheira's northern peninsula is supposed to be, these depths may be the result of gaping fractures, that may exist near the bending-point. The known strikes on Morotai are in the direction of the longer axis of the island and are oblique to the supposed direction of the geanticlinal axis. This conception renders the resemblance between the outlines of Celebes and Halmaheira more complete. The difference between them consists chiefly in the eastern part of the northern peninsula of Halmaheira being covered by the sea.

The row Formosa—Riukiu-Islands.

The prolongation of the Sakishima-group is generally considered to be linked to North-Formosa [1]), also by authors whose interpretation of the known facts differs from the one that will be put forward

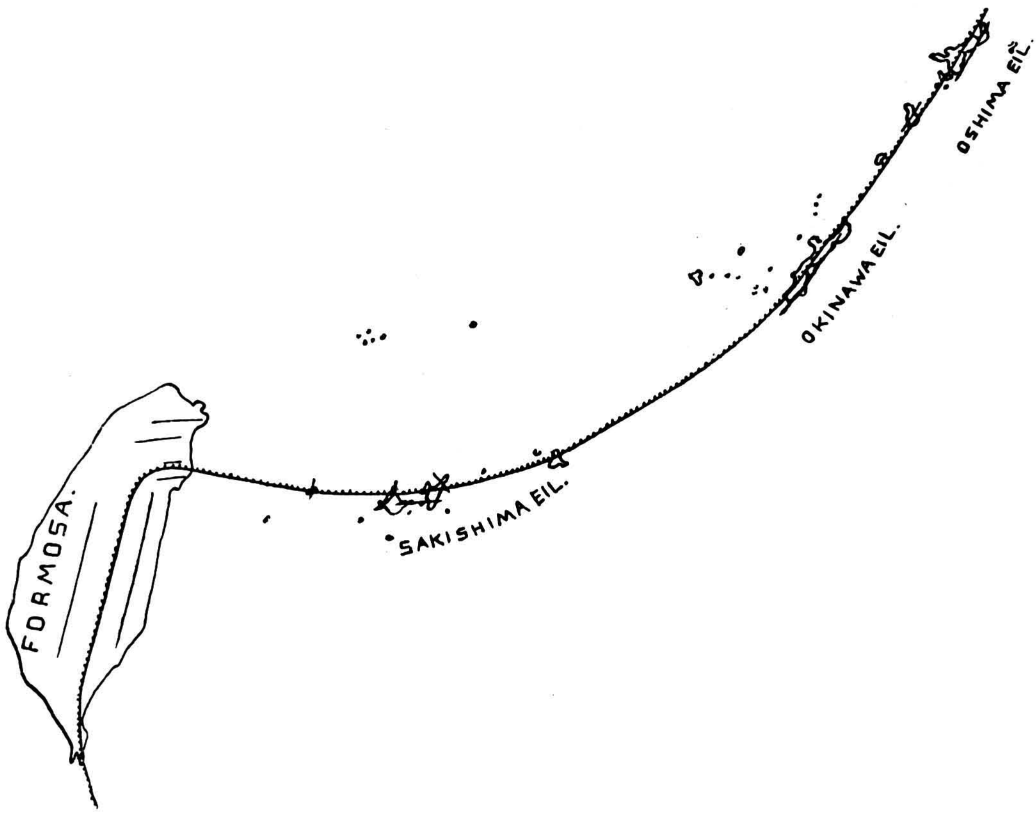

Fig. 3.
Explanation of Fig. 2.

lower down. The older strikes in the major part of Formosa are N.N.E. approximately parallel to the longer axis of the island. In North Formosa, however, their trend is about E—W, and they are cut off by the eastern coastline. In the Sakishima-group of the Riukiu-islands the strikes are irregular and are oblique or normal to the trend of the row of islands, while in the major part of the Riukiu

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[1]) S. Yoshiwara, Geologic structure of the Riukiu Curve etc. Journ. Coll. of Science, Tokyo. XVI. Part I, 1901.

Islands as far as Kiusjiu the strikes are again about parallel to the direction of the row. This example seems to be similar to the two preceding ones, but the areas near Babber, as well as those near Morotai, from which this analogy might appear, are covered by the sea. In Formosa the bending of the older strikes is visible and moreover it can be seen that locally *near the bending point of the horizontal projection of the geanticlinal axis the older strikes are normal, or approximately so, to this projection, while on either side they are parallel to it.*

The movement at the surface of horizontally moving geanticlines.

In another publication we have already pointed to the difference in speed and direction of the movements at different depths[1]). The points, which were originally on the same vertical line, will in a later stage form an irregular curve in space. If the rate of movement has a vertical component, the vertical movement near the surface will be influenced by the vertical movement at greater depth.

