In the Pleistocene also the geosynclinal area of southern Rembang emerged above sealevel. So, in the late Pleistocene a plain of subaerial denudation was formed. Thereafter, in the youngest Quaternary (Holocene), also this erosional surface was warped into broad anticlinal and synclinal belts.

These are from South to North:

The Randublatung depression
The Tjepu anticlinorium
The Lusi-Kening-Lower Solo depression
The North Rembang anticlinorium
The Semarang-Rembang-Java Sea depression.

Meanwhile, the source area in the Java Sea sank down. Its submergence is partly due to regional subsidence, and partly to an eustatic rise of the sea-level.

This part of the Java Sea North of Rembang forms the southwestern part of the **Pulu Laut centre of orogenetic disturbance** distinguished by the author (1933 f).

The northern part of this centre of diastrophism has been discussed in this book under Borneo (Chapter VA). The southwestern part of the Pulu Laut centre is surrounded by the volcanoes Lasem, Muriah, and the islet of Bawean. During the Neogene this southwestern part was the source-area of the sedimentation in the Rembang geosyncline. A first impulse of uplift occurred at the end of the Miocene and a second one, accompanied by external volcanism, in the Pleistocene. Thereafter, in the youngest Pleistocene and Holocene, this centre of orogenetic disturbance subsided below the present sealevel. Its northern part was even engulfed to a considerable depth, now forming the trough in the Strait of Makassar.

The late warping of the plain of subaerial denudation in Rembang has been studied by the morphologist LEHMANN (1936, p. 99 and foll.), who distinguished high terraces arround the border of the synclinal belts, like those described for the Randublatung Zone.

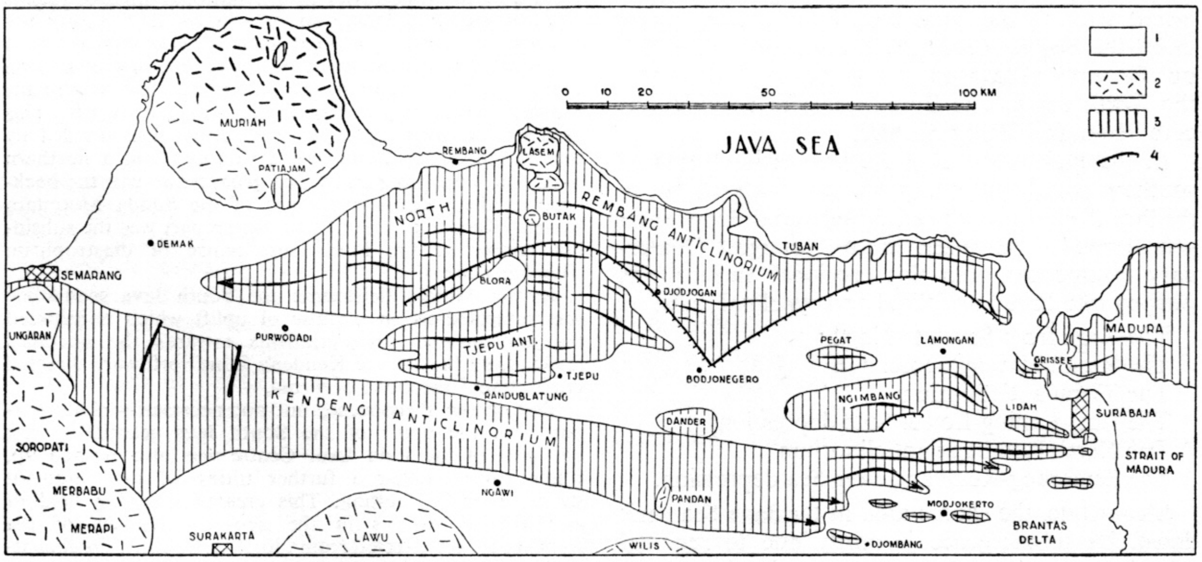

FIG. 292. *Sketchmap of NE Java.*
Showing the position of the hypothetical faults and flexures in the basement complex of Rembang (see also fig. 5 in Vol. II).

