Lower Pleistocene. The marine Upper Pliocene of the South flank between Gemolung and Ngawi is conformably covered by the lower pleistocene **Putjangan Beds.** The latter are not marine any more. Between Ngawi and Trinil their facies is volcanic (volcanic breccias and tuff-sandstones).

These volcanics were produced by the oldest Wilis volcano, the lahars of which dammed up a shallow lake or marsh in the Ngawi Subzone West of it. The Putjangan Beds in this lake are the typical **"Black Clays",** exposures of which are found near Bringinan, in the Sangiran dome, and in the Onto dome. In Sangiran the Black Clays are separated from the marine upper Pliocene by fluviatile volcanic breccias. In the Kedunguter section (sections II and III of fig. 269 on pl. **28**) the Putjangan Beds consist entirely of such volcanic breccias, gravels, and tuff-sandstones.

The Black Clays of Sangiran, Onto and Bringinan contain an intercalation of yellow clay with marine molluscs. Moreover, in Sangiran and Onto some interbeds of diatomaceous clay are found (those of Sangiran are described by Reinhold, 1937).

Onto dome. The marine intercalation of the Black Clays in the Onto dome is 2 m thick. It contains ostreas, pecten, *Strombus*, and a molar (M_3) of *Cervus zwaani*, a key-fossil of the lower pleistocene Djetis fauna. Immediately on top of this marine clay follows a diatom horizon of about \ m thick. The Black Clay itself contains freshwater molluscs *(Vivipara*, *Melania*, *Corbicula*, *Unio)*, and some drifted *Globigerina.* The vertebrate fauna of the Black Clays in this dome has not yet been closely investigated *(Stegodon ci. prae-cursor).* Towards their top more and more tuff-aceous interbeds are found, alternating with Black Clays containing calcareous concretions.

The exposed section of the Black Clays of Onto is about 300 m thick, and that of the upper part of black clays with interbeds of tuff-sandstone has a thickness of about 125 m. Vertebrates have not yet been found in the upper part of the section, so that we cannot determine whether or not the latter belongs already to the Kabuh Beds (Middle Pleistocene).

From Onto eastward the thickness of the Black Clays diminishes, being about 200 m thick in Sangiran and only 100 m in Bringinan.

The "Black Clays" in the western part of the Ngawi Subzone are probably partly contemporaneous with the marine "Blue Clays" of the Ran-dublatung Zone and the Rembang Hills, farther North.

There was already a first emergence of the Ken-deng Zone in the Lower Pleistocene. This is corroborated by the presence of lower pleistocene conglomeratic beds in the Putjangan Beds of Ardjawinangun at the North flank (see below), and in those of the Kedunguter section at the South flank of the Kendeng Zone. A temporary invasion of the Ngawi Subzone is represented by the intercalation of marine yellow clay in the Black Clays of Onto, Sangiran, and Bringinan.

At the North flank of the western part of the Kendeng Ridge the transition of the marine Upper Pliocene into the terrestrial Lower Pleistocene is well exposed in the **Ardjawinangun syncline,** NE of Gundih (see Jaarboek Mijnwezen, 1938, gen. part, p. 21).

In Ardjawinangun the following succession is found: At the northern rim of the Kendeng *Globigerina*-limestones and -marls of the Upper Kalibeng stage are exposed. To the South these strata are separated by a southward dipping upthrusr from Kerek Beds and Banjak Beds. The latter are succeeded by white, unstratified *Globigerina*-marls (Lower Kalibeng Beds), which pass upward into sandy marls and calcareous sandstones and shell-limestones with *Balanus* (Upper Kalibeng, Klitik horizon). Then follow marine marls, rich in molluscs, which probably can be correlated with the Sonde Marls (Upper Pliocene). On top of these marls a fresh-water conglomerate is found with *Stegodon trigonocephalus praecursor* v. Koen. (Lower Pleistocene).

As stated above, this conglomerate is proof that here the emergence of the westernmost Kendeng began already in the Lower Pleistocene.

The Ardjawinangun section ends with black clays with fresh-water molluscs, resembling the Black Clays of the Ngawi Subzone to the South. However, it is questionable whether these black clays of Ardjawinangun once formed a continuous deposit with those of the Ngawi Subzone on the southern side of the Kendeng Ridge. The former were presumably formed in a local marsh or lake, which occupied the Ardjawinangun syncline in the first stage of its folding. Their age might be Middle Pleistocene. The South flank of the Ardjawinangun syncline is cut off by a northward upthrust of *Globigerina-marls* (Lower Kalibeng).

Middle Pleistocene. The western part of the Kendeng Zone was intensely folded in the Middle Pleistocene (by a compressive force from the South). Simultaneously the emerging anticlines were truncated by erosion. The erosion products were deposited as **Kabuh Beds** in the Ngawi Subzone South of it, where their age is determined by the vertebrate fauna of Trinil and Sangiran. The Kabuh Beds are probably also deposited in the Ran-dublatung Zone along the northern side of the Kendeng, but there they are covered by alluvial deposits.

