

TABLE 110. Tentative correlation of the stratigraphy of the Tertiary and Quaternary in East Java.

Southern Mts	Solo Zone	Kendeng Zone		Rembang Zone		Age	Sections in fig. 293 on pl. 35	
	South of Surakarta	North of Surakarta	Semarang-Ungaran	Southern part	Northern part			
Erosion Uplift More or less at sealevel	Young volcanoes	Arching up		Alluvial deposits	Arching up (Java sea subsiding)	Holocene	Section VIII	
	~~~~~ Rifting ~~~~~ Notopuro stage of volcanism (Ngawi Sub-zone)	Waturalang terraces	Notopuro breccias	High terrace accumulation	Lasem + Butak volc. Uplift	Upper Pleistocene	Section VII	
	~~~~~ Rifting ~~~~~	(base-leveling)				Blue Clays with marls and shell-limestones (Malo) Blue Clays		Middle Pleistocene
	Kabuh Beds	Kabuh (Trinil) Beds	Damar Series Upper Kalibeng	Globigerina Marls (Mundu)	Karren Limestones		Lower and Middle Pliocene	Section V
	Black Clays	Putjangan Beds				Ledok Beds		
	Balanus-Limestone	Balanus-Limestone		Kalibiuk Beds	Wonotjolo Beds	(Hiatus)	Upper Miocene	Section IV
	Sondé Marls	Sondé Marls						
	Klitik Limestone (overlap)	Klitik Limestone		Tjipluk Beds	Banjak Beds	Banjak Beds	Middle Miocene	Section III
		Lower Kalibeng (<i>Globigerina</i> marls)						
	Kepek Beds Wonosari-limestone Ojo Beds	Banjak volcanoes. Andesitic and liparitic dike intrusions. Old-andesite volcanoes	Upper Kerek Beds	Penjatan Series	Rembang Beds		Lower Miocene	
	"Old-andesite" Formation		Lower Kerek Beds	Merawu Series			Aquitanian	
	?	Micro-diorite intrusion (Djiwo)	Pelang Beds	Lutut Beds			Oligocene	Section II
	(Not exposed)		"Oligocene"	(Not exposed)			Eocene	Section I
		Eocene (Djiwo)					Pre-Tertiary	
		Cretaceous (Djiwo) and older base-ment complex						

ending with acid rocks, the Banjak volcanoes largely produced andesites characterized by the combination of augite and hornblende as dark constituents.

The intra-miocene uplift of the Solo Zone caused some further subsidence of the adjacent Kendeng Zone. This induced a gravitational reaction. The Kerek flysch series slid northward to the deepest part of the Kendeng geosyncline, which gave rise to some submarine folding. In the resulting submarine synclines the Banjak Beds accumulated, for instance in the Borangan syncline West of Kedungdjati. Farther East this compression caused also some temporary elevation above sealevel (transgressive conglomerates of the *Globigerina*-marls). In the Ungaran

area the Penjatan Series (Upper Kerek) were thrust northward over the Merawu Series (Lower Kerek), and here also some erosion has taken place before the younger neogene strata were deposited.

The subsidence and folding in the Kendeng Zone at the end of the Middle Miocene, caused also a further tilting of the unstable shelf area in the Rembang Zone. Consequently, also there some gravitational reactions occurred causing southward folding and thrusting in the Rembang Layers, which continued for some time during the Upper Miocene (according to SCHUPPLI, 1946).

This orogenic revolution at the end of the older Neogene was followed by a short but intensive phase of volcanic activity in the Solo Zone. The end of the Miocene again showed more quiet conditions of sedimentation.

In the Southern Mountains the Wonosari and Kepek Layers were formed, overlapping northward, while in the Kendeng Zone near Semarang the Tjipluk Beds were deposited. Farther East the lower part of the *Globigerina*-marls (Lower Kalibeng) developed. The Tjipluk Beds differ from the unstratified *Globigerina*-marls in showing many intercalations of augite-hornblende tuffsandstones of the Banjak volcanism.

The Upper Rembang Beds in the North are possibly partly the equivalent of the Banjak Layers farther South; the lower part of the Wonotjolo Beds (Ngrajong horizon of brown quartz sandstones) might be tentatively correlated with the Tjipluk Beds. However, these correlations are speculative owing to their different facies and the interruption of the exposures by the Randublatung Zone.

