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OLIGO-MIOCENE CARBONATES OF JAVA : TECTONIC SETTING AND EFFECTS OF VOLCANISM

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ABSTRACT

In Java, the Oligo-Miocene (Late Oligocene-Early Miocene) platform and reefal carbonates distribute widely. Some of these carbonates are the important producing reservoirs, such as Kujung in East Java and Middle Cibulakan/ Baturaja in West Java. The period is also noted for its volcanism known as the “Old Andesite” which distribute along the southern part of Java Island. This contemporaneity is interesting to evaluate revealing the tectono-volcanic influences on the carbonate sedimentation.

In tectono-volcanic setting, two trends of the Oligo-Miocene carbonates can be recognized : (1) Northern Trend, including the Cepu-Surabaya-Madura, North Central Java, and Ciputat-Jatibarang areas consists of the carbonates of Kujung, Prupuh, Tuban, Poleng, Middle Cibulakan, and Baturaja and (2) Southern Trend, including the Gunung Kidul-Banyumas-Jampang-Bayah-Sukabumi-Rajamandala areas. The Northern Trend has developed in the back-arc setting, 75-150 kms away from the Oligo-Miocene volcanic arc in southern Java. There is no volcanic material found within the carbonates of this trend. The distal location from the volcanic arc is considered as the reason. The Southern Trend was within the intra-arc setting. No reefal carbonates are found to develop contemporaneously with the volcanism in Gunung Kidul-Banyumas-Jampang areas. Significant reefs grew during the Oligo-Miocene in the ridges at the front of the Southern Mountains including Bayah-Sukabumi-Rajamandala areas. The volcanism in Bayah area took place as earlier as Early Eocene and had diminished when Oligo-Miocene transgression resulted in reefal carbonates. In Sukabumi-Rajamandala areas, Rajamandala reefs developed prior to Jampang volcanism which took place in the Early Miocene. When this volcanism intensified, the Rajamandala reefs terminated to grow.

The window of volcanic quiescence in Java from 18 – 12 Ma (Middle Miocene) which occurred contemporaneously with the maximum global sea transgression had resulted in significant reefal carbonates development along the Southern Mountains of Java such as Wonosari/Punung in Gunung Kidul, Jonggrangan in Kulon Progo, Karangbolong/Kalipucang in Banyumas, and Bojonglopang in Jampang areas.

The study has provided the regional framework on the relationship among carbonate sedimentation and tectonics and volcanism. What occurs in the Java Island on this relationship also occurs in other areas with active carbonate sedimentation and volcanism such as in Sumatra, South Sulawesi, and Philippine Arc.

INTRODUCTION

The relationship between tectonic setting, volcanism, and carbonate sedimentation in Indonesia is best described among others in Java Island during the Oligo-Miocene. In this period, tectonic setting of Java were various comprising volcanic island arc, backarc basins, intra-arc basins, and forearc basins (Figure 1). One of the most important events of the island’s volcanism took place in the Oligo-Miocene with the formation of volcanic belt presently occupies the Southern Mountains of Java (Figure 2). Meanwhile, Java’s Cenozoic equatorial position has provided an ideal environment for extensive and prolonged carbonate production. A generally rising eustatic sea level during this period (Haq *et al*., 1987) allowed the accumulation of thick reefal units (Figures 3, 4). Carbonate sedimentation developed during the Oligo-Miocene in many parts of Java and copious amounts of volcaniclastic material strongly influencing the carbonate development.

The traditional view of volcaniclastic derived material being generally prohibitive to carbonate development is over simplified as recent studies showed (Lokier, 1999; Wilson, 2000). Reefs fringe many active and recent volcanic islands in Indonesia, such as Krakatau, Banda, and Sangihe islands (Tomascik *et al*., 1997). Misconceptions that carbonates are unlikely to accumulate and/or be preserved near active volcanic areas have been dispelled by a number of studies of carbonates in ancient arc settings. In more distal areas, shielded from volcaniclastic debris, or during periods of volcanic quiescence, the flanks of volcanoes or nearby areas within the photic zone often become the sites of carbonate production.

Regional review of tectonic and volcanic influences on the development and termination of the Oligo-Miocene carbonates in Java is addressed in this paper. There is no previous publication on this subject for regional Java. The paper is based on a number of published and unpublished studies, synthesized them into a regional review.

REGIONAL TECTONO-VOLCANIC AND SEDIMENTARY FRAMEWORK

Java Island is the best known area in Indonesia from geological point of view. The first geological description of Java Island was given by Junghuhn (1853) and followed by the more complete geological treatise by Verbeek and Fennema (1896). Van Bemmelen (1970) in his excellent book on the geology of Indonesia treated the geology of this island in detail. Modern geological study of Java Island was given by Hamilton (1979) as a part of his broad tectonic compilation of Indonesia. These works are still important references for geology of Java.

The island of Java is constructed predominantly by Cainozoic volcanic rocks which rise mostly above the Neogene marine strata (Figure 1). The basement rocks are of Late Cretaceous or earliest Tertiary melange deposits exposed in a few scattered areas (Hutchison, 1989). In a broad tectonic setting, Java occupies the southernmost margin of the present Asiatic Plate. Java forms the southern active margin of the Sundaland, a continental terrane of the Asiatic Plate. Since the Late Cretaceous (Katili, 1975; Hamilton, 1979) the island has become the site for plate convergence between the Indian oceanic plate and the Sundaland. Tectonic elements resulted from oceanic-continental plates convergence including subduction zone, magmatic arc, accretioanry prism, and sedimentary basins from Late Cretaceous to Quaternary periods overlap to each other in Java Island.

Late Cretaceous subduction zone trends east-west in the southern part of the island in West- and Central Java and bends northeastward across the East Java to SE Kalimantan-SW Sulawesi. Contemporaneous Late Cretaceous magmatic arc was situated to the north of the island in the present Java Sea. During the later period in the Oligo-Miocene a magmatic arc (called as “Old Andesite” by van Bemmelen, 1970) (Figure 2) occupied the site of the Late Cretaceous subduction zone in West- and Central Java trending east-west along the southern island trough southern East Java until Nusatenggara islands and Banda Arc (Katili, 1975). This indicates the southward shifts of the arc and subduction zone from the Late Cretaceous to the Oligo-Miocene. In the Neogene, Java’s magmatic arc shifted northward along the axis of Java Island and this continued into the Quaternary times (Katili, 1975). This indicates a gentler Benioff Zone during the Neogene relative to that of the Paleogene.

The plate interactions are believed to have influenced basinal formation and configuration which is in fact due to the existence of block faultings in the basements. Regional review on Tertiary depositional patterns of Java was made by Sujanto and Sumantri (1977). They said that depositional patterns in Java Island show various phenomena such as growth faulting, regional platforming, flysch like deposition within trough, reef growing on old volcanoes, and turbiditic-sliding-gliding sedimentation.

OLIGO-MIOCENE PLUTONIC-VOLCANIC ARC

The presence of the Oligo-Miocene volcanic arc in Java as controller for carbonate sedimentation is detailed here. Based on geochemistry and geochronology of 35 selected magmatic rocks distributed in Java, Soeria-Atmadja *et al*. (1994) concluded that the Tertiary magmatic activity in Java took place in two distinct periods : Late Eocene-Early Miocene (40-18 Ma) and Late Miocene-Late Pliocene (12-2 Ma) which was succeeded by Quaternary volcanism (Figures 2, 6). The Oligo-Miocene Arc is included into the former period. The presence of this belt marks an active subduction from Late Oligocene time onwards (Hamilton, 1979).

The products of the earlier event had built up the “Old Andesite” (the Oligo-Miocene magmatic-volcanic arc) presently distributed along the southern part of Java. This arc related to the Paleogene subduction located south off Java Island in the Indian Ocean. The distribution of volcanic rocks of the Old Andesite Formation can be followed along the south coast of Java from the Pacitan area in East Java as far as the Pelabuhanratu-Bayah region in the west through Bayat, Parangtritis, Kulon Progo, Luk Ulo, Pangandaran and Cikatomas (Soeria-Atmadja *et al*., 1994) (Figure 2). These rocks are also distributed to the offshore south of Java Island as penetrated by Alveolina-1 and Borealis-1 wells (Shell, 1972-1973). Katili (1975) put this belt from Sumatra through Java to Banda Arc. The petrologic characteristics of this belt are basically calc-alkaline (Hamilton, 1979). Lava flows of this belt are of island arc tholeiites (Soeria-Atmadja *et al*., 1994).