In the Sangiran dome the Kabuh Beds begin with a calcareous conglomerate bed with boulders and pebbles of andesite, concretionary limestone, *Globigerina*-limestone, cataclastic white quartz; further augite, hornblende, feldspar and drifted *Globigerina.* Thus we see that after the relatively quiet circumstances of sedimentation in the Pu-tangan stage suddenly coarse debris of older stages were deposited. The basal conglomerate is about 1 metre thick at the southern border of the Sangiran dome. In the NW corner, near Tegalredja there are some beds of about half a metre thickness consisting of conglomerates and tuff-sandstones, alternating with black clays. This gradational transition of the Black Clays into the Kabuh Beds resembles the situation in the Onto dome.

No stratigraphic gap has been found between the Black Clays and the Kabuh Beds of Sangiran, but in the neighbourhood intensive erosion must have taken place.

The basal conglomerate of Sangiran is succeeded by cross-bedded tuff-sandstone and gravel beds of a white to yellowish brown colour. The tuffaceous constituents are derived from older augite hornblende andesites or andesitic tuffs. Fresh volcanic tuffs are probably absent in this series.

The Kabuh Beds of the Ngawi Subzone are a typical synorogenic formation, being formed during faulting of the geanticline of Southern Java to the South and folding of the Kendeng Zone to the North. They are famous for their rich vertebrate fauna (Trinil fauna) with *Pithecanthropus erectus* DUBOIS.

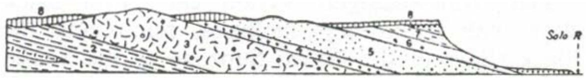

FIG. 286. *Geological section of Trinil.*
(DE TERRA, 1943, fig. 103, p. 447)

1. Black clay with *Globigerina*-marl.
2. Sandy clay.
3. Lahar conglomerate (Lowermost Pleistocene).
4. Bone Bed.
5. Gray-tuff-sandstone with plant remains.
6. Gray sandstone and silt with bones.
7. Gray sandy tuff.
8. Terrace and loam.

Upper Pleistocene. The **Notopuro breccias** cover unconformably the erosion surface of the Kendeng fold-system. They are found at its western end (Old Ungaran and Soropati products) and along its southern flank (Old Lawu products). In the Ngawi Subzone (Sangiran dome) there is generally a pseudo-conformity between the Kabuh Beds and the Notopuro Beds, but in some places, for instance South of Sangiran, a distinct angular unconformity could be observed (see fig. 278). The unconformity between the Kabuh Beds and the Notopuro breccias appears also from the overlap of the latter over the plain of subaerial denudation in the westernmost part of the Kendeng.

Along the Solo River high **terraces** are found (Watualang, Ngandong), containing the upper pleistocene Ngandong fauna with *Homo neander-thalensis soloensis.* Near Setren, 45 km North of Ngawi, the terrace gravels cover the slopes of the hills more or less continuously from the present riverbed (at 38 m above sealevel) up to a level of 71 m. Such a gravel envelope does not represent definite stages of uplift separated by longer periods of denudation; there was a progressive rise of the plain of denudation of the Kendeng, during which the Solo River could maintain its antecedent northward course.

According to DUYFJES (1936, p. 147) the Solo terraces are somewhat younger than the Notopuro breccias. They might be also considered as the final stage of the Notopuro period.

Along the antecedent transverse valley of the Solo River, North of Ngawi, the following stages of erosion were distinguished by LEHMANN (1936, p. 81):

1. The plain of subaerial denudation of the Kendeng, on both sides of the river with a height of 100-125 m above sealevel. This surface was formed during and after the middle pleistocene phase of folding.
2. High terrace of the Solo, near Ngandong at about 55 m above sealevel.
3. Low terrace of the Solo, about 15 m below the high terrace.
4. Present river bed with subrecent flood-terrace (± 35 m above sealevel).

At the northern end of the transverse valley of the Solo, near Mendenredjo, the gravels of the high terrace level are dipping 5° - 10° North (VERBEEK, RUTTEN, TER HAAR 1934, LEHMANN 1936).

This situation points to an arching up of the middle pleistocene erosional surface of the Kendeng. The age of the high-terrace with the Ngandong vertebrate fauna is Upper Pleistocene. It is younger than or represents the final stage of the Notopuro period, and is older than the holocene volcanism.

Holocene. The **holocene volcanic deposits** of the young Lawu are generally restricted to the Ngawi Zone [12]). At is western end the Kendeng Zone is partly covered by the young lahars of the Merbabu, Telemojo, and Ungaran. The Ungaran volcano is situated on the crest of the Kendeng Zone, which proves that in the deeper core of this anticlinorium active magma was present and strived upward.

The folding of the western part of the Kendeng geo-syncline in middle pleistocene time happened simultaneously with the uplift of the Java geanticline South of it. The latter was subjected to tensional stresses and was blockfaulted,

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[12] According to DUYFJES (1936, p. 147) the river terraces along the Solo River near Trinil contain thin intercalations of volcanic ashes which indicates contemporaneous activity of the young Lawu volcano to the South. If these terraces are of the same age as those of Watualang and Ngandong, which contain an upper pleistocene vertebrate fauna, this would mean that the volcanic activity of the young Lawu started already in the Upper Pleistocene.

For the sake of clearness, and because these finer divisions of the stratigraphy cannot be carried through for the whole area, in this book the Notopuro breccias are considered to be of upper pleistocene age, while the young volcanic cones are placed in the Holocene. It has to be borne in mind that the activity of the latter may have started already in the Upper Pleistocene.