Section V, Lower + Middle Pliocene: The older Pliocene was a period of quiet evolution. The Solo Zone was base-leveled, while the Southern Mts formed a low-land with hardly any denudation. In the northwestern part of the Kendeng Zone geosynclinal subsidence continued, so that first the Kapung Limestones and then the Kalibiuk Beds (Middle-Pliocene, Plaisancian) were deposited. Farther East the facies changed into that of the unstratified white *Ghbigerina*-marls of the Lower Kalibeng.

The upper-miocene folding in the Rembang Zone was partly accompanied by some uplift of the adjacent Java Sea area (SW part of the Pulu Laut centre of diastrophism). This had caused some regression of the sea in northern Rembang, while in southern Rembang (Tjepu area) delta deposits were formed (Wonotjolo and Ledok Beds). Thereafter, the sea transgressed again over northern Rembang, where the massive Karren-limestones were formed, the lower part of which probably is the equivalent of the Ledok Beds in the Tjepu area.

Section VI, Upper Pliocene + Lower Pleistocene: In the Plio-Pleistocene the evolutionary period approached its end. The Southern Mts were still lowland, hardly above sea level without notable denudation. In the Solo-Zone base-leveling was almost completed; in its Wilis section volcanic activity had already begun, building up the Oldest Wilis volcano; but in the Lawu area, represented by the sections under discussion, volcanic activity had not yet started.

In the Kendeng Zone limestones of the Upper Kalibeng (Klitik Limestones) and the Sonde Marls were formed during the Upper Pliocene, overlapping southward into the Ngawi Subzone.

The Black Clays of the Putjangan stage, conformably overlying the Klitik Limestones, are entirely restricted to this Ngawi Subzone. These Black Clays were deposited in a fresh-water lake, which was formed by ponding up of the drainage by la har-breccias of the Oldest Wilis volcano. The Black Clays contain a rich vertebrate fauna of lower pleistocene age (Djetis fauna).

The western part of the Kendeng Zone proper emerged already at this time as a low threshold, which can be considered as an initial manifestation of the compression in the next stage (middle-pleistocene folding).

This threshold separated the fresh-water lake in the Ngawi Subzone from the open sea to the North. The Black Clays, deposited in this lake, still contain an intercalation of marine yellow clays, indicating a temporary sea connection. KINGMA (1948), studying the ostracods in this marine inter-bed, found some arguments for the supposition that this marine invasion came from the South coast.

North of the Kendeng Zone the marine sedimentation continued. Here first *Gtobigerina*-marls were deposited (Mundu stage), succeeded by the Blue Clays of the claymarl stage. In northern Rembang the formation of the massive coral-limestones continued (Karren Limestones).

Section VII, Middle (+ Upper) Pleistocene: Now the situation had matured again for an orogenic revolution.

In the Middle Pleistocene the Solo Zone was arched up by endogenic (viz. magmatic) forces. The Southern Mts, forming the southern flank of this geanticline, were elevated and tilted southward. In the series of massive limestones and the Old-andesite Formation of the Southern Mts, consolidated by a framework of intra-miocene dike-intrusions, important gravitational reactions to this uplift and tilting are not apparent. But the North flank of the Solo geanticline was bordered to the North by the neogene sequence of strata in the Kendeng Zone, which were not yet consolidated, but highly plastic.

The field of gravitational stresses, set up by the rising Solo geanticline, exceeded the bearing power of the northern flank of this geanticline.

Consequently, its crest collapsed and the magmatic core was squeezed northward towards the core of the Kendeng geosyncline ("Expressions Gleitung" in the sense of HAARMANN). The southern flank broke off, and along its northern edge normal slip-faults originated, forming a number of tilted and subsided blocks (such as the Kam-bengan Range), whereas the contents of the Kendeng geosyncline were intensely compressed and thrust northward.

Erosion immediately attacked the rising anticlines of the Kendeng Zone, the detritus of which was deposited in the adjacent Ngawi Subzone and in the Randublatung Zone (deposition of the synorogenic Kabuh Beds). It was during this very turbulent time, that the *Pithecanthropus* lived here, threatened by waterfloods, landslides, and frequent earthquakes.

