The folds in the Notopuro breccias of the Ngawi depression lie at distances of 35-45 km from the present summit. Nevertheless, they can be considered as the result of a rather superficial gravitational tectogenesis of epidermal character.

It is possible that also the young arching up of the erosional surface of the Kendeng ridge North of it has been influenced by this collapse. For it appears that this young upwarp culminates with a height of 184 m above sea exactly opposite (viz. to the North of) the Lawu Complex (3,265 m). The Kendeng plunges from there westward to the railway Surakarta-Gundih and eastward to the transverse valley of the Solo River. This holocenc arching up of the erosional surface of the Kendeng is ascribed to endogenic (magmatic) forces (see discussion of the Kendeng). If the magma, underlying the Kendeng Zone, is connected with that of the Solo Zone, as is shown in section VIII of figure 293 on pi. 35, then it seems quite probably that the surplus of pressure exerted by the load of the Lawu Complex is hydrostatically transmitted to the magmatic basement of the foreland, causing there an additional upward pressure.

The same situation is found in the central part of the Kendeng between Ngawi and Djombang, where the young arching up of the erosional surface culminates just opposite the Wilis volcano. Apart from the young Pandan volcano (897 m) the greater height of which is due to external volcanism and its resistance against denudation, the erosional surface of this section of the Kendeng culminates in ridges of 350-450 m North of the Wilis Complex. It plunges from there westward to the transverse valley of the Solo River, North of Ngawi, and disappears eastward under the alluvial delta of the Brantas River.

The **Wilis Complex.** This volcano was already strongly active in the Lower Pleistocene, forming the volcanic facies of the Putjangan Layers in the Kendeng Zone, as was demonstrated by DUYFJES (1938 a). Moreover, its lahars ponded up the water in the western part of the Ngawi depression, where the Black Clays of the Putjangan stage were deposited in a lake.

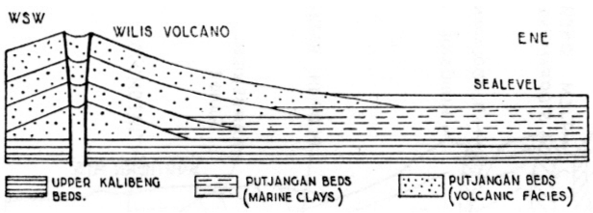

FIG. 282. *Facies alterations in the Putjangan Layers in the Kendeng Zone, South and SW of Surabaja, due to the activity of the Wilis volcano.* (According to DUYFJES, 1938 a, fig. 3, p. 31)

The Wilis is, as far as known, the only giant volcano in the Solo Zone of which the activity began already before the mid-pleistocene upheavel of the Java geanticline. It is quite probable that the volcanic deposits covering the miocene limestones of the Southern Mts in the section East of Popoh belong to the oldest Wilis activity.

A physiographic description of this volcano has been given by TISSOT VAN PATOT (1926). The oldest Wilis volcano has been destroyed by the later ge-anticlinal uplift (at the end of the Middle Pleistocene) and was succeeded by a second cycle of Wilis activity, comparable in age with the Old Lawu, Tengger, etc. This second or Old Wilis generation produced breccias of the Notopuro stage. Thereafter, at the end of the Pleistocene, also this second Wilis volcano was subjected to a volcano-tectonic collapse. A complicated blockfaulted structure originated, which has not yet been studied in detail.

Finally, in the Holocene, a third cycle of volcanic eruptions terminated this Wilis-activity.

A remarkable feature of the rifts and rents in the Old-Wilis is their N-S trend, such in contrast to the crescentic fissures of the Lawu and Tengger groups. Moreover, the Southern Mountains reach rather far northward into the Wilis Complex. This is due to the intersection of two large, crescentic escarpments which cut off the Southern Mts with respect to the depressions of Madiun and Kediri. North of the Wilis, on the southern margin of the Kendeng anticlinorium, we find the little Pandan volcano which is of upper pleistocene age (Notopuro stage). This volcano also shows a N-S trend.