The blocks slid northward causing a northward directed compression in the Kendeng geosyncline. These tecto-genetic movements have presumably taken place along deep-seated, cycloidal planes. The southern parts of these planes formed the normal slipfaults along the southern margin of the Solo Zone (the fault-block escarpments of the Southern Mountains), while their northern ends reappear as the upthrusts of the Kendeng Zone. The hypothetical underground connection between both has been drawn in section VII of fig. 293 on pl. **35**, which will be discussed at the end of this subchapter on East Java.

The collapse of the geanticline of Java and the simultaneous compression of the Kendeng geosyncline North of it is a less superficial process of gravitational tectogenesis than the collapses of the volcanic cones described for the Merapi, Soropati, Lawu, etc.

The geanticlinal collapse occurred without the aid of the extra loads of volcanic cones, because the o!d Lawu is younger than this middle-pleistocene tectogenesis. The potential energy for the collapse of the Java geanticline and the concomitant folding of the Kendeng geosyncline was the result of the preceding vertical crustal movements which created differences in height between the adjacent zones. These differences in height increased without any regard to the bearing power of the crustal foundation, until the latter gave in and gravitational reactions took place.

The strain caused by the regional field of potential energy was diminished by the northward spreading of the Java geanticline and the folding of the anticlines in the adjoining Kendeng geosyncline.

The formation of the synorogenic Kabuh Beds shows that the emerging anticlines of the Kendeng Zone {consisting of young marine deposits) were immediately attacked by erosion. This erosion diminished the weight of the Kendeng Zone which had to counterbalance the thrust from the northward sliding blocks of the Solo Zone. Therefore, the compression of the Kendeng Zone could continue for some time during the Middle Pleistocene while deeper and deeper strata were exposed (e.g. the basal Pelang Beds). Finally, an equilibrium was attained between the strain caused by the remaining differences in height (between the Solo Zone and the Kendeng Zone) and the strength of the resulting structure.

The Solo terraces in the antecedent transverse valley North of Ngawi are highest in the centre of the Kendeng Zone and lower at the North flank near Mendenredjo, where they dip 5-10° North. This indicates that later on, during the Holocene, the erosional surface of the Kendeng Zone was slightly arched up (see TER HAAR, 1934, p. 53, and LEHMANN, 1936, p. 73).

This late arching up of the plane of subaerial denudation of the Kendeng Zone might be considered as an aftereffect of the middle-pleistocene compression. It might be a complementary effect of the collapse of the Old Lawu volcano. However, at its western end the Kendeng Zone is pierced by magma which built up the Ungaran volcano, and its westward extension in Central Java is clearly arched up by endogenic, magmatic forces (see under Central Java). Therefore, it seems more probable that this subrecent arching up is a first indication of the vertical uplift of the Kendeng Zone by endogenic forces (= primary tectogenesis).

The preceding phase of strong geosynclinal subsidence had stimulated the hypo-differentiation in the depth, resulting in the accumulation of a local asthenolithic mountain root under this zone. In Central Java this root had pressed up a mountain range in the Plio-Pleistocene, which is now already more or less in isostatic equilibrium. In the Kendeng Zone this uplift only just started, so that isostatic equilibrium has not yet been established. This appears from the map of regional isostatic anomalies (VENING MEINESZ, 1940 b) on which the Kendeng Zone is marked as a strip of negative isostatic anomalies, ending South of Semarang. So in the future also in the Kendeng Zone the general geological rule will be fulfilled of a geosyncline being the birthplace of a mountain range.

B. The central section of the Kendeng Zone between Ngawi and Djombang

In this section of the Kendeng foldsystem the compression was already less intense than in the western part, so that upthrusts are less frequent. The deepest exposed strata are the miocene **Kerek Beds** [13]), pseudo-conformably overlain by the un-stratified *Globigerina*-marls of the **Lower Kalibeng stage.**

Locally a coarse conglomerate of andesitic boulders was found at the border between the Kerek Layers and the *Globigerina*-marls, e.g. on the trail from Butak to Mijona. This basal conglomerate is comparable with the one found near Megiri in the transverse valley of the Solo, North of Ngawi, mentioned before. It indicates an unconformity between the Kerek Beds and the Lower Kalibeng Beds.

In the South flank (near Butak) these marls are conformably succeeded by hard *Globigerina*- and coral limestones of the **Upper Kalibeng stage** (about 200 m thick). In the more central parts of the foldsystem similar limestones were found overlapping the *Globigerina*- marls and the Kerek Beds (for instance, in the Atasangin anticline North of Butak). DUYFJES (1936, p. 142) was of the opinion that some gentle folding occurred immediately after the formation of the Lower Kalibeng marls, but this is probably not true. In the preceding chapter on the western section of the Kalibeng an intra-miocene unconformity was observed (between the Banjak Beds and the Kerek Beds), older than the one assumed by DUYFJES for the central part of the Kendeng.

Constructing the section across these overlapping limestone blocks, two peculiar facts become apparent. In the first place the limestone blocks do not fit in the constructed level of Klitik limestones. In the second place the erosional surface, covered by these isolated limestone blocks, is certainly the one formed after the middle-pleistocene folding. Therefore, these blocks of Klitik limestones got their present position after the Pleistocene, and not after a hypothetical intra-pliocene phase of folding.