The rocks in the Pacitan area consist of basaltic pillow lavas with crosscutting dykes. In the Bayat area, numerous dykes and other intrusive bodies of mostly basaltic composition are exposed. At Parangtritis, the rocks consist of agglomerate, volcanic breccia, and dykes of andesitic and basaltic composition. In Kulon Progo, numerous necks, lava domes, pyroclastic and laharic breccias, and finer volcanic sediments are exposed. In the Luk Ulo area, the rocks consist of several andesitic to basaltic dykes and sills and plugs intruded the sedimentary covers of Late Eocene to Early Miocene. In Pangandaran – Cikatomas area (southeastern West Java), many lava flows and laharic breccia of calc-alkaline composition are exposed. In Pelabuhanratu-Bayah area, the rocks consist of andesitic to basaltic lava flows, volcanic breccia, and tuffs.

Van Bemmelen (1970) stated that the Oligo-Miocene magmatic arc partly formed submarine volcanoes and contemporaneous with the deposition of *Lepidocyclina*-bearing limestones of Early- to Middle Miocene age. Therefore, an arc of Eocene and Oligocene volcanic islands is widely assumed to have been present in medial or southern Java. The nature as submarine volcanoes affected its association with marine sedimentation, mainly carbonates. Hamilton (1979) doubted this association. He stated that it was difficult to visualize the existence of a chain of active volcanoes within a terrain undergoing deposition firstly of a sheet of quartzose clastic sediments and then of another sheet of shelf carbonate. Old age assignments for volcanic materials may be erroneous (Hamilton, 1979). However, further studies confirm this association as will be discussed below.

TECTONO-VOLCANIC INFLUENCES ON CARBONATE SEDIMENTATION

Recent and ancient volcanic arcs have commonly provided sites for extensive shallow-water carbonate production, yet studies of carbonate sedimentation contemporaneous with volcanic activity are rare. It has traditionally been held that clastic sediments, particularly fine grained volcanic particles, have a strongly detrimental effect on carbonate production. However, recent studies indicate that this is not always necessarily the case (Lokier, 1999; Wilson, 2000).

Fulthorpe and Schlanger (1989) provided review on paleo-oceanographic and tectonic settings of Late Oligocene to early Middle Miocene reefs and associated carbonates of offshore Southeast Asia (Figure 5). They did not discuss the carbonates which become the objective of this paper, but their general conclusions on carbonates developing at convergent plate boundaries in island arc of the Philippines can be used here. In island arc system, the primary site for shallow-water carbonate deposition is the arc massif of volcaniclastics, extrusive, and plutonic rocks, which forms a thickened crustal block. Reef development near islands in an active volcanic arc is hindered not only by the effects of volcanism but also by rapid erosion of the growing volcanic edifice. Shielding from pyroclastic and erosional debris is essential. Reefs have not developed on young, rapidly eroding pyroclastic shores. Reef development depends on the frequency of eruptions. Deposition of thick carbonate sections can occur during periods of volcanic quiescence. Periods of volcanic activity, characterized by eruption, edifice building, and rapid erosion, are unfavorable for development and preservation of thick, continuous reef and associated carbonates. A second reef depositional setting in convergent plate boundaries is back-arc basin. A third potential setting for reef development in an island-arc system is the crest of an accretionary prism.

Fulthorpe and Schlanger (1989) showed four potential sites of reef and associated carbonate sediments within island arc system (Figure 5), including : (1) uplifted, normal-faulted blocks at arc massif, (2) deeply subsided, normal-faulted blocks, pelagic drape or volcaniclastic cap buildups at arc massif and remnant arc behind back-arc basin, (3) volcanic islands of arc massif, and (4) uplifted, thrust-faulted blocks at accretionary prism.

Wilson (2000) investigated tectonic and volcanic influences on the development and termination of the Middle Eocene to Early Miocene Tonasa carbonates in South Sulawesi. Here, she observed that the volcanic activity had limited the lateral extent of the platform, inhibited carbonate production, and terminated it. However, carbonate production contemporaneous with volcanism occurred in more distal, or localized, areas shielded from volcaniclastic input. She also noted the role of normal-faulted blocks for carbonate drowning, exposure and erosion, re-development, and re-deposition. Wilson (2000) concluded that the evolution and demise of the Tonasa Carbonate Platform is similar in many ways to other carbonates developed in back-arc, intra-arc, or other tectonically active settings with some clastic or volcaniclastic input.

REGIONAL DISTRIBUTION OF THE OLIGO-MIOCENE CARBONATES

There are two trends of carbonate deposition in present onshore Java during the Oligo-Miocene (Figure 7), namely : (1) Northern Trend, including the carbonates of Cepu-Surabaya-Madura areas, North Central Java, and Ciputat-Jatibarang areas (2) Southern Trend, including the carbonates of Gunung Kidul-Banyumas-Jampang-Bayah-Sukabumi-Rajamandala areas. Briefly, it can be stated that in tectonic setting and volcanic influence points of views, the two trends are different. The northern trend developed mainly in subsurface of the back arc setting and was located far from the contemporaneous volcanic arc, whereas the southern trend developed in the intra-arc setting and shared the same place with or close to the volcanic arc. Each trend will be treated in detail showing the origin and nature of the carbonate sedimentation, the regional geology, and volcanic influence.

NORTHERN TREND : CEPU-SURABAYA-MADURA, NORTH CENTRAL JAVA, AND CIPUTAT-JATIBARANG AREAS

Cepu-Surabaya-Madura Areas

The Oligo-Miocene carbonates of the Cepu-Surabaya-Madura (Figure 7) areas have been discussed recently by Satyana and Darwis (2001), Satyana (2002), Purwaningsih *et al.*, (2002), and Satyana and Djumlati (2003). These carbonates are important hydrocarbon producers in the East Java Basin as proved by significant hydrocarbon discoveries made in these carbonates in the last five years.

Distribution of these carbonates in onshore Java are concentrated along the basement ridges forming parallel belts trending WSW-ENE in Cepu, Surabaya, and Madura areas (Figure 8). Four ridges are recognized : West Cepu High, East Cepu High, Kemandung Ridge, and “BD” Ridge (Ardhana, 1993). These ridges are Early Tertiary elements resulted from segmentation of the basement during the rifting of the East Java back-arc basin. These ridges continue northeastward into the present East Java Sea forming similar but broader basement ridges such as “JS-1” Ridge and North Madura Platform.

During the Oligo-Miocene, the Cepu-Surabaya-Madura areas were located in the open sea to the south of the shelf edge which situated presently along the northern coast of East Java from Rembang to the north of Madura Island. The shelf area was located to the north of the shelf edge which now is the East Java Sea. Therefore, the West Cepu to "BD" ridges were high areas in the open sea.

Reefal Carbonate deposition took place in these high areas and mostly as pinnacle reefs. In intervening low areas, deep marine marls, chalks, and shales were deposited as proved by several wells. Ngimbang-1 located to the south of the East Cepu High penetrated 200 ft thick chalky facies and Jatirogo-1 well to the east of the West Cepu High penetrated 150 ft thick chalky facies.

The carbonates of this group are called as the Kujung, Prupuh, and Tuban carbonates in Cepu and Surabaya areas or as Poleng and Prupuh carbonates in Madura Island (Figures 4, 11). The group is Late Oligocene to Early Miocene in age. The Kujung Formation consists of three units : Kujung III, II, and I. The basal Kujung III is a clastic-rich regressive sequence. Kujung II is a transgressive sequence of shallow water carbonates and calcareous shales with localized carbonate build-ups over high areas. Kujung I (Prupuh Member) carbonates are high-energy clean limestones and common pinnacle reefal build-ups. Rembang reef developed in the West Cepu High. Kedung Tuban, Banyu Urip, Sukowati, Mudi, and Kembang Baru reefs developed in the East Cepu High. Gondang, Grigis, and Telaga reefs developed in the Kemandung Ridge. Banjarsari, Porong, KE 11-C, KE-11 B and BD reefs developed in the "BD" Ridge. Generally, the ridges tilt to the southwest due to tectonic uplift occurred to the northeast along the Rembang-Madura-Kangean (RMK) Zone. Accordingly, at each high, western reefs usually drowned and stopped growing, whereas eastern reefs continued to grow.