Key:
1. Alluvial.
2. Quaternary volcanoes.
3. Neogene.
4. Faults and flexures, partly buried by neogene and quaternary deposits.

Cause of tectogenesis

This young warping of the Rembang Hifls is ascribed to differential vertical movements of the crust, and is not considered as the after-effect of the preceding phase of lateral compression. The presence of tumescent, active magma in depth appears from the presence of the small volcanoes in the North.

The anticlinorium of North Rembang can be traced eastward into the geanticlinal arch of the Madura anticlinorium.

This late warping of the surface of subaerial denudation by differential vertical movements radically changed the pattern of gravitational stress-gradients which caused the pleistocene folding. Therefore, it would be rash to doubt the gravitational character of this compression, only because at present, in a later stage of evolution, the surface and basement relief no longer show a configuration corresponding with such southward directed gravitational stress-gradients. First the paleo-orographic situation during the folding process has to be reconstructed; only then a picture of the trajectories of gravitational stress-gradients can be obtained. Doing so, it appears that during the Pleistocene the geosynclinal belt of northeastern Java was a zone of low land or shallow sea comprised between the Java-geanticline in the South and the SW part of the Pulu Laut centre of diastrophism in the North. This geosynclinal zone was a double geosyncline, divided by the Randublatung Zone into a southern and a northern part.

The southern part of this geosyncline was the back-deep of the volcanic inner arc of the Sunda Mountain System (Kendeng Zone); the northern part was the subsiding border of the Pulu Laut centre of diastrophism (Rembang area).

In the Middle Pleistocene the South Java geanticline was subjected to an impulse of uplift which re-inforced the gravitational stress-gradients towards the northern lowland, so that in the Kendeng Zone northward directed gravitational reactions occurred.

During the Pleistocene, but not necessarily simultaneous with the uplift of the South Java geanticline, the SW part of the Pulu Laut Centre was also pushed up, which caused either a further tilting of the basement structure or its faulting. This created a strong field of gravitational stresses in the neogene deposits of the Rembang area, directed from North to South. Consequently, the ensuing folding was generally directed southward. These reactions tended to neutralize the existing gravitational stresses (tensional spreading of the highs and compression of the lows).

In some of the northern structures (Tawun, for instance) northward upthrusts are known, and other anticlines have alternating steeper North and South flanks in the different sections. These deviations from the general southward tendency of the movements might perhaps be interpreted as underthrusting of the southward gliding lower part of the neogene strata, aided by laccolithic intrusions as those of the Butak in the North (see fig. 293, section VII). Thereafter, in late quaternary time, the surface of subaerial denudation, which truncated the folds of the preceding phase of gravitational compression, was warped by a differential vertical uplift. This process, in combination with the engulfment of the Pulu Laut Centre, changed (and even reversed) the remaining field of stresses, so that the present situation radically differs from the one which gave rise to the pleistocene phase of folding.

Gravimetry. The gravimetric Bouguer anomalies of this area, based on observations with an "Askania" torsion-balance by the Bataafsche Petroleum

Maatschappij and published by VREUGDE (1935), show a distinct positive field. This field begins East of Semarang and broadens eastwards between the line Rembang-Tuban on the North coast, and the line Tjepu-Surabaja at the southern margin of this fold system, thus comprising the whole of the Rem-bang anticlinorium.

In the central part of this positive field, a belt of slightly positive or even slightly negative values extends from Blora to Grissee. This strip coincides with the central depression zone of the Rembang anticlinorium (Blora-Djodjogan-Bodjonegoro-Ba-bad-Lamongan), which was subjected to a late (holocene) downwarp, according to the morphological analysis by LEHMANN (1936).

The steep gradients of the Bouguer anomalies along the lower course of the Solo River downstream of Bodjonegoro (Δg = 30 milligals for 3 kilometres of the cross section) indicate that the downwarp has the character of a fault in the basement complex. According to VREUGDE, this fault has a throw of at least 1500 m, East of Bodjonegoro. In the South flank of the Dermawu-Mahindu structure (North of Bodjonegoro) and farther NW (South flank of Tawun), there is a steep southward dipping flexure in the neogene strata, which may conceal a real fault in the underlying basement complex.