The following tentative explanation of the position of these unconformable limestone blocks in the central part of the Kendeng foldsystem might be given:

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[13] A limestone intercalation (G. Godeg in sheet 99, Butak, of the 1 : 100,000 map) contains *Lepidocyclina*, *Cycloclypeus*, *Miogypsina*, and *Trillina howchini.*

The massive Klitik limestones form a rigid layer on top of the marine sequence of strata in the Kendeng geo-syncline. During the folding process of this zone the limestones were broken into blocks. The erosion attacked particularly the softer strata of *Globigerina*-marls and Kerek-marls exposed in anticlines, causing an inversion of the relief. Large blocks of limestone could slip down to the deeper and softer parts of the valleys. Of course these limestones were never folded to the heights indicated in the section by broken lines with question marks. As has been suggested already for the western Kendeng, during the folding the rising anticlines were rapidly truncated by erosion. Meanwhile the blocks of limestone, which were resistant against erosion, slid down into the valleys.

After this baseleveling of the Kendeng foldsystem in the younger Pleistocene, the plane of subaerial denudation was arched up in the Holocene. At present these isolated blocks of Klitik limestone are found on secondary sites in a pseudo-unconformable position.

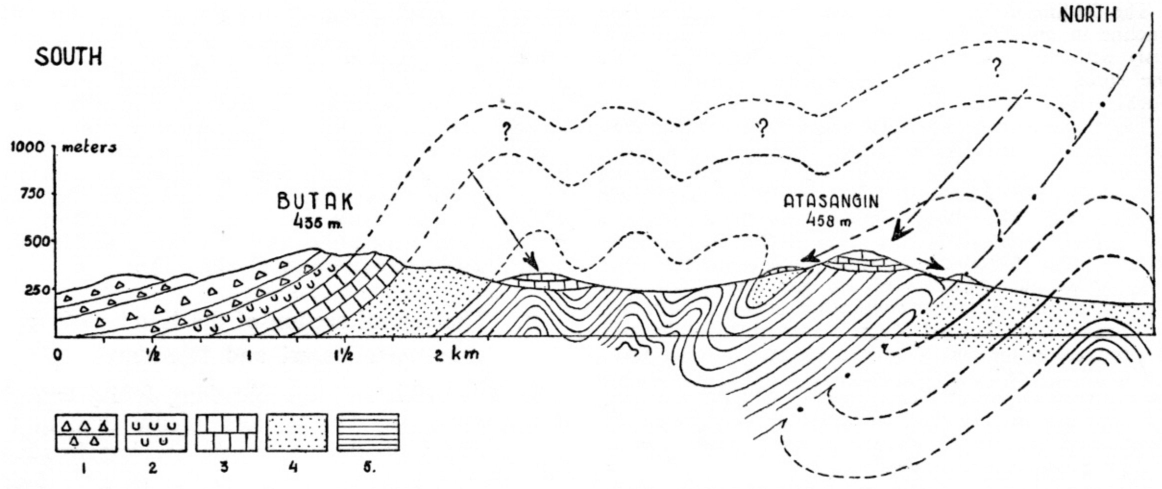

FIG. 287. *Section across G. Butak- G. Atasangin (Central part of the Kendeng Zone).*

1. Notopuro Breccias	Lower Pleistocene.
2. Ngronan Horizon	Plio-Pleistocene.
3. Klitik Limestones (= Upper Kalibeng)	Upper Pliocene.
4. Unstratified *Globigerina*-marls (Lower Kalibeng)	Lower Pliocene. (+ Upper Miocene).
5. Kerek Layers	Lower-Middle Miocene.

The Upper Kalibeng Beds (limestones) of the South flank are conformably overlain by calcareous tuff-sandstones with marine molluscs and locally some *Balanus*-limestones. This **Ngronan Horizon** is 100 m thick and forms the transition to the following volcanic Putjangan Layers. This Ngronan Horizon is comparable with the Sonde Marls and *Balanus*-limestones in the western Kendeng, but might be somewhat younger in age according to DUYFJES (1936, p. 143), who assigns it already to the lower-pleistocene Putjangan Layers. This is in accordance with the general observation that the boundary between the marine strata and the terrestrial deposits is situated from West to East in ever higher parts of the section until in Strait Ma-dura the marine conditions persist up to the present time.

The Putjangan Layers in volcanic facies follow conformably on this Ngronan horizon. They consist of the eruption products of the oldest Wilis volcano, and contain near Kedungbrubus (South of Butak) a lower-pleistocene Djetis fauna (VON KOENIGSWALD, 1934, DUYFJES, 1936).

The Putjangan Layers are again conformably covered by about 225 m of cross-bedded, coarse-grained andesitic sandstones and conglomerates with some intercalations of ashtuff. These deposits contain vertebrate fossils of the Trinil fauna, therefore they are the equivalent of the middle-pleistocene **Kabuh Layers.** These layers also contain intercalations of sandy *Globigerina*-marls, up to 30 m thick; however, on account of the presence of fresh water molluscs *(Melania, Unio)* these *Globigerina*-marls are fresh water deposits, consisting of erosion products of the marine *Globigerina*-marls of the Kendeng. Also pebbles of *Globigerina*-limestone are found in the Kabuh Layers. These observations prove that the central part of the Kendeng Zone was folded up during the deposition of the Kabuh Layers, the latter having a synorogenic character, as was already pointed out for the Kabuh Layers of Sangiran and Trinil in the western Kendeng.