The upper carbonates of this group, called as the Prupuh carbonates, expose to the east of Tuban town (Burgon, 2002). The Prupuh limestone in the outcrop is a slope facies of mixed chalky sediments and allochthonous reefal debris. It is about 105 to 175 meters thick. In the type area near Prupuh village there are many calcarenite beds rich in larger foraminifera. The bedded calcarenites must be considered transported. The interbedded marls are abundantly rich in planktonic foraminifera indicative of basal Early Miocene Zone N4 age, and benthic assemblages indicative of a fairly deep marine setting (approximately deep outer shelf, possibly upper bathyal equivalent). The underlying Oligocene beds also have rare, thin limestone beds containing transported larger forams. In Madura Island, marine Oligo-Miocene sediments (Rembang Beds) (van Bemmelen, 1970) form the core of the island. These deposits were folded in the Middle Miocene.

Submarine volcanic arc developed to the south of these ridges and called as Old Andesite. This arc represented the island arc formed by partial melting of both subducted Indian oceanic crust to the south and overlying accreted-continental crust. Therefore, the basement ridges where the Oligo-Miocene reefs developed, situated within the back-arc basin since they were formed relatively behind the volcanic arc. Well and outcrop data of the Oligo-Miocene carbonates show no volcanic materials interbeds within the Kujung/ Poleng/ Prupuh/ Tuban carbonates indicative that contemporaneous volcanism to the south did not affect the carbonate sedimentation.

Based on the field study in South Sulawesi, Wilson (2000) suggested that carbonate sedimentation was localized in areas near to volcanic activity. In areas within 5-15 kms from the volcanic centers, volcanogenic input commonly hindered shallow-water carbonate production. The Tonasa Carbonate Platform developed up to 40-50 kms to the west of the main inferred volcanic arc. Except for limiting eastward lateral extent of the platform and the interdigitation and minor volcaniclastic input to the east, volcanic activity had little overall tangible effect on the development of the carbonate platform in western South Sulawesi. In Java, the carbonates of Cepu-Surabaya-Madura areas are 75-125 kms from the Old Andesite volcanic arc. This distance is considered to shield the carbonates from the volcanism.

North Central Java Areas

Aquitanian (earliest Miocene) Sigugur Limestones (van Bemmelen, 1949) in the central part of the North Serayu Range physiographic zone may represent the Oligo-Miocene carbonates of this area (Figure 9). This bed cover transgressively Eocene rocks. In the South Serayu Range (southern trend), Sigugur limestones are found as fragments within Gabon Old Andesite. No further published works are found for the Sigugur Limestones in Central Java.

The presence of Oligo-Miocene carbonates of the North Central Java Trend (Figure 7) is based on subsurface data. However, the carbonates have been lack of studies. Three wells were drilled by joint of Pertamina and Jolco in 1987-1988 in northern Central Java in the area between Pemalang and Semarang. Two wells (NCJ A-1 west of Semarang and NCJ B-1 east of Pekalongan) found Oligo-Miocene carbonates interbedding with shales and some intercalations of sands and coals. The third wells (NCJ C-1 south of Pemalang) drilled more to south than other wells did not find any carbonates in the Oligo-Miocene section, but shales. The carbonate of NCJ A-1 overlies diorite porphyry with K-Ar age of 14.65 Ma (Middle Miocene). This igneous rock is considered not a basement but intrussive body or ramifications of plutono-volcanic body south of Semarang (old Ungaran complex). Carbonate of NCJ B-1 overlies un-dated volcanic breccia considered as volcanic product of Gabon Old Andesite which protruded more to the north in Central Java. However, no volcanic impurities were reported within the carbonates.

The carbonates penetrated by NCJ A-1 and NCJ B-1 are considered to develop within the shelfal area. Based on biostratigraphic data, it is known that carbonate sedimentation took place in inner to middle sublittoral conditions of clear warm water with open marine influences. Age-equivalent shelf areas more developed in West and East Java. The NCJ C-1 well is considered to penetrate off shelf Oligo-Miocene section. Oligo-Miocene's shelf edge of North Central Java is therefore still showing continued trend with those in West and East Java.

Ciputat-Jatibarang Areas

Early Miocene carbonates and reefs developed at the land-attached platform of the present northern West Java in sub-basins of Ciputat, Pasirputih, and Jatibarang (Figure 7); and intervening highs of Rengasdengklok, Pamanukan, and Gantar-Kandanghaur (Patmosukismo and Yahya, 1974; Adnan *et al*., 1991). The carbonates were resulted from sea transgression on the shelf during the period. The carbonates are called as the Middle Cibulakan Formation which is age-equivalent with the Baturaja Formation in South Sumatra and offshore West Java Sea area (Figures 4, 12). The formation consists of framiniferal/algal shelfal limestones with coral reef buildups and bank limestones on top of the platform, on top and flanks of ancient highs, possibly also on the crest of active growth faults. With a progressive shaling out of the formation basinwards, particularly to the southern Bogor basin, reservoir distribution is clearly dependent on the basin's structural configuration.

The carbonates cover Late Oligocene basal sands of Lower Cibulakan (equivalent with Talang Akar Formation). The formation was formed by sediments eroded from pre-Tertiary basement or Eocene to Oligocene Jatibarang volcaniclastics. In West Java Sea, some carbonates directly onlap old highs such as Seribu Platform and Krisna High.

The Jatibarang volcanics were deposited during rifting in the latest Eocene (?) and Oligocene and their thickness increased with the progressive subsidence of the basin (Pertamina and Beicip, 1985) and mainly is found in the Jatibarang Sub-basin. Lavas and breccias distribute in the southern part of the basin, while tuffs are found more to the north. In vertical section, the Jatibarang Volcanics are composed of pyroclastics with minor fracturing in the lower part. Andesitic lavas interbedded with tuffs with vugs and cavities dominate the middle part. Interbedded pyroclastics, conglomerates, shales, thin limestone and sandstone layers deposited in a marine to paralic environment. The origin of the Jatibarang Volcanics has not been fully understood. Some datings on the basement (monzonite and diorite) overlying the Jatibarang Volcanics resulted in ages of 65-58 Ma (Late Cretaceous to Paleocene time) but also

213 Ma (Triassic age) for silty argillite (Patmosukismo and Yahya, 1974). The present author considers that the Triassic-aged basement is a part of the southernmost rim of the Sundaland. The Late Cretaceous-aged basement is a part of the Late Cretaceous-earliest Tertiary magmatic arc, and the Jatibarang Volcanics is a later magmatic arc (Eo-Oligocene volcanic arc) which was migrating southwards before occupied the southern coast of Java in Oligo-Miocene time. However, the distribution of the Jatibarang Arc should be further detailed. No influence from the Jatibarang volcanism to the Middle Cibulakan carbonates since the volcanism had ended before the development of the carbonates.

The Ciputat-Jatibarang area was in back-arc setting during the Early Miocene relative to the Oligo-Miocene volcanic arc developed in southern Java. Jampang volcanism in the Southern Mountains of West Java reached its maximum activity during this period. However, no volcanic materials found within the Middle Cibulakan carbonates, meaning that contemporaneous volcanism did not affect the carbonate sedimentation. The Ciputat-Jatibarang area was 100-150 kms away from the volcanic arc. The distance is too far for volcanism to affect the carbonate sedimentation.

SOUTHERN TREND : GUNUNG KIDUL-BANYUMAS-JAMPANG-BAYAH-SUKABUMI-RAJAMANDALA AREAS

Eastern Spur of Java

In the eastern spur of Java (Figure 7), the Southern Mountains consist of volcanic deposits of the “Old Andesite” with intercalations of *Lepidocyclina*-bearing limestones of Lower- to Middle Miocene age (van Bemmelen, 1970). Moreover, there are extensive formations of reef-limestones in south of Malang, Nusa Barung, the surrounding of Puger, and the Blambangan Peninsula. However the reefs are younger than the Merawan granite intrusions (post-Middle Miocene). These limestones are probably the equivalent of the Wonosari Limestones in the Gunung Kidul area, which are considered as the upper part of the Middle Miocene.

Jiwo Hills and Southern Surroundings

The Southern Mountains of East Java are best studied in the area south of Surakarta and Klaten (van Bemmelen, 1970) called as the complex of the Jiwo Hills and their southern surrounding areas (Figure 7). First geologic description of the area was given by Verbeek and Fennema (1896). Detailed stratigraphy was provided by Bothé (1929, 1934), van Bemmelen (1970), Sumosusastro (1957), Sumarso and Ismoyowati (1975) and later by geologists from UPN and UGM in Yogyakarta.