These features point to the presence in the Wilis section of a N-S transverse fault system across the Solo Zone, comparable with the N-S transverse fault of the Merapi-Ungaran row of volcanoes farther West.

The latter fault is connected with the different stage of evolution between Central and East Java, Central Java being older than East Java. It is possible that this transverse fault of the Wilis-Pandan Complex has a similar meaning. It separates the western part of the Java geanticline in East Java, which was uplifted during the Middle Pleistocene, from its eastern part in East Java, in which the arching up occurred somewhat later, presumably in the Upper Pleistocene.

The Andjasmoro - Ardjuno - Kelud - Kawi – Butak Complex. The Andjasmoro Mts are the oldest part of this complex of volcanoes in the Solo Zone. The foot of this group formed the Djombang Layers of the Kendeng Zone. DUYFJES (1938, p. 55) is of the opinion that the Djombang Layers belong to the uppermost Middle Pleistocene. However, there is no coercive reason for a middle pleistocene age; as they succeed the definitely middle pleistocene Kabuh Layers we prefer to consider them, provisionally, as Upper Pleistocene, just as the Notopuro breccias farther West.

The Andjasmoro volcanoes broke down to irregular blocks and simultaneously the gentle folding of the Djombang Layers occurred in the Brantas delta (anticlines of Djombang, Podjok, Watu-dakon, Sekarputih, Kedungwaruh in sheets 110 (Modjokerto), and 116 (Sidoardjo); DUYFJES, 1938 c&d).

No detailed study has been made of the relation between this blockfaulting on the one side (tension movements) and folding on the other (compression movements); but their mutual relation as the complementary effects of gravitational tectogenesis seems quite probable.

Next in age is the older part of the Ardjuno volcano; the summit of this Old Ardjuno may have been the Ringgit.

Here also the highest portion of the volcano slid northward, folding its foot, the Bangil-Ratji anticline. The corresponding slipfault escarpment is partly exposed in the Alas ridge (see fig. 283). About this collapse of the Ardjuno group the author 1937 c, p. 164) remarked:

"This volcano was built up on the southern border of the geosyncline of northern Java, where this geosyncline passes into the geanticline of southern Java. This volcano, therefore, rested on the marine, neogene and older quaternary sediments of this geosyncline, which rapidly increased in thickness to the North. The pre-miocene initial surface below this volcano had a strong northward inclination or even flexure.

Without any regard to this bad foundation, volcanic action built up the volcano, increasing the load on the plastic foundation. Its northern part broke off along a crescentic fault rift and slid to the deeper parts of the geosyncline in the North. Along this rift volcanic activity continued, building up the younger cones of the Ardjuno-Welirang group, which, nowadays, partly hide the underlying rift-zone.

On the northern foot of the volcano this northward sliding caused compression of the geosynclinal strata, which explains the origin of the Bangil anticline. This anticline is younger than the breccias of the Old Ardjuno and older than those of the younger one. Thus, its compression coincides with the tensional faulting of the Ardjuno group to the South of it.

This simultaneous origin indicates a genetic relation between the compression (folding) in the northern geosynclinal lowland and the tensional slip-faulting in the southern volcanic highland. Such tectonic processes belong together as the complementary expressions of gravitational tectogenesis."

At the western end of this anticline the young small Penanggungan volcano was formed (described by KUENEN 1935 b, and DUYFJES 1938 d). This volcano is presumably connected with a transverse fault which forms the northward extending arm of the crescentic Alas slip-fault, limiting the Bangil anticline to the West. In this respect its position is comparable with that of the Baluran volcano on the northeastward extending arm of the large crescentic rift through the Old Idjen volcano, marked by the Raung-Merapi row of volcanoes.