Notopuro breccias were deposited conformably on top of this Butak-Kedungbrubus section. Their southward dip in the South flank of the Kendeng gradually diminishes towards the central axis of the Ngawi Subzone near Saradan, where they are found in a horizontal position. Moreover, the breccias become coarser in a southward direction (large angular blocks). They belong to the Old Wilis volcano. South of Saradan they are covered by the products of the younger Wilis volcanism.

To this Notopuro stage belongs also the Small **Pandan volcano,** situated on the southern margin of the Kendeng foldsystem, East of Butak. Its tuff mantle covers all the forementioned strata. Only the Notopuro breccias in its neighbourhood contain some intercalations of coarse breccias presumably belonging to the Pandan.

The fact that the magma pierced the Kendeng fold-system in the Upper Pleistocene, forming the Pandan volcano points to presence of active, upward striving magma in the core of this anticlinorium. This magma might be responsible for arching up of the latter in post-Notopuro time, and contemporaneous subsidence of the adjacent strips.

LEHMANN (1936, p. 76) is of the same opinion, stating that the high elevation of the crosional surface of the Kendeng Zone in the Pandan sector (350-450 m) has been caused by a later magmatic intumescence ("Aufblähung") of this area in relation with the Pandan volcanism.

Just as in the western section, the main folding of the Kendeng Zone occurred already in the Middle-Pleistocene, when the synorogenic Kabuh Layers were formed. Doming up of the Kendeng plane of subaerial denudation by endogenic forces happened later, after the upper-pleistocene Notopuro stage.

C. The eastern section of the Kendeng Zone between Djombang and Strait Madura

In this section of the Kendeng anticlinorium the folds become more simple and they plunge one after the other under the alluvial deposits of the Brantas delta. This area was described by DUYFJES in the explanatory notes for the sheets 109 (La-mongan), 110 (Modjokerto), 115 (Surabaja), and 116 (Sidoardjo) of the geological map of Java (scale 1 : 100,000). Fig. 288 on pl. **28** is a composite section across this part of the Kendeng ridge according to DUYFJES.

FIG. 288 on PLATE 28. *Composite section across the eastern Kendeng and the Solo Valley near Babad.* (According to DUYFJES)

1. Alluvium.
2. Djombang Beds.
3. Kabuh Beds.
4. Putjangan Beds in volcanic facies.
5. Putjangan Beds in marine clay facies.
6. Upper Kalibeng in Pengampon facies.
7. Upper Kalibeng Beds in limestone facies.
8. Lower Kalibeng Beds.

Neogene. In this part of the Kendeng Ridge the Kerek Beds are not exposed; the series begins with the *Globigerina*-marls of the **Lower Kalibeng Beds.**

The limestones of the **Upper Kalibeng Beds,** occurring farther westward, pass gradually into a complex of thinly laminated diatomaceous marls, which are called the **Pengampon facies** (REINHOLD, 1937).

In the upper part of the Upper Kalibeng stage locally already a thin horizon with fresh water molluscs *(Unio)* occurs, indicating an interruption in the sequence of marine strata due to very slight oscillations.

Lower Pleistocene. In the **Putjangan stage** the volcanic facies appeared eastward in higher and higher levels, and the lower part of the Putjangan Beds developed in a marine facies of increasing thickness. SMIT SIBINGA (1947 a) ascribes this retreat of the coast line to the Mindel regression, thus attempting to fit this phenomenon into his scheme of glacial chronology. However, DUYFJES pointed out, that it probably has a quite local cause, viz. the growing height of the Wilis volcano and the corresponding eastward extension of its terrestrial foot of lahar breccias (see fig. 282).

The transition from the Putjangan Layers with fresh water molluscs into the marine facies has been closely studied in the western part of sheet 110 (Modjokerto), where the volcanic facies already contains three key-horizons with marine molluscs:

h. Upper breccias level
g. Molluscan horizon III } 225 m.
f. Sandstone and tuff-sandstone
e. Molluscan horizon II
d. Middle breccias level
c. Bedded sandstone and tuff-sandstone } 275 m.
b. Lower breccias level
a. Molluscan horizon I

The molluscan horizon I is the eastward extension of the Ngronan horizon in the South flank of the Central Kendeng near Butak.

Still farther eastward, in the NW corner of sheet 116 (Sidoardjo), the Putjangan Layers arc exposed in the core of the Kedungwaru anticline near Perning, where they show the following succession (DUYFJES, 1936, p. 138-139):

h (p.p.) =	7.	Coarse and fine grained tuff-sandstone	± 35 m
g =	6.	Marly and argillaceous tuff-sandstone with marine molluscs and echinids (Molluscan horizon III	± 10 m
	5.	Green clay horizon	± 5 m

f =	4.	Coarse sandstone in thick beds and lenses of andesitic conglomerates. Also intercalations of argillaceous tuffs, towards the base thinner beds of tuff-sandstone, forming the transition to 3..	± 100 m
	3.	Thin bedded, fine grained tuff-sandstones containing more or less mud............	± 10 m
e =	2.	Marly and clayey, sometimes somewhat conglomeratic tuff-sandstone with marine molluscs and solitary corals Molluscan horizon II	± 15 m
d or *e* =	1.	Tuff-sandstone and argillaceous tuff-sandstone, sometimes also with molluscs and then not clearly distinct from 2...	± 25 m

