TABLE 108. *Correlation scheme of the Kendeng Zone and the Strait of Madura Zone.*

	Western Kendeng (Between Ungaran and Ngawi)	Central Kendeng (Between Ngawi and Djombang)	Eastern Kendeng (East of Djombang)	Strait of Madura
Holocene	Arching up of the erosional surface of the anticlinorium. Young Ungaran volcano	Arching up of the erosional surface of the anticlinorium	Continuance of the geosynclinal subsidence in the Brantas delta	Continuance of the geo-synclinal subsidence
Upper Pleistocene (upper part)	Local folding by volcano tectonic collapses (Old Ungaran, Soropati, Old Lawu)		Gentle folding of the whole zone	Gentle folding along its southern margin
Upper Pleistocene (lower part)	Deposition of Notopuro breccias	Pandan volcanism and formation of Notopuro breccias	Deposition of the Djombang breccias	Geosyn-clinal subsidence
Middle Pleistocene	Intensive northward folding and thrusting (synorogenic fluviatile Kabuh Beds)	Northward folding (synorogenic fluviatile Kabuh Beds)	Continued geosynclinal subsidence (limnic and marine Kabuh Beds)	
Lower Pleistocene	First emergence (Formation of Black Clays in the Blitar Subzone = fluviatile-estuarine Putjangan Beds)	Final filling up of the geosyncline (Oldest Wilis volcanism forms the volcanic Putjangan Beds)	Continued geosynclinal subsidence (marine facies of Putjangan Beds)	
Upper Pliocene	Northwestern flank (Ungaran) Synorogenic Lower Damar Beds Southern flank Upper Kalibeng (Klitik limestone and Sondé marl)	Marine Upper Kalibeng (*Globigerina*- and coral limestone)	Diatomaceous marls (Pengampon facies)	
Middle-Lower Pliocene	Kalibiuk Beds Kapung limestones	Unstratified white *Globigerina*-marls of the Lower Kalibeng Beds	Lower Kalibeng *Globigerina*-marls	
Upper Miocene	Tjipluk Beds Banjak Beds			
Lower-Middle Miocene	Kerek Beds	? Kerek Beds	Not exposed	
Aquitanian	Pelang Beds	Not exposed		
Oligocene	Not exposed (occurring in aquitanian congl.)			

Stille's orogenic phases. We will finish our discussion of the Kendeng Zone with a general discussion of the orogenic phases distinguished by STILLE. This author discerns in the earth's history a number of orogenic phases of relatively short duration, separated by longer phases of more quiet evolution. This is STILLE's wellknown canon for the geological history of the earth (see, for instance, STILLE, 1944 a). In his earlier papers STILLE considered the Quaternary as a quiet period, on account of the conditions in Europe. In 1935, however, after a visit to California, this author had to add a new phase to his scheme, the Pasadenic phase, which was active in the younger Quaternary. The duration of this phase would be about a quarter of a million years. This phase would be separated by a more quiet period from the late pliocene Wallachic phase.

This distinction cannot be made for the Kendeng Zone. This zone belongs to a continuous orogenic belt, viz. the geosyncline of northern Java. Eastward it joins on to the Strait of Madura, and westward to the North Seraju Mountains in Central Java.

Folding in this belt occurred from West to East, over a distance of about 400 km, in gradually younger stratigraphical levels:

North Seraju Range	late Pliocene
Westernmost Kendeng (Ardjawinangun)	Lower Pleistocene
West and Central Kendeng	Middle Pleistocene

Eastern Kendeng	Upper Pleistocene
Strait of Madura	(not yet started).

Thus it appears that for this orogenic belt no distinction can be made between a Wallachic and a Pasadenic phase. There is a gradual shift of the age of folding in the course of about one million years over an axial distance measuring only about 400 km. If considered as belonging to one and the same orogenic phase, the short duration of STILLE'S phases would become questionable. If split into more than one phase we come into conflict with the regional geological facts. It appears from this example that STILLE'S system is overschematized. The tectonic phases are either not of short duration or not world-wide. The greater eras of mountain-building, such as the Alpidic and the Variscic eras, certainly comprised very large portions of the earth's surface. But their subphases, most probably, only had a local or regional importance. Considering these subphases as world-wide means a straining of stratigraphical data. This has been pointed out by HAARMANN (1933). We will return to this question in the final chapter of this volume (Chapter VI).

4. THE RANDUBLATUNG ZONE

This is a physiographic depression zone, separating the Kendeng foldsystem (with northward folding and thrusting) from the Rembang anticlino-rium (with a prevalent southward compression). Physiographically, the Randublatung Zone is narrowest (5 km) near Randublatung, West of Tjepu, and from there it becomes wider to the West and East.