The Oligo-Miocene volcanic products of this area are represented by turbiditic gravity flows of Kebo-Butak, Semilir, Nglanggran Formations (Late Oligocene to early Middle Miocene) in the western part which are correlatable with Besole Formation in the eastern part, and peaked by Sambipitu and Oyo Formations in the end of Early Miocene to early Middle Miocene (Geologi UGM, 1994) (Figures 10, 11), . The Kebo-Butak is made up of andesitic to dacitic tuffaceous shales, fine bedded silts, sandstones, conglomerates and tuffites. Basaltic andesite sills intruded the sequence. Andesitic to basaltic lava is found in the middle part, whereas andesitic breccia is in the upper part. Based on fossil assemblages, the Kebo-Butak Formation is Late Olgocene and earlymost Miocene in age and deposited in an open marine environment (Sumarso and Ismoyowati,1975). Conformable overlying the Kebo-Butak Formation is the Semilir Formation consisting of white tuffaceous material alternating with bright tuffites, clayey glass tuffs and pumice-tuff breccias. The formation is N5-N9 in age (Early Miocene). Interfingering with the Semilir Formation, is the Nglanggran Formation comprising volcanic breccia, agglomerate, poorly bedded tuff, and andesitic to basaltic pillow lava, and ‘autoclastic’ and ‘hyaloclastic’ breccia. Equivalent Besole Formation consists of andesitic-dacitic pillow lava, dacitic tuff, and local dioritic intrusions.

No platform and reefal carbonate interbed or intercalation is found within the Kebo-Butak, Semilir, and Nglanggran Formations. Fragment of foraminifera-bearing limestone was found in the Kebo-Butak Formation (Suyoto-UPN-personal communication). The fragment is possibly from limestone of upper part of the

Late Eocene Wungkal-Gamping Formation. Intensive volcanism during the Oligo-Miocene as manifested by rock assemblages of Kebo-Butak to Nglanggran Formations is considered to hinder coeval carbonate deposition and reef development in the area.

Entering the Middle Miocene, sea reached maximum transgression and carbonate deposition and development replaced the volcaniclastic dominance. This was contemporaneous with the end of the Paleogene volcanism in Java at 18 Ma (Early Miocene) which resumed at 12 Ma (12 Ma) (Soeria-Atmadja *et al*., 1994). The declined volcanism and maximum transgression during the Middle Miocene had provided good environment for development of carbonate sedimentation. Carbonate beds began interbedded early Middle Miocene Sambipitu turbidites, continued to Oyo Formation which shows firstly in the area the contemporaneous sedimentation between carbonate and volcanism as expressed by well-bedded tuffaceous limestones, tuffaceous marls, and andesitic tuffs. Dominance of carbonate sedimentation over volcanism is shown by thick (more than 800 meters) Middle-Late Miocene carbonates of Wonosari (Punung) Formation which consists of bedded and reefal carbonates with interbeds of tuffaceous sandstones, tuffaceous and marly limestones, and siltstones. Paleogene volcanics is considered to provide sites for shallow-water Wonosari reefs. Wonosari Formation is widely exposed to the south of Bayat, from Parangtritis in the west to Pacitan area in the east (Surono *et al*., 1988). The formation is a reefal complex comprising four facies (Siregar, 1996; Praptisih and Siregar, 2002) of : (1) tidal algal packstone which dominates the distribution in the south area, (2) reef crest-reef front of coral boundstone facies, (3) upper slope orbitoid-algal packstone, and (4) lower-slope packstone wackestone. The last three facies distribute in the north. Siregar (1996) concluded that the facies of Wonosari Formation is deeper northwards.

Wonosari Carbonate-Volcaniclastic Sedimentation

Volcaniclastic controls on carbonate sedimentation has been published recently by Lokier (1999). This was based on the study centred around the Miocene Wonosari/Punung Formation situated in the Gunung Sewu southeast of Yogyakarta (Figure 10). Lokier (1999) concluded that the effects of volcaniclastic input on biotic development can be assigned to at least three distinct categories. Where the input of volcanic derived material was low, a wide variety of epifaunal and infaunal organisms including : forams, algae, corals, molluscs, and echinoids occurred. During short periods of elevated volcanic sediment input, there was a rapid increase in the number of individuals and the number of species. Sustained volcanic input, resulted in a decrease in the number of species present but with elevated numbers of individuals. Energy levels and volcaniclastic sediment grain size appear to have been the main factors controlling the prevalent biota. High energy levels and coarse volcaniclastic material appear to have resulted in a dominance by laminar concentric rhodoliths. Lower energy conditions along with finer volcaniclastics are associated with abundant larger benthic foraminifera.

Kulon Progo-Banyumas-Cilacap Area (South Central Java)

The Oligo-Miocene Old Andesite in this area (Figure 7) is known as the Gabon or Waturanda Volcanics (Figure 9). They are breccia tuffs, volcanic breccias and lahars. Contemporaneous structures developing in this area had resulted in formation of high and low areas. Significant physiographic-tectonic outline included : Gabon High, Citanduy Low, Besuki-Majenang High, Kroya Low, Karang Bolong High, Kebumen Low, Kebumen High, and Kulon Progo High (Sujanto and Sumantri, 1977). Volcanism during the Oligo-Miocene had deposited volcano-turbidites of Waturanda Formation in the low areas. No carbonate sedimentation during the dominance of the volcanism. In the upper part of the Gabon Volcanics, limestone fragments called as Sigugur Limestones locally are found. However, they are transported from some areas outside the Cilacap area (Hening Sugiatno, Lundin Banyumas, personal communication).

First carbonate sedimentation occurred in the upper part of Early Miocene and took place in high areas such as Kulon Progo High and Karang Bolong High resulting in Early-Middle Miocene Sentolo, Jonggrangan and Karang Bolong / Kalipucang Reefs. The reefs built up on the former volcanic bodies. Van Bemmelen (1970) stated that on the northern side of the Karangbolong High tuffaceous layer is intercalated between the Sentolo limestones and the Old Andesite breccias and that the oldest post-volcanic formation consists of the Early Miocene Jonggrangan marls and limestones. However, recent paleontological analysis on Gunung Kucir and West Gunung Dlanggung (Kulon Progo) samples (Pambudi and Budiadi, 1999) showed that Sentolo Formation is older than the Jonggrangan. The Sontolo is Early Miocene and Jonggrangan Formation is Middle to Late Miocene in age, both deposited unconformably above the Old Andesite as transgressive shallow marine sediments.

In South Central Java, as the axis of volcanic activity progressively shifted to the north, in Early and Middle Miocene time, the remnant volcanic highs formed potential areas for carbonate development (Clarke, 1976). These volcanic highs were of varying sizes and patterns. Some were subaerial, and thus contributed erosional volcanoclatics to the carbonates; others remained submerged in shallow water allowing reef carbonates to develop, while some were deeper, permitting only skeletal biostromal carbonates to accumulate. One of the last types of the carbonates were drilled by Djawa Shell in 1972-1973 (Alveolina-1, Borealis-1) and revealed that the carbonates which in contact with the volcanics at the base of the sequence are completely dolomitized and it is argued empirically that dolomitisation is due to the proximity of the volcaniclastic sediments.

Karangnunggal-Pangalengan-Jampang

The Southern Mountains of West Java begin at Nusa Kambangan, increasing westwards in width to 50 km in the Southern Mountains of the southern West Java and ending at the Pelabuhan Ratu Bay (Figure 7). The Oligo-Miocene volcaniclastic deposits in the Southern Mountains of West Java are represented by the Jampang Series (van Bemmelen, 1970) (Figure 12).

The eastern part of the Southern Mountains in West Java is called here as the Karangnunggal area. The deepest exposures of the Jampang Series consist of pyroxene-andesitic breccias with rare intercalations of marly tuff-sandstones and limestones with *Lepidocyclina* and *Trillina howchini* (Early Miocene). In this deepest part of the section basalto-andesitic dikes occur, and it is also intruded by the granodiorites of Tenjolaut, causing hydrothermal (propylitization) of this Old Andesite Formation. The middle part of the Jampang Series is formed by about 800 meters of well-stratified tuff-sandstones and ash-tuffs. The top part of the section consists of well-stratified dacitic ash-tuffs and pumice-tuffs with intercalated silicified dacitic lava or tuff flow of Genteng dacite which Middle Miocene in age. Carbonate sedimentation just dominated the area in the Late Miocene with the deposition of the Bentang Formation consists of tuff-marls, tuff-sandstones and conglomerates, with lignitic beds and resin nodules and massive reef limestones formed farther offshore.