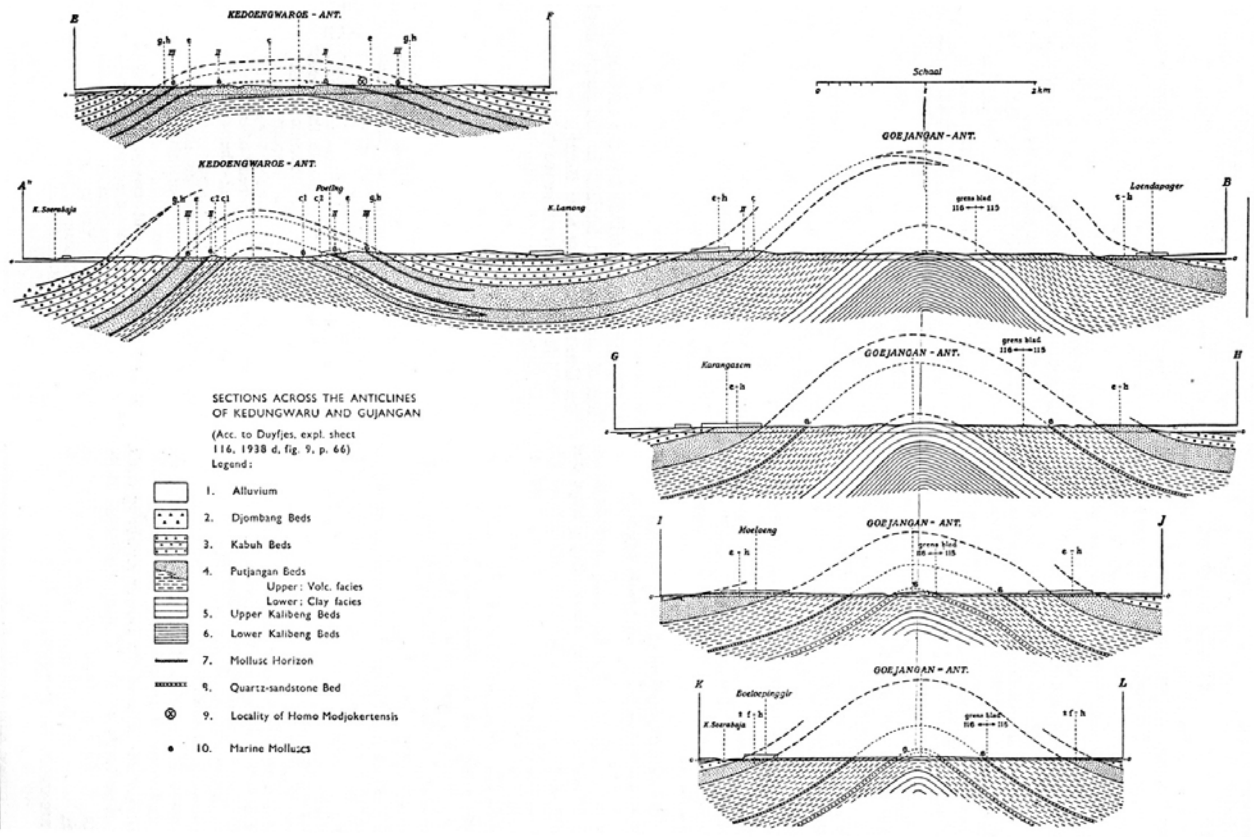

FIG. 289. *Sections across the anticlines of Kedungwaru and Gujangan*, according to DUYFJES.

The basal part of the Putjangan Layers is not exposed near Perning, but farther East it appears to consist of blue marine clays of the non-volcanic Putjangan facies, while West of Perning the volcanic facies begins already in the section 250 m below the molluscan horizon II.

Some kilometres West of Perning the level (7) of tuff-sandstones is still covered by 25 m of ande-site-breccias, forming the border with the Kabuh Layers, but these breccias wedge out eastward.

The molluscan horizon II is identical with the lower mollusc horizon of COSIJN'S stratigraphy (COSIJN, 1932) and the molluscan horizon III with the upper one of this author. MARTIN (1932) determined the molluscs collected by COSIJN and found in the lower level 128 marine species, + 68 % of which are still living, so that he concluded to an upper-pliocene age. The upper level furnished 28 species and resembles very much the molluscan fauna in the lower one.

However, the sandstones between these two marine levels contain a rich fauna of vertebrates, which occasionally were also found by COSIJN in the molluscan horizons II and III (1932, p. 139 and 141). This vertebrate fauna according to VON KOENIGSWALD (1934, p. 190) belongs to the lower Pleistocene (Djetis-fauna). It was also found in levels of the Putjangan layers below the molluscan horizon II. Therefore, the vertebrate stratigraphy assigns a younger age to these Putjangan Layers than MARTIN'S method with the percentage of living species of marine molluscs. The former method for the determination of the age is prefered, as the vertebrates show a quicker evolution in young neogene and quaternary time than the molluscs; therefore, they provide a more dependable basis for a detailed stratigraphical subdivision in this epoch than MARTIN'S method.