In the wide eastern part, between Bodjonegoro and Surabaja, some gentle folds and domes are found, neither clearly belonging to the Rembang anticlinorium nor to the Kendeng fold system. These are the anticlines or domes of Dander, Pegat, Ngimbang, Metatu, Grigis, and Lidah, described by DUYFJES, 1938 (sheet 109, Lamongan, and 115, Surabaja).

In the eastern anticlines (Metatu, Grigis, and Lidah) only the pleistocene strata are exposed (lower pleistocene Putjangan Layers in marine, and volcanic facies, middle pleistocene Kabuh Layers in marine facies of green and blue clays). In the western ones also the pliocene strata are exposed: Upper Kalibeng developed as limestones and marls, and Lower Kalibeng (only in Ngimbang) occurring as white *Globigerina*-marls.

The anticlines of Pegat, Grigis, and Metatu are somewhat asymmetric with steeper South flanks, so that they were presumably formed by the southward directed pressure field of the Rembang anticlinorium. The southern ones (Dander, Ngimbang, and Lidah) are more symmetrical sinus-folds. The dome-like elevation of the Ngimbang structure shows tensional faulting in the Upper Kalibeng limestones.

On its southeastern side the Ngimbang dome is cut off by a crescentic slip-fault along which its SE portion subsided toward the depression of the Lamong River.

This means that already such slight differences in height as were caused by doming up of Ngimbang at the end of the Pleistocene may locally have caused some superficial phenomena of gravitational tectogenesis in these plastic marine strata.

It appears from the gravimetrical section, published by VREUGDE (1935) (see fig. 88) that this eastern part of the Randublatung Zone, comprised between the lower course of the Solo River and the Kendeng Zone, is probably underlain by an upward bulge of the basement complex, lying near Ngimbang presumably only about 1.3 km below sealevel.

The positive Bouguer-anomalies in this part of the Randublatung Zone belong to an extensive field of positive anomalies underlying the Rembang anti-clinorium. In its broadest part a central strip shows smaller positive or even negative anomalies. The negative anomalies (1-3) are found North of Ngimbang, in the alluvial plain of the Solo between Babad and Lamongan. Farther North the anomalies increase again with a very steep gradient towards the pliocene limestone belt of Tuban. This steep rise indicates a southward dipping normal fault in the basement complex. This field of positive Bou-guer anomalies will be discussed in the next section on the Rembang anticlinorium. It is mentioned here only as an argument for the conception that these folds between Bodjonegoro and Surabaja form part of the Rembang fold system.

West of Bodjonegoro (Dander) the Randublatung Zone is essentially a belt of subsidence without young folds. Tilted high terraces occur on both sides, as has been demonstrated by LEHMANN (1936).

The gravels of the high terraces lie on the southern border of the Solo Valley at 40-45 m above sealevel and rise on the border of the Kendeng up to a level of 85 m (Triangulation point S 639, West of Ngambon). The erosional surface upon which these terrace gravels were deposited cuts off the neogene strata of the Kendeng. The same situation is found near Tjepu, where the quaternary gravels are found on the hills on the NW side of the town, up to a height of 47 m above sea (Tjepu is built, on the lower terrace of alluvial deposits at 25-30 m above sealevel). The high terrace deposits dip toward the axis of the Randublatung syncline, disappearing under those of the low terrace. The line of intersection between both is situated North of the main road from Tjepu to Bodjonegoro.

The high terraces are bent up along the borders of the Randublatung depression, while in its central part the accumulation of alluvial deposits continues at the present time. At some places also the lower terrace level shows already such a morphological sagging.

LEHMANN (1936, p. 100-109) attempted to correlate these terraces with the custatic alterations of the sealevel due to the quaternary glaciations. This method has been elaborated by SMIT SIBINGA (1944, 1947), and has been amply discussed in Chapter II. According to the present author first the local orogenic influences have to be considered. Only if it appears that these terraces cannot be explained by local or regional oscillations, warping, and folding, then it might be attempted to take world-wide, eustatic oscillations of the sealevel into account. The application of glacial chronology to this highly mobile region is a very hazardous enterprise.