The complicated horizontal and vertical movements, which differ already at a comparatively short distance, will cause new portions of the surface to form the crests of the moving geanticline. The direction of the older strikes with regard to the new geanticlinal axis in a subsequent phase of the movement, will depend upon the rate of movement at greater depth and that near the surface and upon the rate of erosion.

If the forces, which cause the movement of a geanticline, of which the highest parts rise above the sea-level as rows of islands, are deep-seated, the vertical movements will cause the uplift or subsidence of the islands, while the rate of horizontal movement at greater depth may differ considerably from the rate near the surface. We distinguish two extreme types of movement: 1° The horizontal movement near the surface is equal to zero. 2° The horizontal movement near the surface is similar to the movement at greater depth. In general neither of the extreme types will occur. In the first case no horizontal fracture-movements will take place at the surface, and straits generally correspond with a depression, islands with a culmination of the geanticlinal axis in a given stage of the movement.

In the second case the islands as such move in a horizontal direc-

[1]) H. A. Brouwer, The horizontal movement etc. loc. cit.
Id. The major tectonic features of the Dutch East Indies. Journ. Wash. Acad. of Sciences, 1922, p. 172—185.

tion, and straits may originate near the fractures without a subsidence of the geanticline along the axis. The movements near the surface are not equal to those at greater depth. But we suppose an extreme case, in which, considering broadly, the portions near the surface move at the same rate as those at greater depth.

The vertical movement and the effect of erosion.

Considering that during the movement erosion will continuously be at work in the portions above the sealevel, it will generally be possible to compare in the terminal phase the direction of the geanticlinal axis with the direction of the exposed older strikes. In case of a brief and not very intensive erosion, the tectonic details of a more plastic deformation at greater depths, are still invisible. The intensity of erosion decreases if, as in many rows of islands, the deformation of the geanticline takes place near the surface of the sea, and it is especially, when the vertical component of the rate of movement is great, that the tectonic details, which have been formed by a more plastic deformation at greater depth will soon be visible.

Rectilinear old strikes and curved geanticlinal axis with a bending-point in the last phase of movement under consideration.

The two extreme cases, mentioned above are:

1. *No horizontal movement at the surface.*

In the case represented by fig. 4 the old strikes cut the geanticlinal axes of the terminal phase on either side of the bending-point of $A'B'$ at an angle of about 45°, while nearer to A' and B' the older strike will gradually coincide with the new geanticlinal axis. If we assume that in the portions AC and DB, the movement has

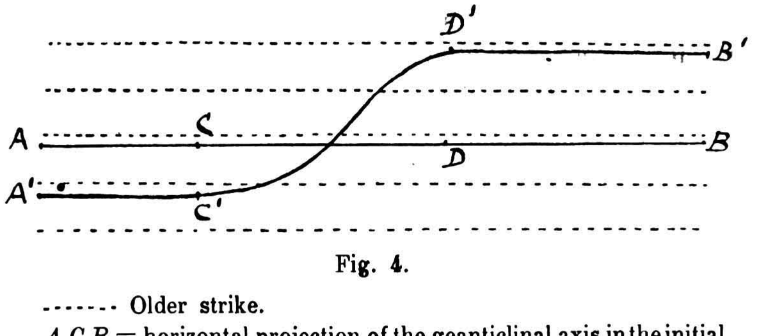

Fig. 4.

------ Older strike.

$A\ C\ B$ = horizontal projection of the geanticlinal axis in the initial stage of the movement under consideration.

$A^1\ C^1\ D^1\ B^1$ = Ibid. in the last phase of the movement under consideration.

taken place without velocity-differences and normal to the geanticlinal axis, gaping fractures will nevertheless be lacking in the portion $C''D'$, and in the case of a row of islands a strait will correspond with a minimum of the vertical projection of the geanticlinal axis.

2. *Horizontal movement at the surface, corresponding with the movement at greater depth.* In the portion $C'D'$ gaping fractures will be formed which — in so far as they occur near the surface of the sea — may be visible as straits between the islands.

In the positions $A'C'$ and $B'D'$ the old strikes will not differ from the direction of the new geanticlinal axis; to what extent they will do so in the portion $C''D'$, will depend on the movements near the surface. If these movements are non-rotational, differences up to 45° will occur; with rotation of the portions of the fractured surface the differences may be approximately zero.

Curving older strikes with a bending-point, and curving geanticlinal axis with displaced bending-point in the final stage.

One of the numerous variations of this more general case is represented in Fig. 5.

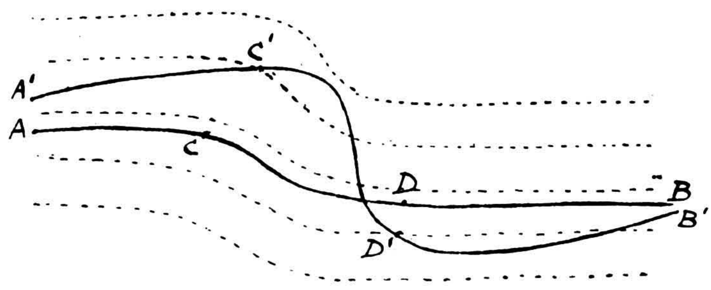

Fig. 5.