In the sandstones between the molluscan horizons II and III the skull of *Homo modjokertensis*, and a baby-skull, perhaps of *Pithecanthropus* was found in 1936 (VON KOENIGSWALD, 1936). This skull was collected in an excavation in a layer, dipping 10° North; therefore, it is a clear example of a hominide fossil found *in situ* in a folded series of strata. Jt lies in the lahar deposits of the Oldest Wilis volcano. These lahars or mudflows had killed the then living vertebrates and hominides and swept them into the marine basin of the eastern Kendeng Zone.

The *Homo Modjokertensis* of Perning (fig. 289, section E-F) is up to the present the oldest, well-established find of a hominide skull in Java, lying in lower-pleistocene strata. (The Black Clays of the Putjangan stage in Sangiran probably contain also skeletal parts of hominides, but these are always found at the surface, washed out and displaced by erosion, so that it is not quite certain whether they were not derived from the surrounding escarpments of the Kabuh Layers with their middle-pleistocene Trinil fauna.)

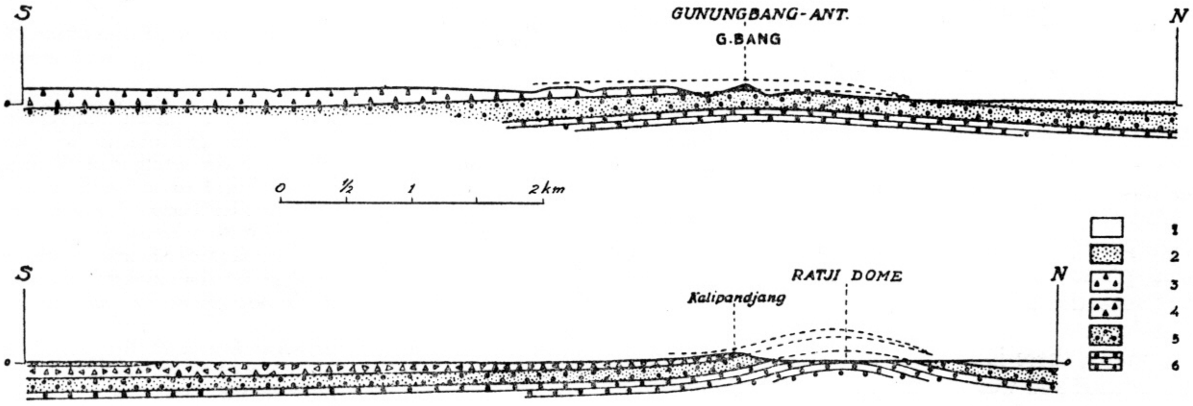

FIG. 290. *Sections across the anticlines of Gunungbang and Ratji near Bangil.* (According to DUYFJES, 1938 d, fig. 4, p. 42)

Legend:
1. Alluvium.
2. Young volcanic deposits.
3. Old-Ardjuno breccias.
4. Djombang Beds (breccias).
5. Djombang Beds (sandstones and conglomerates).
6. Kabuh Beds.

Middle Pleistocene. The **Kabuh Layers** follow conformably upon the Putjangan Layers. They consist of fine- and coarse-grained cross-bedded sandstones and tuff-sandstones with conglomeratic lenses. In the Perning area a marine intercalation was found at about 50 m above the Putjangan Layers, but in the higher levels of the section only badly preserved fresh water molluscs were found. The collected vertebrate fossils belong to the middle-pleistocene Trinil fauna.

Farther eastward the facies of the Kabuh Layers becomes more and more marine, while fresh water molluscs disappear. In sheet 110 (Modjokerto) the central strip of the Kabuh Layers has still a terrestrial -fluviatile facies, passing to the South and North into a marine facies. It appears that in sheet 116 (Sidoardjo) also the eastward extension of the central strip assumes a marine facies, as green marly clays are intercalated between the tuff-sandstones.

Also the Kabuh Layers exposed in the Ratji dome (East of Bangil), at the North foot of the Ardjuno-Welirang volcano, have a marine fades (green clays and clay-sandstones with marine molluscs, most of them recent with the exception of *Area menengtengana;* DUYFJES, 1938, sheet 116, p. 39-40). See fig. 290.

Upper Pleistocene. In the southern part of the Brantas plain we find on top of the Kabuh Beds a series of gently folded volcanic deposits, called **Djombang Layers,** belonging to the Notopuro stage. They are provisionally considered to be of upper-pleistocene age on account of their strati-graphical position on top of the Kabuh Layers, but vertebrates have not yet been found in them. The basal strata of the Djombang Layers were deposited in a marine environment, as could be observed in the exposures of the Ratji dome (DUYFJES, 1938, sheet 116, p. 41).

The alterations of the littoral fades of the Upper Kabuh Layers into the terrestrial facies of the Djombang Layers was obviously the result of the deposition of a relatively thick pile of volcanic breccias (lahar deposits) on the floor of a very shallow sea. Consequently, the latter was crowded out. This change of facies cannot be ascribed to the Riss regression, as was suggested by SMIT SIBINGA (1947 a). See table 19.

Tectogenesis. In general the Kendeng foldsystem plunges eastward under the young alluvial deposits of the Brantas delta. One after the other the southern anticlines disappear and, finally, only the northern anticline (that of Kedungwaru-Gu-jangan) can be traced to Surabaja.