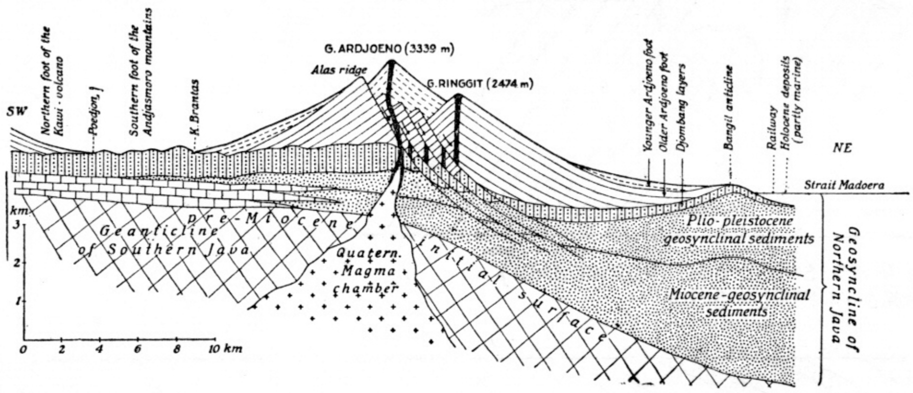

FIG. 283. *Schematic section across the Ardjuno-Welirang group, showing its volcano-tectonic structure and the concomitant folding of its North foot.* (According to VAN BEMMELEN, 1937 C, fig. 4, p. 164)

With the Bangil-Ratji anticline begins the series of compression features formed at the end of the Pleistocene along the North coast of the eastern spur of Java (e.g. Ringgit-Beser structure).

The **Kelud, Kawi, and Butak** are a group of younger, volcanic structures, chiefly holocene, masking the older (upper-pleistocene) volcanic structures, burying also partly the escarpment of the Southern Mts.

3. THE KENDENG ANTICLINORIUM

The Kendeng Ridge consist of an East to West trending foldsystem. It shows asymmetric folds and northward upthrusts in its western end; the intensity of folding gradually diminishes eastward until some gentle folds plunge under the Brantas delta at its eastern end.

Three parts can be distinguished: (A) the western part between the Ungaran volcano and the transverse valley of the Solo (N. of Ngawi), (B) the central part from this valley to Djombang, and (C) the eastern part, East of Djombang and in the Brantas Delta where it passes into the Strait of Madura. These sections arc respectively 115, 85, and 70 km long.

A. The western section of the Kendeng Zone.

The western section of the Kendeng joins on to the North Seraju Range in Central Java, the axis of which plunges eastward. The Ungaran volcano is situated on the transition between the North Seraju Range and the much lower Kendeng Ridge. Due to this plunge of the axis the lower neogene strata have their greatest distribution in the western end, while eastward only younger neogene strata are exposed.

Neogene stratigraphy. The stratigraphy of the westernmost part of the Kendeng Zone (West of the railway Surakarta-Gundih) shows more resemblance to that of central Java (the Semarang-Ungaran area, described by the author, 1941 d), while the sedimentary column of the section between this railway and the transverse valley of the Solo River North of Ngawi shows already the normal Kendeng stratigraphy as described by DUYFJES (1936, 1938). The transition between both lies between Djuwangi (Telawa) and Gundih.

Along the Tuntang and the Serang Rivers important transverse faults are present, along which the westernmost part of the Kendeng has been elevated to a greater height than the Kendeng Zone *sensu stricto* farther East. Therefore, in this western portion of the Kendeng Ridge also deeper strata of the neogene column are exposed.

Old Neogene. In an upthrust zone, about 1 km South of Djuwangi, the basal layers of the neogene series are exposed. They are strongly crushed gray marly mudstones with lenticular intercalations of limestone with large *Eulepidina* (diam. 10 mm). Also the small limestone hill of Mrisi at the North foot of the Kendeng belongs to these basal layers with *Eulepidina.* These basal strata are called **Pelang Beds.**

The latter are conformably overlain by a monotonous series of marly clays (with Globigerina, Radiolaria, sponge spicules, discoasters) alternating with calcareous tuff-sandstones and quartz-sandstones containing *Lepidocyclina* and *Cycloclypeus (Katacycloclypeus) annulatus* MARTIN. These strata are called the **Kerek Beds.** Due to the absence of key-horizons and very intensive folding and thrusting, no exact estimate of their thickness can be given (fig. 284). It is estimated to be more than 1000 m.