The erosion of the soft Kendeng strata was very rapid, diminishing the weight of this fold system, which had to counterbalance the thrust from the Solo Zone. Therefore, folding and thrusting in the Kendeng Zone could proceed for some time during the Middle Pleistocene, until an equilibrium was attained between the load of the Solo Zone on the one side and that of the Kendeng anticlinorium on the other.

Thereafter the magma broke through the faulted crust in the Solo Zone, building up the Old Lawu volcano. This volcanism began already in the Middle Pleistocene and continued during the Upper Pleistocene. The Notopuro breccias, belonging to this Old-Lawu volcanism, unconformably covered the Kabuh Layers of the Ngawi Subzone and partly overlapped the surface of subaerial denudation in the Kendeng Zone.

The rise of the geanticline of Southern Java was accompanied by a subsidence of the basement complex in the adjacent Zones (Java trough to the South and Kendeng Zone to the North). However, in the Kendeng Zone this subsidence of the basement complex was over-compensated by the compression of the geosynclinal contents, so that the surface of the Kendeng fold system was elevated to some height above sealevel.

The subsidence of the pre-tertiary basement in the Kendeng Zone also affected the unstable shelf underlying the Rembang Zone, which was still more tilted to the South, inducing gravitational gliding of the plastic neogene strata to the South. This field of gravitational stresses was presumably enforced by some uplift of the adjacent part of the Java Sea (southwestern part of the Pulu Laut centre of diastrophism). In the elevated northern area tensional stresses prevailed; there the magma broke through the crust and the neogene strata, building up the Butak and the Lasem. Thus the Rembang area was disturbed by gravitational tectogenesis which had a prevailing southward direction. Both the sliding movements, viz. that of the Kendeng Zone and that of Rembang, converged toward the Randublatung Zone.

Section VIII, (Upper Pleistocene +) Holocene: The elevated and tilted peneplain of the Southern Mts was warped, forming the basins of Wonosari and Baturetno and partly reversing the drainage pattern from N → S into S → N.

The Old Lawu volcano in the Solo Zone collapsed and broke off along major crescentic rents. The northern portion of the Old Lawu slid northward and crumpled its North foot by superficial gravitational tectogenesis. The Gamping anticline at its North foot is shown in the section (see for further details the tectonogram fig. 281). Next the Young Lawu volcano and the Djobolarangan volcano were formed on these rifts.

Thereafter, the surface of subaerial denudation in the Kendeng Zone was arched up, causing the formation of the high terraces of Watualang, Ngandong, etc. This arching up is ascribed to the upward pressure of an not yet isostatically compensated mountain root at its base, indicated by negative isostatic anomalies. It is possible that the culmination of the Kendeng geanticline exactly opposite to (North of) the Lawu is caused by the extra load of this volcanic complex; this would be an additional factor to the endogenic rise of the Kendeng Zone. The downward pressure of the Lawu volcano is transmitted via the plastic (migmatized and magmatic) underground to the lower foreland of Kendeng, adding there to the upward pressure of the Kendeng root. So this might be an instance of a combination of a purely endogenic uplift by a mountain root with a rise due to lateral compression¹⁷). Meanwhile the downwarp of the Ngawi Subzone and the Randublatung Zone continued on both sides, and alluvial deposits accumulated in these depressed belts.

The Rembang Zone was also subjected to some warping of the surface. Two elevated areas (that of Tjepu and that of North Rembang) are separated by a downwarp (Lusi-Kening depression). Gravimetrical observations of the B.P.M. (published by VREUGDE, 1935) indicate below the Rembang area a broad geanticlinal upwarp of the basement complex with an asymmetric depression on its crest. This upwarp is presumably related with the concomitant submergence of the adjoining source-area to the North (southwestern part of the Pulu Laut Centre, now forming the southeastern part of the Java Sea, between Bawean and Rembang).

Of course the above sketch of the structural evolution of East Java is speculative in many respects. It will need corrections in the future when more facts become known. But we attempted to take into account all observations, which are often embarrassing and contradictory if interpreted by the classical method of a deep-seated, uniform compressive force in the crust. It appears that the observations harmoniously fit in this synthesis, and, therefore, it might be accepted as a working hypothesis.