This situation might perhaps be interpreted as the result of an asymmetric depression on the crest of a broad geanticlinal upwarp of the basement complex in Rembang (see fig. 88). Farther East, where this Rembang geanticline becomes narrower again, forming the Island of Madura, the axial depression disappears.

The gravimetrical minima of the Rembang Zone coincide with the topographical depression. The normal, southward dipping fault in the basement complex, indicated by the steep gradients of the Bouguer anomalies, is marked at the surface by the arcuate southern border of the Tuban limestones, concave to the South. This great crescentic rift extends between Bodjonegoro and Grissee. It is bord-ered to the South by the alluvial plain of the lower course of the Solo. South of this plain the upwarp of Ngimbang and the other anticlines in the eastern part of the Randublatung Zone are found.

This situation suggests a mutual relation between the upwarp of Ngimbang, etc. in the South and the downwarp of the geanticline in the North. Both might be the effect of rather deep seated gravitational adjustments in the basement complex. This is repeated in a similar, but more restricted and superficial way, by the downslip of the SE-part of the Ngimbang dome (see DUYFJES, 1938, sheet 109). West of the arcuate downthrow between Bodjonegoro and Grissee, another one is found between Blora and Bodjonegoro. This one is less pronounced and less well surveyed by gravimetric observations. But the analogy with the Bodjonegoro-Grissee downthrow is remarkable. South of the elevated area of North Rembang we find first the depressed basins of Blora and Djodjogan with the Lusi-and the Kening Valleys, and then the Tjepu anticlinorium emerges South of this depression zone.

The gravimetrical character of the Rembang (Madura) Zone differs distinctly from that of the Kendeng Zone. The latter is characterized by strongly negative Bouguer anomalies, corresponding with negative isostatic anomalies, (see map of regional isostatic anomalies by VENING MEINESZ, 1940 b); the former is occupied by a field of positive Bouguer anomalies (see fig. 1, p. 921 in VREUGDE, 1935).

VREUGDE attempted already to explain these gravimetrical features by accepting differences in depth of the underlying basement complex. It would be well worth to continue this work in the future; first by applying a geological correction to the Bouguer and isostatic anomalies and, thereafter, the meaning of the residual anomalies can be discussed, as has been done by EVANS & CROMPTON (1946) for NE-India and Burma (see Chapter IV).

The gravimetric contrast between the Kendeng Zone and the Rembang Zone might then perhaps be explained by accepting in the former a thin crust covered by a thick series of neogene sediments and corroded at its lower side by (dioritic-granitic (?)) magma, and in the latter a thick, heavy basement complex less deeply buried by neogene strata and underlain by more basic (gabbroic ?) rocks.

6. SUMMARY AND SCHEMATICAL SECTIONS ACROSS EAST JAVA

In the preceding pages an analysis has been made of the tertiary and quaternary evolution of the parallel structural units of East Java. These are from South to North the Southern Mountains, the Solo Zone, the Kendeng Zone, the Randublatung Zone, and the Rembang Zone.

Now these zones have to be viewed in combination, so that the mutual relations between their structural development can be studied. To this effect a series of eight schematical sections has been drawn across East Java between Patjitan in the South and Lasem (Rembang) in the North, illustrating the successive stages of evolution from the Eocene up to the present.

The stratigraphical and field geological units in these zones are tentatively correlated in table 110.

FIG. 293 on PLATE 35. *Eight schematical sections, illustrating the tertiary and quaternary evolution of East Java.*

Explanation of fig. 293:

Section I, Eocene: The end of the Mesozoic era was marked by an uplift of the cretaceous geosyncline and a general regression of the sea; but in the Eocene renewed geosynclinal subsidence began in the Solo Zone, initiating a new orogenic cycle. The ensuing tertiary and quaternary diastrophism forms part of the great system of crustal waves spreading from the Anambas centre in the Sunda Land since young paleozoic time, as has already been depicted in the subchapter on Borneo. In Borneo the relation between the pre-tertiary orogenesis and the younger evolution could be studied more in detail, and also for Sumatra such will be done (see subchapter on Sumatra). However, for Java this is not possible, as the connecting links are inaccessible for geological research due to the late quaternary submergence of the Sunda Land, during which the Java Sea was formed.