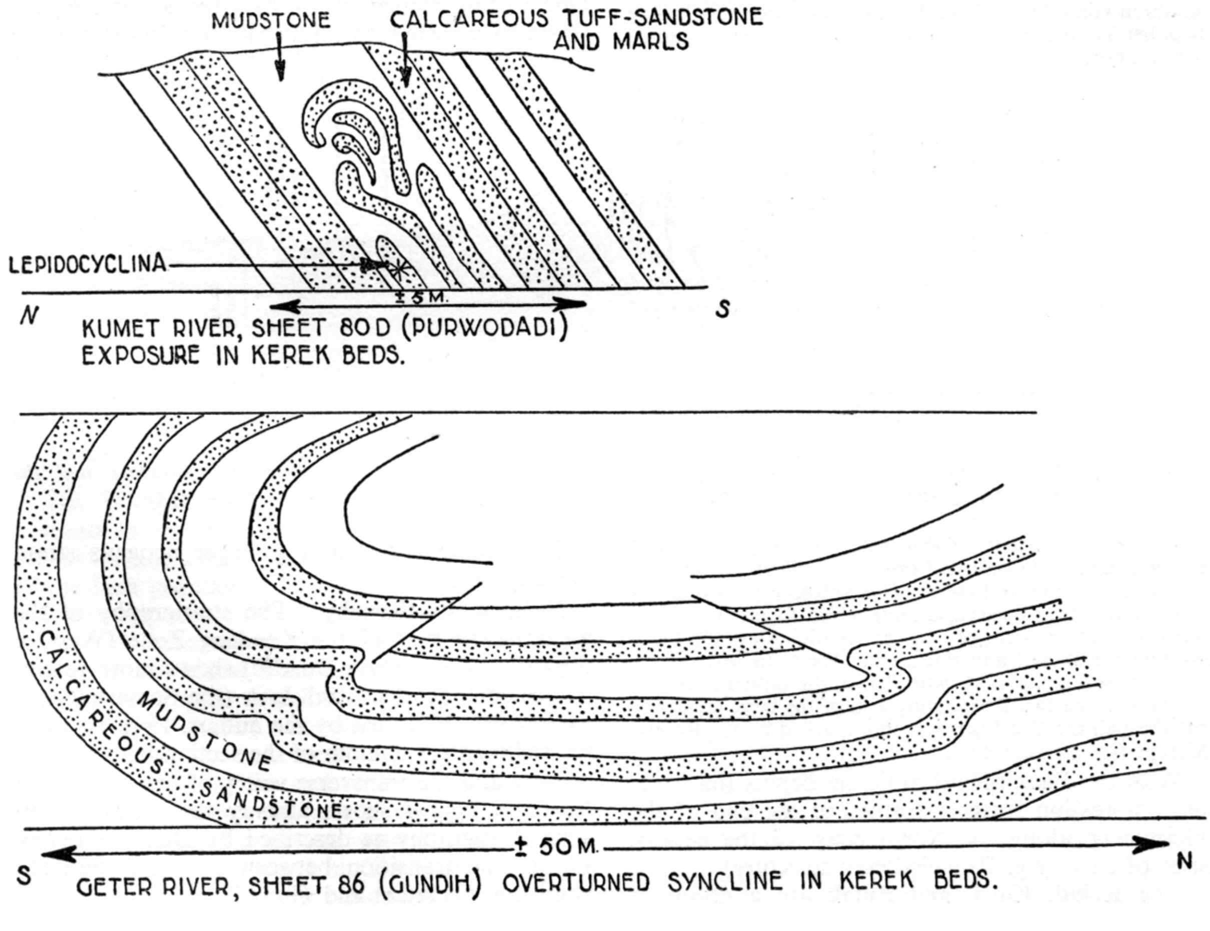

FIG. 284. *Two sketches of structural details in the Kerek Beds.*

In the upper part of the Kerek Beds volcanic intercalations (tuff-sandstones) are much more frequent than in the lower part. The lower part of the Kerek Beds can be correlated with the flysch-like