7. THE SEMARANG-REMBANG DEPRESSION

The geanticlinal upwarp of the basement complex in the Rembang Zone, discussed in relation with the gravimetrical observations, is bordered to the North by a downwarp. Between Semarang and Rembang this downwarp has the character of a broad synclinal basin between the westward plunging end of the Rembang anticlinorium on the one side and the Muriah dome on the other. This syncline has an ENE-WSW trend. Farther eastward it joins on to the submerged source-area of the Rembang Zone, now forming the SE-part of the Java Sea.

The Semarang-Rembang downwarp existed already in the Neogene, as appears from the presence of Wonotjolo Beds in its underground, which are absent in the North Rembang anticlinorium between the Rembang Beds and the Karren Limestones. Therefore, it can be considered as a part of the unstable shelf border which has not been subjected to subsequent impulses of uplift or lateral compression.

In the late Quaternary the eustatic rise of the sealevel transformed this downwarp into a strait between the Rembang anticlinorium and the Muriah Complex. Silting up of this strait was not completed before the middle ages, as at that time ships could still sail South of the Muriah.

According to Prof. NIERMEYER in Colijn's book "Neer-lands Indië" (1913, Part I, p. 41) seagoing vessels in the 18th century could still pass through the strait from Demak via Kudus and Pati to Rembang. The alluvial stretch which separates the Muriah from the mainland of Java is very young indeed.

¹⁷ A similar combination of primary, upward pressure by endogenic (magmatic) forces and secondary lateral pressure due to the field of gravitational stress-gradients is suggested for the Garba and Gumai Mts in South Sumatra (see next subchapter on Sumatra).

Djapara on the western foot of the Muriah was an important harbour in the 16th and 17th century for the direct hinterland (Demak, Kudus, and Pati). The last area has not been of any importance before the end of the 15th century, and is not mentioned in the list of Javanese districts of the Pararaton. The road from Sema-rang to Djapara, known in the 17th century, is of recent date (VAN MILAAN, 1942). It appears from these historical facts, that the rice-producing area of Demak-Kudus-Pati is of comparatively recent date; it became habitable since the 15th century.

8. THE MURIAH COMPLEX

The Muriah volcano is of young pleistocene age. At present it is an extinct, heavily dissected volcano, with radial sector-graben. The most conspicuous of these trough-shaped valleys are those drained by the northern- and the southern Gelis River; these rivers are separated by the Sutorenggo water shed. The southern Gelis River flows through the Rahtawu cauldron, and the northern one through the Temur cauldron. In the latter the basal parts of the Muriah arc exposed.

KUIPER collected in the Rahtawu cauldron samples from large lenses of metamorphic limestone which were microscopically studied by the present author (1947 a). It appears that the Muriah magma intruded into a neogene sequence of strata, rich in limestones. In one sample *Cycloclypeus (Kalacyclo-clypeus) annulatus* MARTIN occurs, together with large microspheric and macrospheric *Lepidocyclina* and *Cycloclypeus*. These fossils indicate the presence of the (middle) miocene Rembang limestones. In another limestone inclusion an *Alveolinella* of the *quoyi*-type occurs, which can be found from the young Miocene up to Recent, so it represents younger strata of the Rembang Series. Also marly limestone inclusions with smaller Foraminifera, molluscs, echinoids, corals (*porides*), gastropods, algae, etc. were found; these limestones presumably belong to the younger Neogene.

Inclusions of sandy calcareous sediments contain detrital material from the Sunda Land (cataclastic quartz, feldspar with undulatory extinction, tourmaline, andalusite, glaucophane, muscovite).

In the core of the heavily eroded Genuk tuff-cone, which presumably is the oldest eruption-centre of the Muriah complex, BOOMGAART (1947) found also limestones with Foraminifera, lamellibranchi-ates, and gastropods.