------ = Older strike.
$A\ C\ D\ B$ and $A'\ C'\ D'\ B'$ = horizontal projection of the geanticlinal axis, resp. in the initial-, and the terminal stage of the period under consideration.

1. *No horizontal movement at the surface.* In the final stage the old strikes are nearly all oblique to the geanticlinal axis, near the bending-point even approximately normal to it. Straits will correspond with depressions of the geanticlinal axis. If the geological structure changes chiefly in the direction vertical to the old strike, islands of highly different structure will in some places be located side by side.

2. *Horizontal movement at the surface corresponding with that at greater depth.* When, in the terminal stage of the considered period of movement, the points A, B, C and D have reached respectively

A', B', C' and D', gaping fractures will appear all along the line $A'\,C'\,D'\,B'$, which may have helped to form straits. If during their displacement the parts near the surface had at the same time rotating movements, the angles between the old strikes and the geanticlinal axis may approach zero in the final stage.

Explanation of the abnormal strikes near the bending-points.

The abnormal strike of the island of Babber (fig. 1) may be accounted for by assuming that the deformation of the geanticline at greater depth has been attended with similar horizontal movements near the surface, so that e.g. the geanticlinal portion near the surface of the Tenimber Islands may originally have been situated N.N.E. of Babber, while these parts have since been displaced considerably relative to each other in a horizontal direction.

When assuming that no horizontal movement has taken place near the surface, the abnormal strike in Babber may also have originated from the great velocity-differences in a horizontal direction at greater depth, with this difference that the submarine geanticlinal part between Babber and the Tenimber-Islands is not disrupted near the surface. If the bending-point is the horizontal projection of a point that gives a minimum in the vertical projection, it may be that near it a large part of the geanticlinal axis is below the sea. In that case data will be lacking for a comparison of the present morphology with the older tectonic structure of the parts on either side of the bending-point.

Likewise the connection of Halmaheira with the Pelew-Islands is covered by the sea in a considerably area on either side of the bending-point, but in Morotai, where the older strike is oblique to the geanticlinal axis, the geanticline still emerges from the sea, while here the resemblance of the coastline to that of the neighbouring part of Halmaheira points to horizontal movements of the islands as such. In the row Formosa-Riukiu Islands (Fig. 3), unlike in the preceding instances, the bend of the older strikes is not covered by the sea, which facilitates a more correct explanation of the phenomenon. The dips in the older formations of the Taiwan-mountains in Formosa point to WNW. movements, those in North-Formosa to southward movements, those in the major part of the Riukiu-Islands to S—E movements. It is evident therefore, that already during the older phases of the orogenetic process, there was a tendency to form a bending-point between Formosa and the Riukiu-Islands. Similar movements during the youngest phase of the mountain-building process gave origin to numerous fractures, e.g. those which cut off the E– W strikes of North-Formosa at a right angle and separate the Sakishima Islands from each other and from Formosa.

According to our conception of the differences in character and rate of movement at different depths, the absence of islands between Formosa and the Sakishima Islands may be looked upon as resulting from the formation of gaping fractures, in connection with the velocity-differences in a horizontal direction at the surface near the bending-point, and from a minimum elevation of the geanticline near the bending-point of the horizontal projection of the axis. The abnormal strikes of the Sakishima-Islands find an explanation in the assumption of movements, such as have been referred to above in the discussion of a geanticlanal movement with curving older strikes and with a displaced bending-point in the final stage (Fig. 5). The movement can be described only in broad outlines, the details cannot be derived from the visible facts. Thus the strikes on the Sakishima-Islands have no constant direction, and differences occur between the strikes of the older and those of the more recent deposits. Near the bending-point, however, irregular movements can be expected, while at the same time the rate of vertical movement, and consequently the rate of erosion must in a high degree have influenced the present-day tectonic structure.

The abnormal strikes of the Sakishima-Islands have been explained differently by VON RICHTHOFEN [1]), who speaks of transverse subsidence causing an abnormal dip of the strata in connection with his explanation of the origin of the mountain arcs of Eastern Asia by tensional and not by compressional stress. In contradistinction to this interpretation by *vertical* movements, we have compared the features with those of other belts of islands and find an explanation of the abnormal strikes near the bending-points of the geanticlinal axis in considerable *horizontal movements*, which have already been discussed by us for various geanticlines in connection with other features.

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[1]) F. VON RICHTHOFEN, Geomorphologische Studien aus Ost-Asien. III. Sitz. Ber. Akad. d. Wiss. Berlin. Phys.-math. klasse. 1902, p. 944 et sec.