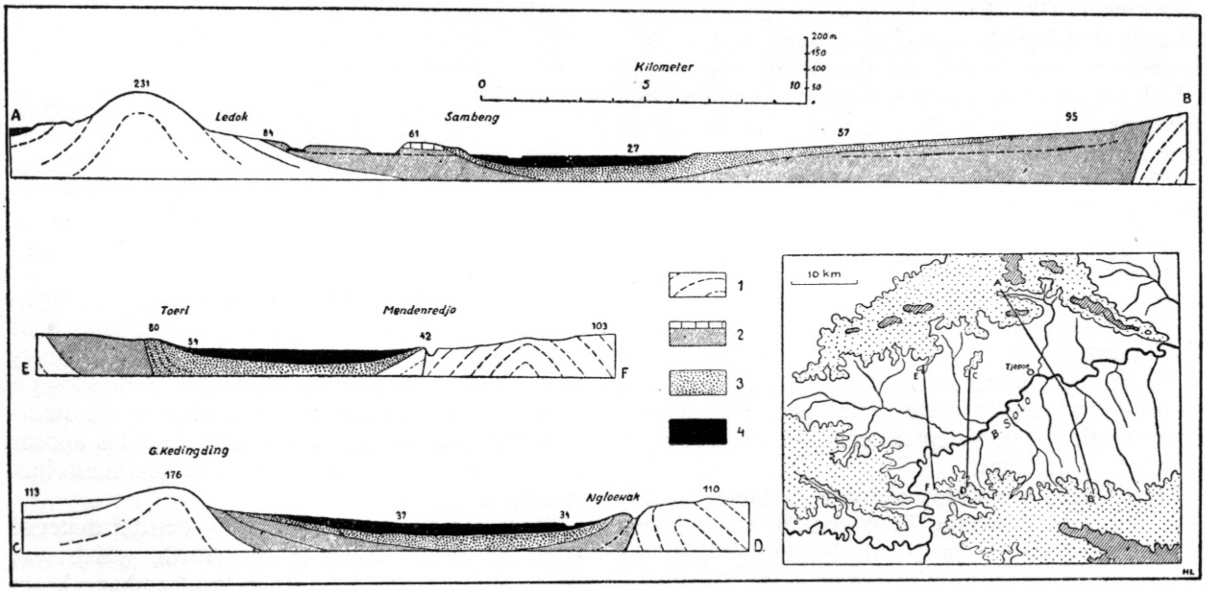

FIG. 291. *Three sections across the Solo Valley near Tjepu.* (According to LEHMANN, 1936, with revised stratigraphy)
1. Neogene.
2. Lower pleistocene Turi Beds or Putjangan Layers in marine facies.
3. Upper Pleistocene (high terraces along the borders; in the deeper, central parts also middle-pleistocene Kabuh Layers).
4. Holocene.
The accessory map shows the contour lines of 100 and 200 m and the position of the sections.

5. THE HILLY DISTRICT OF REMBANG [14])

The stratigraphy of this area is known in details to the Oil Companies, especially the "Bataafsche Petroleum Maatschappij", which have made detailed geological and stratigraphical investigations with all possible methods. However, only the general outlines of the stratigraphy and tectonics of this area are published, e.g. by 'T HOEN (1930), SCHUPPLI (1932, 1946), VREUGDE (1935).

On the other hand, little work has been done in this area by the geologists of the Geological Survey of the Netherlands Indies, as this would mean a duplicating effort, the results of which would never attain the completeness of the knowledge already gathered by the geologists of the oil-companies by their field work, the study of drilling cores, and geophysical, paleontological, and sediment-petro-graphical methods. It is a regrettable circumstance that commercial interests of the oil companies has not permitted the full publication of the geological data known from their concession terrains in the East Indies.

Moreover, it seems that in later years the stratigraphy of Rembang had to be revised, as it appeared that small *Lepidocyclina* may occur in much higher strata, than was formerly accepted. DUYFJES (1938, sheet 115, note p. 29-30) stated already that *Lepidocyclina* were found in the Klitik limestones near Ngawi, the young-pliocene age of which was fixed by a sondean molluscan fauna. But it seems that even in the Putjangan Layers sometimes small *Lepidocyclina* do occur.

Therefore, the correlation of the Rembang stratigraphy with that of the Kendeng Zone is still uncertain in several respects.

Stratigraphy. For the Tjepu area the following general succession can be given (table 109).

[14] See also the geological sketchmap of this area in Vol. II, fig. 5 (Economic Geology of the East Indies).

The Wonotjolo and Ledok stages were considered by Bataafsche Petroleum Maatschappij geologists to be of upper-miocene age (T.g), but there seems to be a tendency to place their upper part higher in the section. The basement complex has not been reached by drillings.