The central part of the Southern Mountains of West Java (Pangalengan area) is elevated somewhat higher than the western and eastern parts, and is more deeply dissected by rejuvenated erosion. The narrow ridges of pyroxene-andesites and breccias are residual hard-rock ridges of the Old Andesite formation. There is no significant carbonate sedimentation until the Late Miocene when fossil-bearing, marly tuff-sandstones of a littoral-neritic facies of Koleberes (Cigugur) were deposited. These deposits are equivalent with the Bentang Formation.

The western part of the Southern Mountains of West Java is called the Jampang area and becomes the reference for the Oligo-Miocene volcaniclastic deposits in West Java (Figure 12). The Jampang Series begin with tuffaceous *Globigerina*-marls, tuff-sandstones, and beds of calcareous tuff-breccias of andesitic and dacitic composition, intercalated with thick lenses of limestone with larger foraminifera (*Spiroclypeus, Eulepidina, Nephrolepidina, Lepidocyclina, Miogypsina, Cycloclypeus, Trillina howchini*) indicating the Oligo-Miocene age. Upper part of the Jampang consists of dacitic tuff-sandstones and pumice tuffs, alternating with breccias and tuffs of an andesitic composition. Intercalated limestone lenses sometimes contain *Spiroclypeus* indicating the Early Miocene age. The area between Lengkong and Jampangkulon was one of the eruption centres of this Jampang volcanism. Here coarse breccias alternate with massive andesitic and basaltic lava flows. Moreover, great intrusive bodies of andesite and dacite are found.

Significant carbonate sedimentation started when Jampang volcanism was already more or less extinct in the Late Miocene. The formations include the Lengkong Formation and Bojonglopang reef limestones. The Lengkong Formation consists of marls, mudstones, and calcareous sandstones with hard, platy limestones and minor tuffaceous materials. The Bojonglopang reef limestones comprise 250-300 meters thick complex of unstratified, hard coral-limestones and soft, porous *Globigerina* limestones, passing eastwards into platy limestones.

The occurrences of limestones in the Southern Mountains of West Java can be considered as being deposited on off shelf platforms, presumably base-leveled submarine volcanoes, or, folded uplifted and subsequently abraded volcanic debris sediments of the Jampang Formation. This uplift and subsequent erosion took place during the mid-Tertiary orogeny (Koesoemadinata *et al*., 2000).

Bayah Mountains

The Bayah, Sukabumi, and Rajamandala (Figure 7) area form mountains and ridges made up of Tertiary formations which rise above the axial depression of West Java called as the Bandung Zone by van Bemmelen (1970). Significant Paleogene carbonate sedimentation took place within these ridges with more or less volcanic influence from the Old Andesite formation.

The Bayah Mountains in South Banten area form the western extension of the Bandung Zone. The Old Andesite volcanism had started as early as Early Eocene as tuff intercalations within the Bayah Layers. The Late Eocene of Cicarucup Layers cover already Old Andesite and contains Old Andesite detritus. This proves that the Old Andesite volcanism began in this area already in the lower part of the Paleogene, that is earlier than in the rest of Java. The fauna of the Cicarucup contains larger foraminifera and strikingly resembles that of Nanggulan in Central Java.

Transgression occurred during the Oligocene, the Bayah area subsided and sediments of the Cijengkol Formation were deposited (Figure 13). This is in accordance with the conception that at that time the southern belt of Java was elevated above sea level, while basin subsidence continued in the adjacent northern tract. Lower Cijengkol consists of coarse andesitic conglomerates and andesitic tuffs with occasional coal seams. Reefal carbonates, marls, clay-shales, and sandstones occurred in the Upper Cijengkol. In the Oligo-Miocene, sediments of the Citarate Formation were deposited mainly in the southern area, consisting of reef limestones at the lower part and the “tuffite zone” in the upper part. The limestones contain terrigeneous detritus. The tuffite zone comprises tuffaceous limestone-gravels, conglomerates, breccias, sandstones, marls, and limestones, always with detritus from the Old Andesite formation. The Citarate Formation can be correlated with the lower part of the Jampang Series.

The reef limestones which alternate with volcaniclastic deposits are still found in the Early Miocene Cimapag, Sareweh, and Badui Formations (Figure 13). The Cimapag extend transgressively over all older formations mainly in the central area. The basal strata are polymict breccias and conglomerates, and are succeeded by a very variable complex of andesitic and dacitic volcanic products, which alternate with conglomerates, sandstones, clays, and occasional reef limestones. The Cimapag is disconformably overlain by the Sareweh Formation in the northwestern area and consists of reef limestones, marls, sandstones, and tuffites. The Badui Formation distributes in the northern area disconformably above the Sareweh and consist of andesitic conglomerates and sandstones passing upward into limestones, mudstones, and marls. The Cimapag-Sareweh-Badui Series form a group of sediments deposited around the central Bayah High during the Early to Middle Miocene, especially in the adjacent Bogor Basin.

Sukabumi - Rajamandala Highs

Significant Oligo-Miocene reef carbonates of West Java called collectively as the Rajamandala Reefs/Formation crop out at the highs of Sukabumi and Rajamandala (Padalarang) which are ridges emerging from central depression and are considered as the eastward continuation of the Bayah Mountains (van Bemmelen, 1970) (Figure 7). The ridges, trending WSW-ENE is a complicated steep anticlinorium of Tertiary sediments with northward thrusting. South of the ridges, there is a transition between the central depression of the Bandung Zone and the Southern Mountains. In the core of the Rajamandala anticline a number of andesitic intrusions are found, which were intruded contemporaneously with and after deformation. Detailed published reef studies on the Sukabumi High were provided by Adinegoro (1973) and Carnell (2000) and on the Rajamandala High by Koesoemadinata and Siregar (1984) and Premonowati and Satyawan (1998), and Koesoemadinata *et al*. (2000). Regional geology of the area was described by Baumann *et al*. (1973).

Reef limestones have developed during the Late Oligocene to Early Miocene on the Sukabumi High platform (Figure 12), corresponding to N3-N4 or late Te (Adinegoro, 1973), is was equivalent with the development of the Kujung Reefs in East Java. The reef building organisms are primarily calcareous algae. Coral colonies are only locally important as reef builders. *Bryozoans* are rare. Accumulation of larger foraminifera, mostly *Lepidocyclina*, is able to build up platy limestones and they also contribute as reef building materials. Several reef limestones facies can be distinguished : reef limestone with growing reef and detrital limestones with reef debris. The reef limestones developed on the substratum of Early Oligocene quartzitic sandstone of Gunung Walat Formation and on Late Oligocene sandy clay and sandy marls of Batuasih Formation. Carnell (2000) based on his field investigation in the area south of Cibadak concluded that the Rajamandala carbonates are dominated by a shallow algal/foraminiferal carbonate shelf containing numerous reefal build-ups dominated by the fore reef debris facies and the algal/foraminiferal shelf facies.

No volcanic material was found within the Rajamandala Carbonates of the Sukabumi High, indicating that the contemporaneous Old Andesite volcanism to the south at the Jampang Segment of the Southern Mountains did not affect the carbonate sedimentation. It is considered that the Jampang volcanism just began and did not have significant influence to the earlier carbonate sedimentation in the Sukabumi High. To the south, the Sukabumi High was separated by the Cibadak-Pelabuhanratu Low from the Jampang Segment. Entering the Early Miocene, deepening environment due to the subsidence of the Bogor Basin which contemporaneous with increasing Jampang volcanism had ended the Rajamandala Reef development (Figure 12). Volcaniclastic turbidites of the Citarum Formation consisting of mudstones, siltstones, and volcaniclastics with occasional sandstones and detrital limestone lenses covered the Rajamandala carbonates.

To the northeast, after the interruptions in Cianjur area due to facies change, presence of channel or Quaternary volcanic cover, the Oligo-Miocene Rajamandala Reefs re-appear in the Rajamanda/Padalarang High to the west of Bandung. These limestones with thickness of minimum 600 meters are dipping to the south and are involved in asymmetric folding and thrusting to the north. Koesoemadinata *et al*. (2000) provided the general stratigraphy of the carbonates. Correlation of measured sections demonstrate that the limestones becoming more massive and less stratified from NE to SW while the insoluble residue decreases. Corals increase in abundance towards the southwest, while planktonic forams increase toward the northeast. The major constituents of the limestones are red algae and large foraminifera, while corals form a very significant constituent, especially in the massive thick beds. Koesoemadinata and Siregar (1984) detailed the facies of these carbonates. Along its WSW-ENE trending, the limestones exhibit shallower facies to the south including : (1) a graded granular limestone representing turbidites at the toe of the basin-slope facies, (2) a foraminiferal algae with rudstone representing a fore-reef facies, (3) a coral-algal bafflestone to boundstone representing reef crest to reef flat facies and (4) a possible milliolid limestone with isolated patch reefs representing lagoonal back-reef facies. The milliolid facies is also observed to erode the massive coral limestone (Permonowati and Satyawan, 1998).