Merawu Series and their upper part with the volcanic Penjatan Series of the North Seraju Range (lower Middle Miocene). The basal Pelang Beds are the equivalent of the Lutut-Beds in the Sema-rang-Ungaran area (VAN BEMMELEN, 1941 d, p. 20-21), and of the Sigugur limestones in the Karang-kobar area (VAN BEMMELEN, 1937 d).

Young Neogene. The Kerek Beds are pseudo-conformably overlain by a series of marine tuff-sandstones and volcanic breccias, alternating with *Globigerina*-bearing tuffaceous marls. [10]) The volcanic constituents are augite-hornblende andesitic. This volcanic formation is called **Banjak Beds.** On account of the occurrence of small *Lepidocyclina* they are considered to be of middle- or upper-miocene age. In the Borangan syncline, halfway between Ungaran and Kedungdjati, the thickness of the Banjak Beds is 1600 ra. It diminishes northward to 500 m over a distance of some kilometres, while southward a decrease in thickness to 800 m was observed over a short distance. There are no indications that the thicker part represents the centre of a submarine volcano in the Kendeng geosyncline. Presumably, the Banjak tuffs accumulated here in a submarine syncline, formed in the underlying Kerek Series before or during the sedimentation of the Banjak Beds. This is an argument for submarine folding of the Kerek Beds prior to the deposition of the Banjak Beds.

Farther East the volcanic material tapers out and the *Globigerina*-marls become the common rock type. This change in facies can be observed at the southern flank of the Kendeng anticlinorium, from Gesi eastward. These *Globigerina*-marls correspond in facies and level in the stratigraphical column with the Lower Kalibeng Beds of the Kendeng Zone (see below). On account of the observation that the lower part of the Lower Kalibeng marls passes laterally into the Banjak Beds with small *Lepidocyclina*, it is probable that the deposition of the former began already in the younger Miocene, continuing upward into the Lower Pliocene.

There are some difficulties in the correlation of the young neogene series of the North flank of the Kendeng between Ungaran and Gundih on the one side and those of the South flank from Gemolong eastward on the other.

This is partly due to a change in facies from West to East.

In the North flank of the Kendeng, West of Gundih, we find the following neogene series (see section I, fig. 269 on pl. **28**):

a.	Tuffaceous clay marls, sandy tuffs, volcanic gravel beds with *Globigerina* and molluscs, alternating with hard, calcareous andesite conglomerates with vertebrate remains	Lower Damar Beds (± 150 m)
b.	Green and gray clay marls rich in molluscs and *Globigerina*-bearing tuff-sandstones. Intercalations of limestones with *Balanus* (Cheribonian molluscan fauna)	Kalibiuk Beds (± 500 m)
c.	Platy or massive limestone	Kapung Limestone (10-250 m)
d.	White, unstratified *Globigerina*-marls	Tjipluk Beds (± 500 m)
e.	Stratified hornblende-andesitic tuff- sandstones, conglomerates, and breccias	Banjak Beds (variable thickness)
~~	~~~~~~~~~~~~~~~~~~~~~~~~~~~ Submarine folding ~~~~~~~~~	~~~~~~~~~~~~~~~~~~~~~~
f.	Well stratified series of tuff-sandstones and mudstones	Kerek Beds (?<1000 m)

The Kapung Limestones sporadically contain tribliolepidinic *Lepidocyclina* (VAN BEMMELEN, 1941 d, p. 31), and the overlying Kalibiuk marls have a Cheribonian molluscan fauna (Lower post-Pontian according to OOSTINGH; see VAN BEMMELEN, 1941 d, p. 32-38). Consequently the age of the white unstratified *Globigerina*-marls of the Tjipluk Beds, situated beneath the Kapung Limestones, is presumably still younger Miocene.