Folding is here much less intensive than in the western part of the Kendeng Zone. It occurred after the deposition of the upper-pleistocene Djombang Layers, as in the anticlines of the southern part of the Brantas plain (e.g. in the Bangil anticline) the Djombang Layers are also folded. Moreover, in the southern flank of the Kedungwaru anticline a southward dipping bed of volcanic breccias, belonging to the Djombang stage, lies conformably upon the middle-pleistocene Kabuh Layers (see fig. 289).

These observations indicate that the main phase of folding occurred after the Djombang stage, at the end of the Pleistocene. The middle-pleistocene phase of folding, which is the main folding process of the central and western Kendeng, is hardly recognizable in this eastern part, whereas the post-Notopuro phase of folding, being only a superficial after-phase in the central and western Kendeng, becomes the main folding process in the eastern Kendeng.

Finally, there is already an initial arching up of the central and western Kendeng Zone in the Holo-cene, whereas the eastern end of the Kendeng geo-syncline is still subsiding, as appears from the presence of black soil in artesian wells at depths up to 120 m below sealevel (Duyfjes, 1938, sheet 110, p. 57, sheet 116, p. 58).

In the middle ages, till 1396, the estuary of the Brantas River was still navigable for sea-going ships upstream to Modjokerto (Maclaine Pont, 1928). Its final silting up cannot have taken place before historical time.

The pre-neogene basement complex in the eastern Kendeng presumably lies about 6 km below the surface, according to the interpretation of gravi-metrical observations published by Vreugde (1935) (see section, fig. 88).

Thus it can be said that the stratigraphy as well as the tectonics of the Kendeng Zone indicate that its eastern portion is in a younger stage of evolution than the central and western ones. This eastward rejuvenation is also shown by the fact that in the Strait of Madura, which forms its eastern extension, the geosyncline has not yet been filled up, while only some gentle folding occurred at the end of the Pleistocene along its southern margin.

Duyfjes (1938) has shown that the anticlines of Gujangan near Surabaja and Pulungan South of it are cut off by transverse faults, with a downthrow of the eastern parts. These faults mark the transition between the end of the Kendeng Zone (where already some gentle folding occurred at the end of the Pleistocene on the one side, and the Strait of Madura which was neither filled up nor folded on the other.

Summary of the Kendeng anticlinorium. This conception of the evolution of the Kendeng - Strait of Madura Zone is summarized in table 108.

Tectogenesis of the Kendeng.

In the foregoing analysis of the evolution of the Kendeng Zone in neogene and quaternary time three types of folding and warping can be distinguished in accordance with the local circumstances in this zone and the adjacent belts. Distinction has been made between:

1. Folding by the collapse of the Java geanticline	Gravitational- or secondary tectogenesis
2. Folding by the collapse of volcanic cones	
3. Arching up of the plain of denudation by upward pressure of endogenic (magmatic) forces	Differential uplift or primary tectogenesis

At first sight, this manner of treatment may appear rather confusing. Indeed, it would be much simpler to ascribe these various tectogenetic phenomena to one general cause, viz. a compressive force acting from S to N in the Kendeng Zone, which effected successively; 1. the main folding during the Middle Pleistocene, 2. the gentle folding at the end of the Upper Pleistocene, and 3. the arching up of the erosional surface in the Holocene. Such an unicausal treatment certainly has the advange of being more surveyable, and meets our desire for uniformity of conception.

Such an unicausal analysis is based on the postulate that all these folding and warping movements are the result of a compressive force in the crust. But in nature many ways may lead to analogous results; for instance, an emergence of a tectonical belt may be either the result of its lateral compression, or of its vertical uplift, or even of a eustatic lowering of the sealevel. It is the task of the geologist to combine the numerous local and regional data to a general picture of the crustal evolution in which all these possible causes have been considered and the most probable ones selected. If it appears that the main phase of folding of the Kendeng geosyncline in the Middle Pleistocene probably occurs contemporaneously with the uplift, blockfaulting and dilatation of the adjacent Java geanticline, then it seems logical to combine these processes as the complementary effects of gravitational tectogenesis. Further, when folding of the upper-pleistocene Notopuro breccias appears to be restricted to areas opposite to portions of volcanoes which broke off and slipped down to the lower foreland, then this folding is better interpreted as the effect of gravitational movements of a more restricted and superficial type. Finally, when a general upwarp of the erosional surface of the Kendeng foldsystem in the Holocene can be stated, combined with a comtemporaneous downwarp of the adjacent Ngawi- and Randublatung Zones, while, moreover, it is an isostatically uncompensated zone with negative isostatic anomalies, then it appears to be more probable that endogenic forces acting vertically upward were the fundamental cause of this differential uplift.

There might even be a genetic relation between the culmination of the arching up of the western section opposite the Lawu volcano and that of the central section opposite the Wilis volcano on the one side, and the extra loads of these volcanoes on the other. There might be a hydrostatic transfer of pressure from these volcanic loads via the migmatized and mobilized lower part of the crust to their foreland.

All these possibilities should be considered. It is evident that a close agreement between the real character of the natural processes on the one side, and our conception of them on the other, can be attained only by a careful arrangement of the observations, and the selection of one solution from a score of possibilities. When our interpretation of the facts is based on a single possibility, viz. the *a priori* postulate of a hypothetical compressive force of unknown magnitude, then we put our conception of Nature into the strait jacket of a hypothesis.