The facies of Rajamandala is similar with the facies of Middle Miocene Wonosari reefs and carbonates in Gunung Kidul area which also deeper to the north facing a central depression of the Solo Zone. The sub-stratum of the Rajamandala Reefs in this area is the Batuasih Formation which is Early Oligocene in age and they are covered by a thick turbiditic sequence of Early Miocene Citarum Formation.

The Rajamandala reefs is interpreted by Koesoemadinata and Siregar (1984) as a barrier or fringing reef, extending WSW-ENE with reef spurs protruding towards the Bogor Basin in the north, into which reef debris were deposited forming slope and toe-of slope deposits. The relationship to the Southern Mountains is that the reefs formed the northern edge of the Southern Mountains which positioned as an off-shelf platform (isolated platform) relatively to the land-attached shelf area in Northwest Java. The off-shelf platform of the Southern Mountains was separated by a regional normal fault trending WSW-ENE with the southern block being upthrown and tilted to the south towards the Indian Ocean. No volcanic materials are discovered within the Rajamandala carbonates. The development of the Rajamandala reefs ended in mid-Early Miocene when the Southern Mountains were uplifted and volcanic activity was intensified. This contemporaneously with the subsidence of the Bogor Basin to the north. Influx of volcaniclastic turbidites buried the reefs.

CONCLUSIONS

1. During the Oligo-Miocene (Late Oligocene-Early Miocene) in Java, there were active development of platform and reefal carbonates and “Old Andesite” volcanism in southern Java.
2. In tectono-volcanic setting, two trends of the Oligo-Miocene carbonates can be recognized : (1) Northern Trend, including the Cepu-Surabaya-Madura, North Central Java, and Ciputat-Jatibarang areas, and (2) Southern Trend, including Gunung Kidul-Banyumas-Jampang-Bayah-Sukabumi-Rajamandala areas.
3. The Northern Trend has developed in the back-arc setting, 75-150 kms away from the Oligo-Miocene volcanic arc in southern Java. There is no volcanic material found within the carbonates of this trend meaning that contemporaneous volcanism did not affect the carbonate sedimentation. The distal location from the volcanic arc is considered as the reason.
4. The Southern Trend was within the intra-arc setting. No reefal carbonates are found to develop contemporaneously with the volcanism in Gunung Kidul-Banyumas-Jampang areas. Not significant foraminiferal limestones developed to intercalate the Jampang volcanics in West Java during the Early Miocene.
5. Significant reefs grew during the Oligo-Miocene in the ridges at the front of the Southern Mountains including Bayah-Sukabumi-Rajamandala areas. Platform and reefal limestones developed during the Paleogene in Bayah Area. The volcanism in this area took place as earlier as Early Eocene and had diminished when Oligo-Miocene transgression resulted in reefal carbonates. In Sukabumi-Rajamandala areas, Rajamandala reefs developed prior to Jampang volcanism taking place in the Early Miocene. When this volcanism intensified, the Rajamandala reefs terminated to grow.
6. The quiescence of volcanism in Java from 18 – 12 Ma (Middle Miocene) which contemporaneously with the maximum sea transgression had resulted in significant reefal carbonates development along the Southern Mountains of Java such as Wonosari/Punung in Gunung Kidul, Jonggrangan in Kulon Progo, Karangbolong/Kalipucang in Banyumas, and Bojonglopang in Jampang areas. The sub-stratum of these reefs are base-leveled submarine volcanoes.

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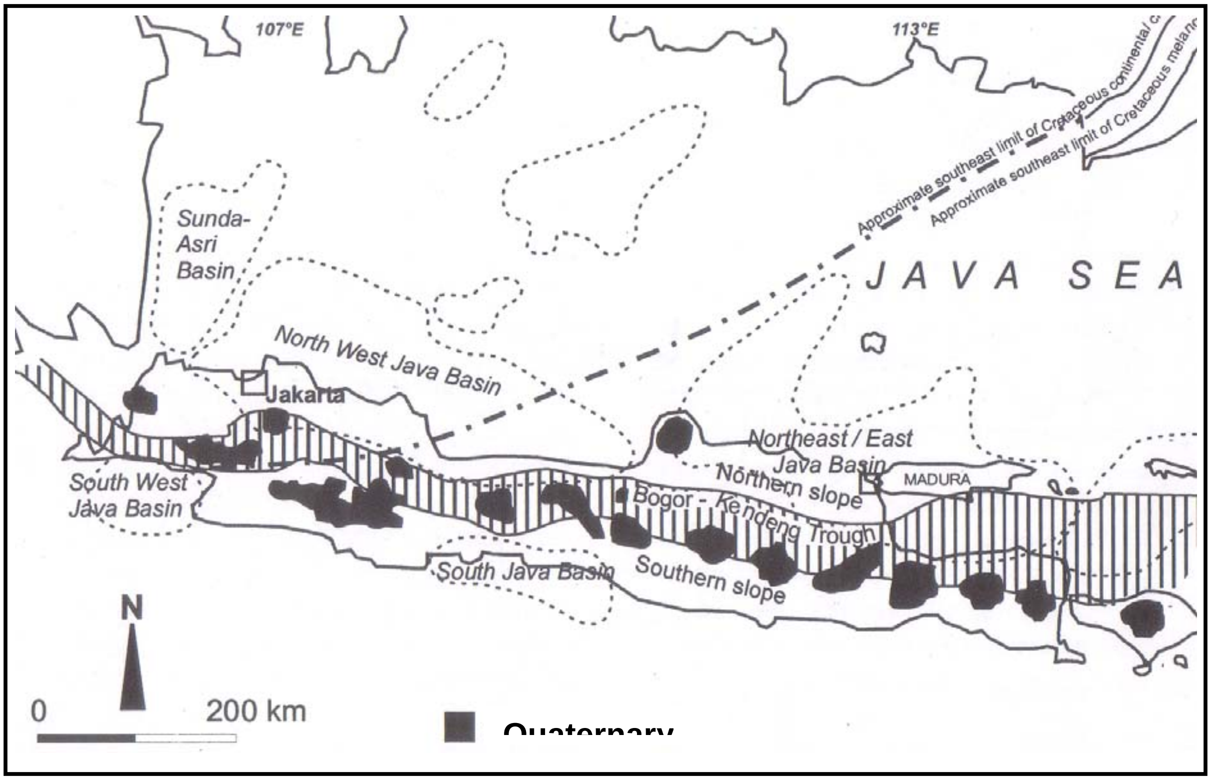


Figure 1 Tectonic setting of Java Island Sea showing the tectonic provinces, Quaternary volcanoes, and sedimentary basin outlines (modified after Darman and Sidi, 2000).