The author assigned the Tjipluk Beds to the Lower Pliocene (in the explanation of sheet 73-74, Semarang-Ungaran, of the geological map of Java; 1941 d) as they do not contain *Lepidocyclina.* However, this is probably due to the unfavourable facies, as in the overlying Kapung Limestone *Lepidocyclina* are still sporadically present. Provisionally an upper miocene age is now accepted for the Tjipluk Beds.

Eastward the pelagic facies of the Tjipluk Beds persists up to higher stratigraphical levels, forming the **Lower Kalibeng Beds** of the Kendeng stratigraphy given by DUYFJES. These Lower Kalibeng Beds attain a thickness of over 1000 m. They comprise the horizons of Tjipluk-Kapung-Kalibiuk and their age ranges probably from Upper Miocene to Middle Pliocene. The Lower Kalibeng Beds are probably separated from the Kerek Beds by an unconformity. Owing to the lack of stratification in the former this unconformity is generally not apparent. However, in the transverse valley of the Solo River, North of Ngawi near the village of Megiri, we observed on the left bank of the river a very coarse conglomerate of 5 m thickness at the boundary of the Kerek Beds and the Lower Kalibeng Beds. This conglomerate consisted of boulders of basalt and andesite (Old-andesites), dense limestone, and coral-

[10] Their unconformable position on the middle-miocene Penjatan series was distinctly observed in the Kaloran Basin, SW of the Ungaran (see VAN BEMMELEN, 1941 d, p. 28).

stocks. Moreover, the white *Globigerina*-marls of the Lower Kalibeng contain in their lower part intercalations of the hornblende-andesitic tuffsandstones of the Banjak Beds (between Gesi and Trinil).

The Lower Kalibeng Beds are conformably succeeded by the young pliocene **Upper Kalibeng Beds.** The latter occur also in a limestone facies **(Klitik Limestones)** and a marl facies rich in molluscs **(Sonde Marls).** From the latter MARTIN described an upper pliocene molluscan fauna (OOSTINGH'S "Sondian")- Although the Klitik Limestones and the Sonde Marls at the South flank of the Kendeng resemble in facies very much the Kapung Limestones and the Kalibiuk Beds in the westernmost part of the North flank, they appear to be somewhat younger. This is probably the result of the fact that the facies divisions cut obliquely through the time divisions of the stratigraphical column, as is shown in fig. 285.

The change from a marine into a terrestrial facies occurred in the North Seraju Range already in the Upper Pliocene (Kali Glagah Beds, to be discussed hereafter). Also in the transitional area between the North Seraju Range and the western Kendeng Ridge the change in facies falls in the Upper Pliocene (Lower Damar Beds). However, in the South flank of the western and central parts of the Kendeng Ridge the change in facies is found between the Upper Pliocene and the Lower Pleistocene. Moreover, in the eastern part of the Kendeng the boundary between the marine and the terrestrial facies shifts farther upward through the Pleistocene up to the Holocene. Finally the Strait of Madura is reached, where marine sedimentation is still continuing in present time. Thus we find a gradual filling up of the Kendeng Zone from West to East. We will return to this question afterwards.

The relations in the western part of the Kendeng ridge are illustrated in the section across this zone North of Surakarta (section II of fig. 269 on pl. **28**). .

The Lower Kalibeng marls of the Kendeng Zone wedge out southward; in the Gamping anticline on the northern slope of the Lawu volcano limestones of the Upper Kalibeng (the Klitik horizon) directlyoverlie hornblende andesites of the Banjak stage (see fig. 280 on pl. **28**).

The molluscs in the neogene deposits of the Kendeng Zone have been described by VAN REGTEREN ALTENA (1938, 1941, 1942 [11])) and SCHILDER (1942), smaller Foraminifera by BOOMGAART & VROMAN (1936), and diatoms by REINHOLD (1937).