In the Eocene the Gunung Wungkal- and the Gamping Layers of the Djiwo Hills were deposited on the subsiding basement complex.

Section II, Oligocene: The oligocene deposits overlapped the borders of the Solo geosyncline, especially to the North, where their presence is indicated by limestone boulders with *Camerina fichteli-intermedia* in the basal Lutut Beds of the Merawu series (see section III). In the Djiwo Hills no Oligocene has been found, neither in the Nanggulan and Loh Uloh areas farther West (South Seraju Range of Central Java). This points to an initial uplift of the Solo Zone in the Upper Paleogene and a concomitant subsidence of the adjacent Kendeng Zone, representing the preliminary stages of the orogenic revolution at the end of the Paleogene.

Section III, Aquitanian and Lower (+ Middle) Miocene: In the paleogene geosyncline there had possibly been formed a median ridge during the Oligocene. The main phase of orogenic revolution, terminating the lower tertiary evolution, occurred at the end of the Paleogene. The median ridge in the Solo Zone was further pushed up, and it was penetrated by the magma which reached the surface.

The Solo Zone had been subjected already to a first impulse of orogenic uplift at the end of the Cretaceous. This first uplift in the Oligocene was non-volcanic. The second uplift at the end of the Paleogene brought the magma to the surface, giving rise to intensive volcanic activity ("Old-andesite" volcanism). This is the normal evolution of a geosynclinal beit: the first uplift is non-volcanic and the second one shows external volcanism.

South of the Solo Zone, the slopes of the Old-andesite volcanoes were deposited partly below sealevel and alternated with calcareous formations.

North of the Solo Zone, in the subsiding Kendeng Zone, first some gravitational folding of the Lower Tertiary occurred, followed by the deposition of coarse, trans-gressive conglomerates of the Lutut- and Pelang Beds (Aquitanian). Thereafter, the thick flysch series of the Kerek Beds were deposited, belonging to the Lower-Middle Miocene. In their upper part more and more volcanic tuffs are found, belonging to the growing submarine slopes of the Old-andesite volcanoes which increased laterally in area. In the Ungaran area the flysch-like tower part and the volcanic upper part of this Kerek Series can be sharply distinguished, and are called respectively Merawu Beds and Penjatan Beds.

Meanwhile, also the SW part of the Pulu Laut centre of diastrophism, the SE Java Sea, was elevated. This uplift was partly compensated by the subsidence of the marginal part of the old Sunda Land in the Rembang Zone.

The latter area had the character of a tilting marginal tract of a continental block, on which marine deposits were formed. In the northern part of Rembang these sediments contain intercalations of coal seams indicating paraiic conditions.

Section IV, Middle + Upper Miocene: Towards the end of the preceding period the magma rising in the Solo Zone, and causing the "Old-andesite" volcanism, had corroded the crust from below. An impulse of uplift caused tensional stresses and the invasion of the Old-andesite Formation. Swarms of andesitic and liparitic dikes were intruded, followed by the rise of the plutonic rocks into the lower part of the Old-andesite volcanoes. In this section, however, no granodioritic intrusions have been exposed by subsequent erosion, like those of the Merawan batholith in the eastern spur of Java. Only acid dikes and phenomena of hydrothermal metamorphism are found in the Southern Mts of Solo (sulphidic minerals). Owing to this intra-miocene uplift the Old-andesite volcanoes were block-faulted and attacked by erosion.

Then the rising magma caused another phase of intensive volcanic activity, building up the "Banjak" volcanoes. The southern slopes of the latter formed the Ojo Beds in the Southern Mountains, and their northern slopes formed the Banjak Beds of the Kendeng geosyncline. The age of this Banjak volcanism is Middle to Upper-Miocene. While the composition of the Old-andesite volcanoes was chiefly pyroxene andesitic or basalto-andesitic,