Northward, important changes in facies occur. The northern Rembang Beds contain some intercalated coal-seams. In North Rembang there is moreover an unconformity between the Rembang Beds and a massive pliocene limestone called "Karren"-limestone. This Karren-limestone seems to be the northern facies of the Ledok and (the lower part) of the *Globigerina*-marls. The strati-graphical gap in North Rembang is probably represented by the Wonotjolo Beds in southern Rembang (Tjepu area).

According to sediment-petrographical investigations by EDELMAN & DOEGLAS the Rembang Beds contain zircon as a typical constituent of the heavy minerals. The base of the Wonotjolo Beds shows a transition from the zircon-association to the staur-olite-titanite association. The first epidotes appear in the Wonotjolo Beds, mixed with the staurolite-titanite association.

TABLE 109. *Stratigraphy of the Tertiary in the Tjepu area.*

Name	Composition	Age	Thickness
Marl-clay formation (Turi stage)	Blue clays with marls and shell-limestones (Malo)	Plio-PIeistocene	± 300-400 m
	Lower stage of blue clays [15])		
Mundu stage	Diatomaceous horizon at the base of the blue clays (5-10 m). *Globigerina-marls*	Pliocene	± 200 m
Ledok stage	Glauconitic sandstones alternating with platy limestones and softer sandstones, with small Foraminifera. Often cross-bedding. Delta formation		± 200 m
Wonotjolo stage	Sandy *Globigerina*-marls with some giauconitic sandstone beds. Platy sandy limestones and calcareous sandstones	Mio-Pliocene	± 700 m
Rembang Beds	Foraminiferal limestones, clays, and sandstones [16])	Lower-Middle Miocene	> 3000 m

These sediments are apparently detrital material from the Sunda Land in the North, which was the source area for deposits in the Rembang basin during the Neogene.

Higher in the section the epidote association and the hornblende-pyroxene association are found. Apparently, during the Pliocene volcanic activity was the chief source of heavy-fraction minerals.

Some of the miocene and pliocene beds become increasingly tuffaceous towards the South, indicating the existence of volcanoes in the present geanti-clinal parts of Java (SCHUPPLI 1946, p. 17).

Tectogenesis. First folding occurred already after the deposition of the Rembang Beds. While northern Rembang emerged above sealevel during the Mio-Pliocene, the marine sedimentation continued uninterrupted in southern Rembang. But also in the Tjepu area some late miocene folding took place during the sedimentation.

SCHUPPLI (1946) writes about this late miocene folding as follows:

"The oil is accumulated in moderately deep anticlines, generally intersected by normal faults, and commonly characterized by pronounced asymmetry. The steep flanks are in places associated with thrust faults observable at the surface or revealed by drilling. Interesting observations in this respect have been made in the Nglobo field. This anticline at the surface is gentle with flank dips of about 10°, which, however, in a longitudinal zone in the south-flank steepen to about 20°. At a depth of approximately 2500 feet this slightly steeper zone has developed into a pronounced steep zone connected with a thrust fault of small throw. These observations cannot be explained by an unconformity related to a distinct period of folding. Slight folding evidently took place more or less continuously during the deposition of the upper-mioccne beds. This is also indicated by detailed surface mapping, which revealed facies changes in different formations of the Upper Miocene, coinciding with structural configuration."

The main phase of folding occurred in the Pleistocene, after the deposition of the Blue Clays. The direction of these folding and thrusting movements was generally southward, just as the late miocene folding. In northern Rembang also some northward upthrusts are found.

This second phase of folding occurred during a renewed uplift of northern Rembang and the adjacent part of the Java Sea. During this second uplift the magma could reach the surface, building up the small volcanoes of Lasem and Butak near the North coast. The Butak andesite occupies the core of an anticlinal structure.

[15] SCHUPPLI (1932) gives a list of molluscs determined by VAN DER VLERK with 51.7 % recent species, while Sonde has 53 %. Identical with Sonde are: *Pleurotoma gendinganensis* MART., *Voluta gendinganensis* MART., *Strombus Isabella* LAMK. var. *thersites*, *Strombus madiunensis* MART.

[16] Molluscs from the Rembang Beds were described by MARTIN, HAANSTRA & SPIKER (1932), WANNER & HAHN (1938), and Miss A. PANNEKOEK (1936). These form the so-ca!led "Rembangian" of OOSTINGH'S molluscan faunas, with a lower-miocene age (Burdigalian). According to Miss A. PANNEKOEK 212 molluscan species have been determined from the Rembang Beds, 40 of which are found in the recent Indo-Malayan area, that is 19 per cent. This corresponds with a lower miocene age.