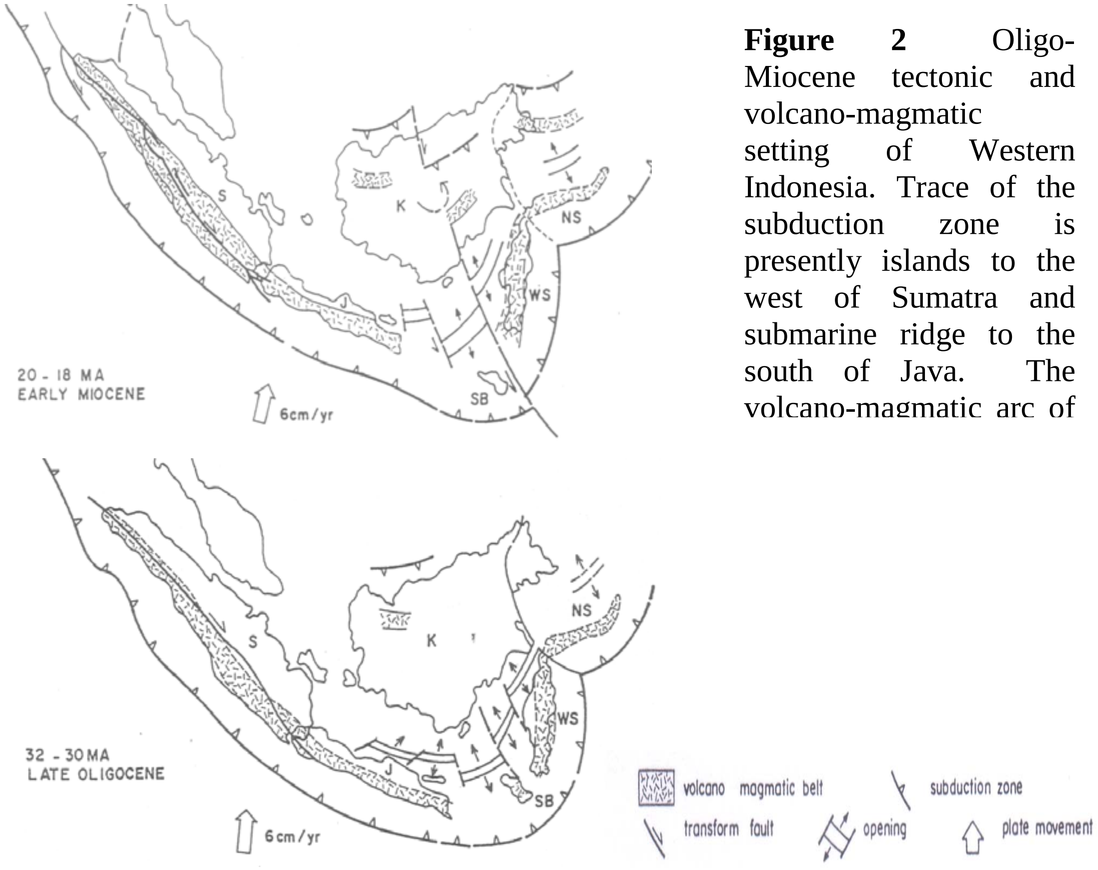


Figure 2 Oligo-Miocene tectonic and volcano-magmatic setting of Western Indonesia. Trace of the subduction zone is presently islands to the west of Sumatra and submarine ridge to the south of Java. The volcano-magmatic arc of

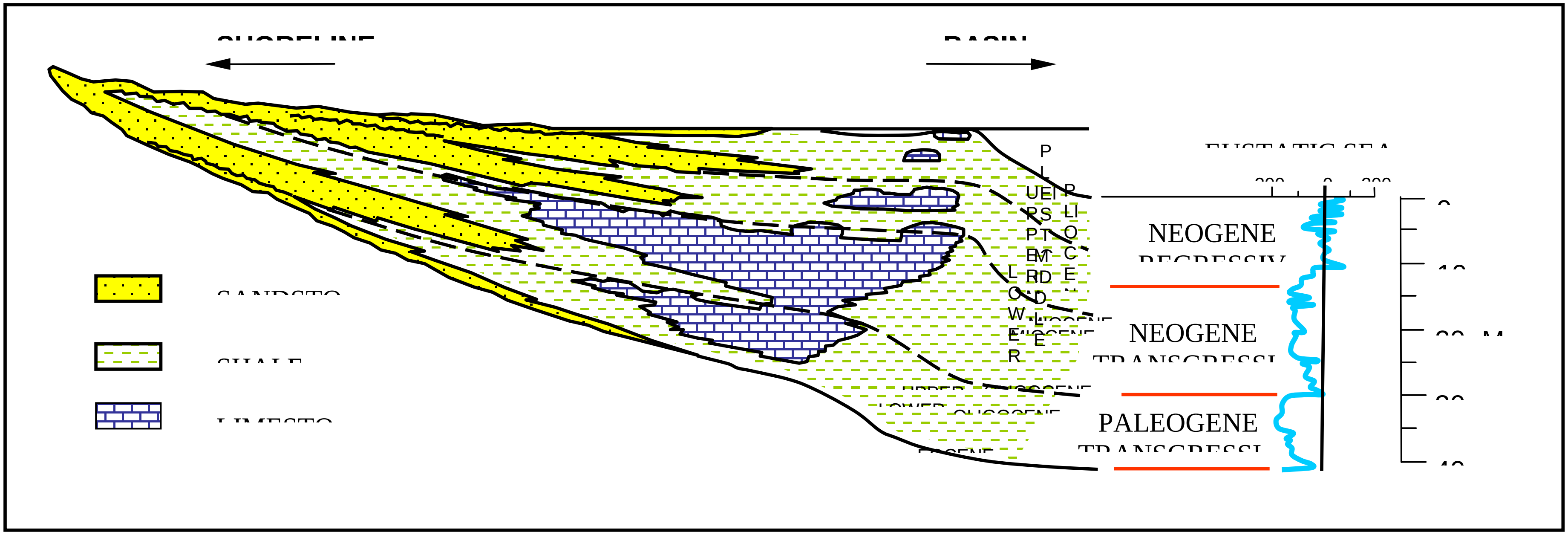


Figure 3 Tertiary sedimentation cycles in SE Asia. Neogene Transgressive Cycle corresponds to period of rising eustatic sea level.

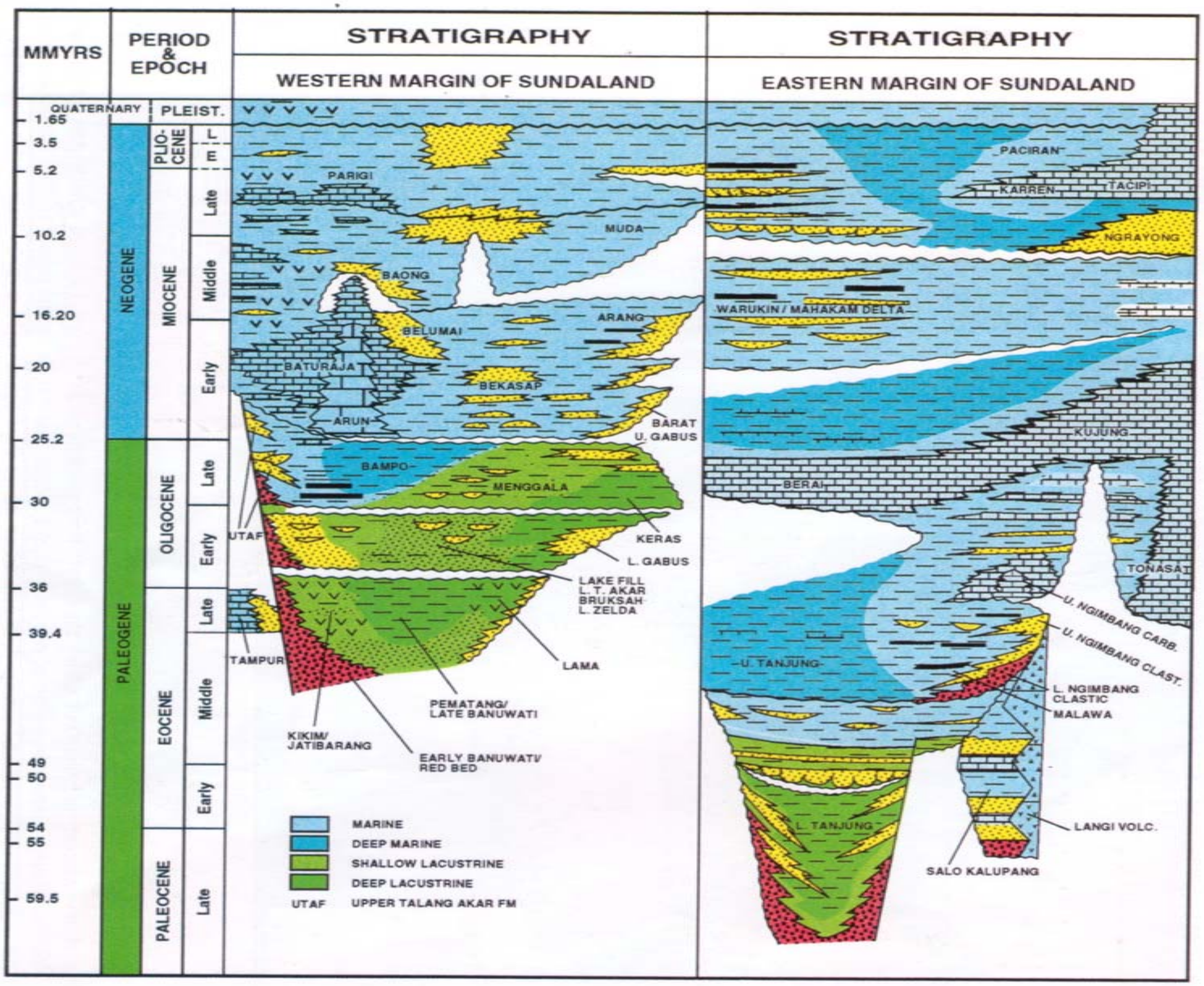


Figure 4 Carbonate development in stratigraphy of the Sundaland's margins (after Sudarmono et al., 1997). East Java Basin is included into the eastern margin of the Sundaland. No volcanic impurities into the carbonates. Early Miocene Lower Cibulakan carbonates in West Java Basin are equivalent with Baturaja carbonates in western margin of the Sundaland. No volcanic impurities into the carbonates.