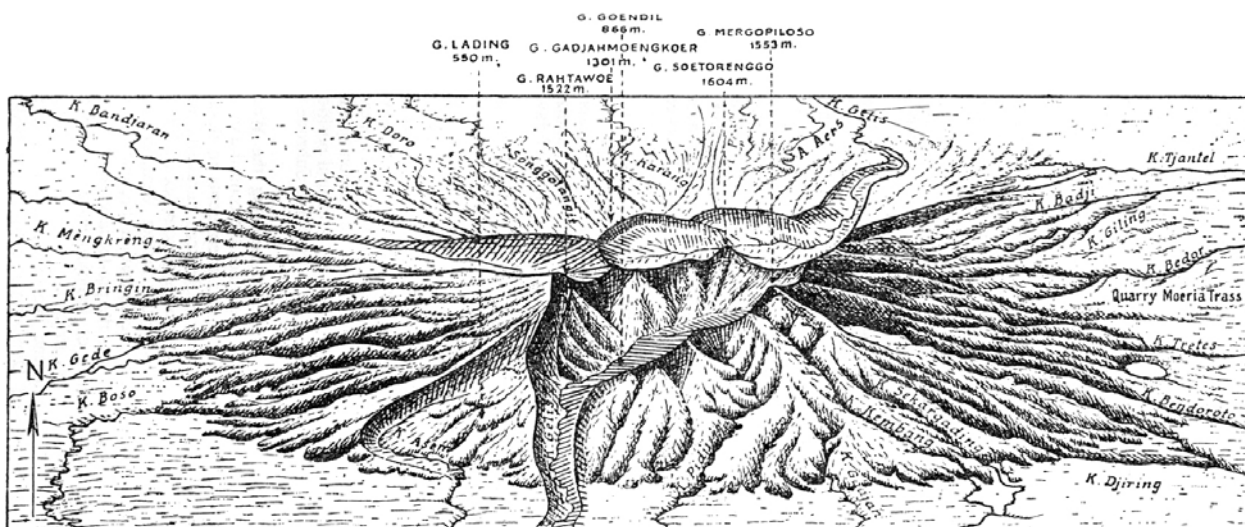


FIG. 294. Isometric diagram of the Muriah. (From VAN BEMMELEN, 1947 a)

These observations prove that the basement of the Muriah volcano consists of neogene sediments, rich in limestones, which were invaded by the Muriah magma. In the chapter on Volcanology we discussed already the possibility of the formation of Mediterranean volcanic rocks due to excessive limestone assimilation (VAN BEMMELEN, 1947 c). An alternative hypothesis has been advanced by VAN BAREN (1948). This author suggests that the desilication of the original calcalkaline magma has been effected by incoming alkaline emanations from the depth.

The South foot of the Muriah volcano has been domed up, forming the **Patihajam dome**, described by VAN Es (1931). In the core of this dome argillaceous marine sediments are exposed, which can be correlated (according to VON KOENIGSWALD in the "Jaarboek Mijnwezen", 1938, general part. p. 20) with the lower-pleistocene Putjangan Beds of the Kendeng stratigraphy. These marine deposits are conformably covered by 300 m of leucite-bearing breccias of the older Muriah, which contain a typical Trinil vertebrate fauna (Middle Pleistocene). The sequence ends with lahar debris of the younger stage of the Muriah, which partly cover and surround the dome structure. These unfolded breccias are assigned to the Notopuro stage (Upper Pleistocene).

Mechanism of the formation of the Patihajam dome.

This proves that the Muriah volcano was active during the younger Pleistocene. It is not certain whether the Patihajam dome has to be considered as the result of a laccolithic intrusion, or that it is the result of the doming up of the Muriah complex at the end of the Middle Pleistocene. In the latter case rifting of the central dome and sliding down of its southeastern part towards the adjacent syncline of Semarang-Rembang might have caused the bulging up of the Patihajam dome.

Still another mechanism can be imagined for the formation of the Patihajam dome at the Southeast foot of the Muriah. This volcano was built upon a plastic basement of marine clays, marls, and deeper-seated limestone. When the volcano at the end of its eruptive activity was slightly domed up owing to the endogenic, magmatic forces which no longer found an outlet through the clogged vents, it lost its inner coherence by radial rifting. The highest and heaviest sectors of the volcano sank down into the plastic and lighter basement, squeezing out the latter to the lowest and weakest site at its foot. There the plastic strata bulged forth, forming the Patihajam dome. At the summit the typical sector-graben and cauldrons of Rahtawu and Temor developed. The lahar breccias of Muriah material, which flowed around the Patihajam dome, are in that case not the result of the last stage of Muriah activity, but the debris of strong erosion after this volcano-tectonic tecto-genesis. According to the present author this mechanism by squeezing out of the plastic foundation of the Muriah volcano ("Expressionsgleitung" in the sense of HAARMANN) is the most plausible explanation of its origin. A similar mechanism is suggested for the origin of the Nanggulan dome at the East foot of the West-Progo Mts (see fig. 299).