UMBGROVE (1946) studied the corals of the Upper Kalibeng Beds and this author could identify (in localities of the sheets 93 B and 99 B), 29 species in a collection of 35 specimens. Twenty of these belong to still living species, that is 69 %. This percentage agrees with the figure 68.8 resulting from UMBGROVE'S revision of the list given by FELIX for corals from the region of Trinil and Sonde. This percentage of recent corals points to Upper Pliocene ($T.h_2$).

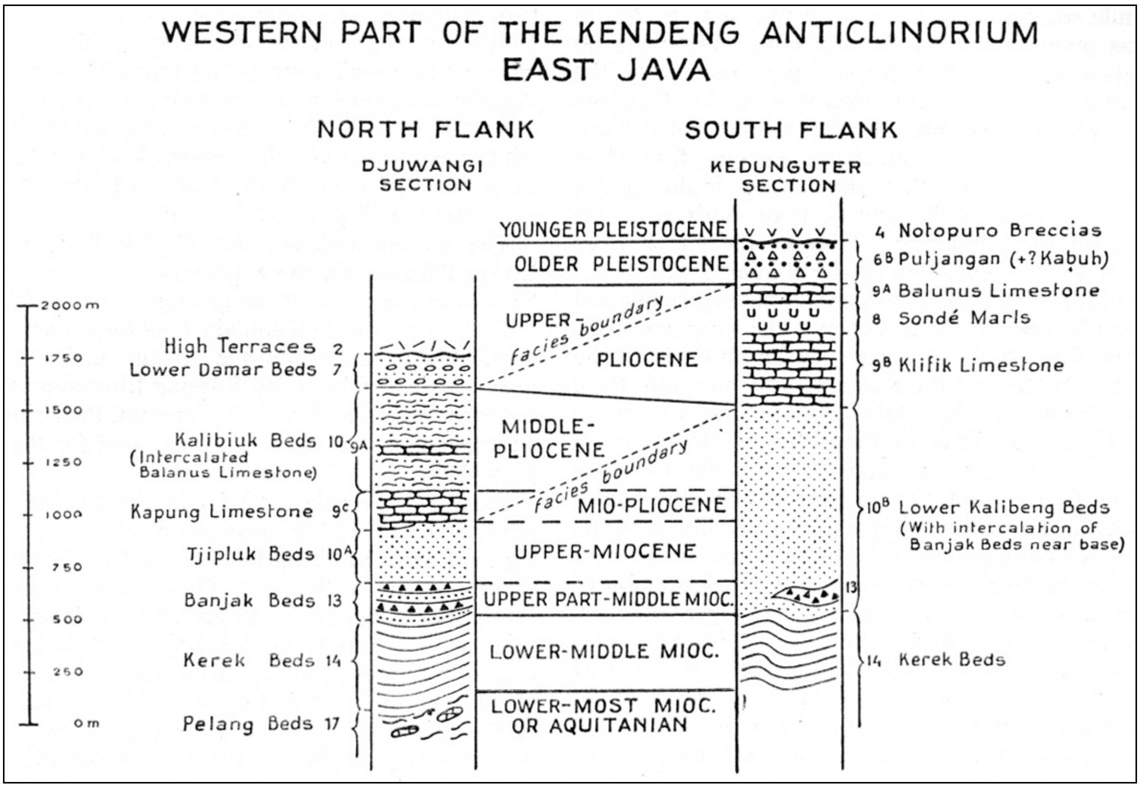

FIG. 285. *Scheme of the fades alterations in the Young Neogene of the Western Kendeng Zone.*
(The numbers refer to the legend of fig. 268 on pl. **34**)

[11] VAN REGTEREN ALTENA completed in 1948 the MS on the families *Muricidae-Volemidae* (part V of the gastropods of the Kendeng collection). About three more parts on the gastropods of this collection will follow.