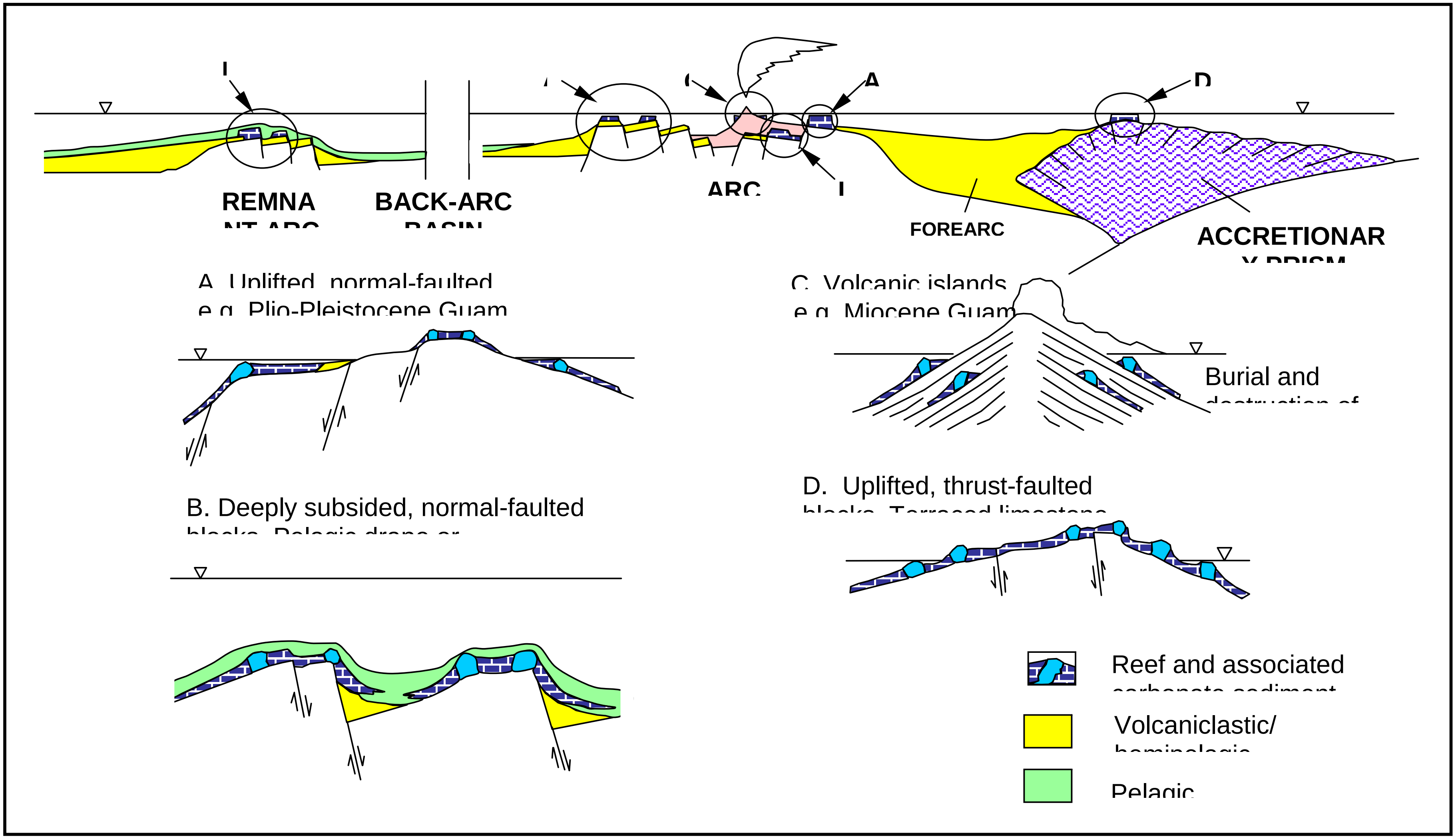


Figure 5 Cross section showing potential sites of reef and associated carbonate sediments within island-arc system. Sites of active deposition and of deeply subsided and buried build-ups are shown. (after Fulthorpe and Schlanger, 1989)

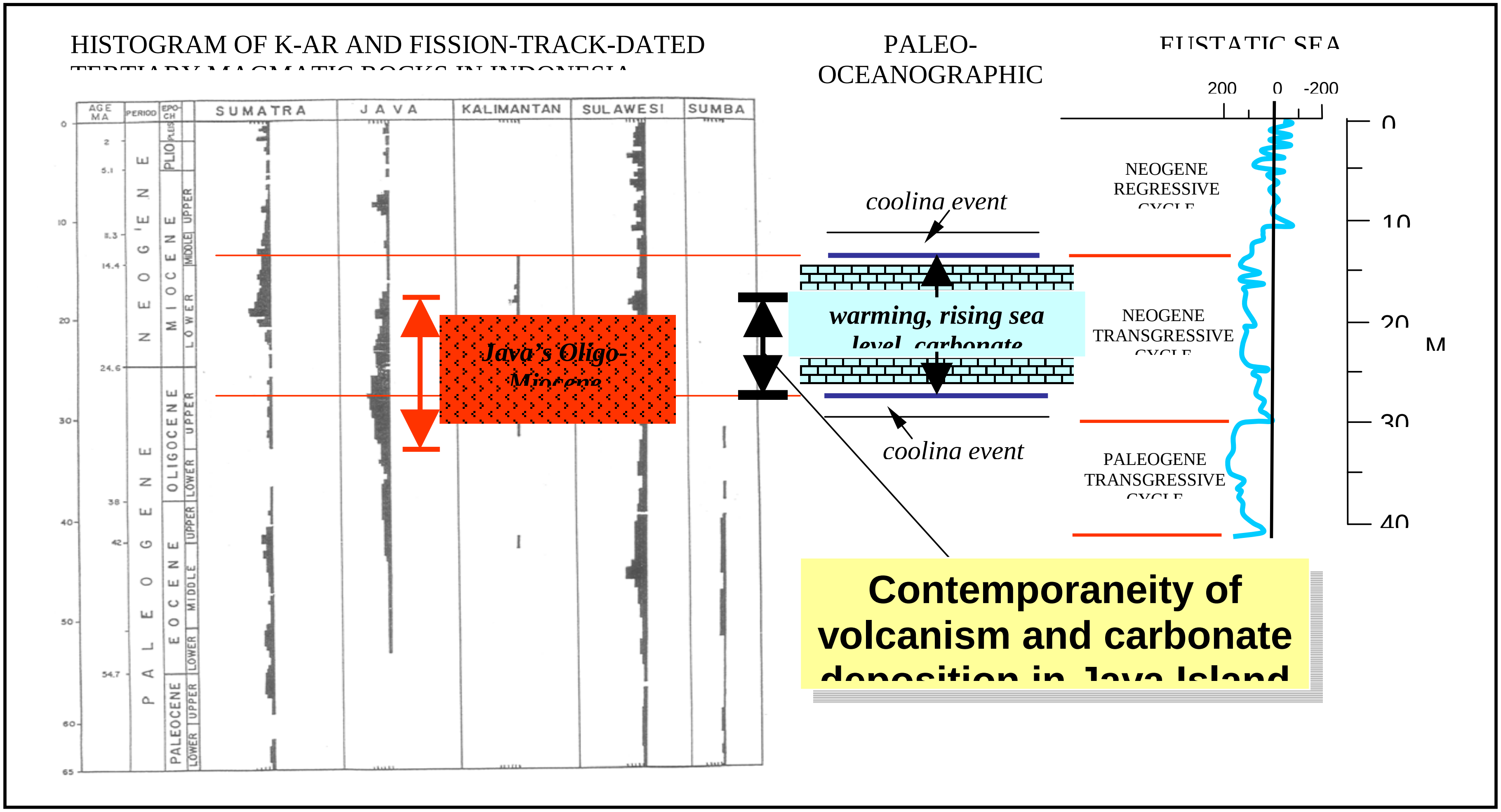


Figure 6 Relationship between volcano-magmatic period in Java and carbonate deposition during the Oligo-Miocene. Note around 75 % contemporaneity occurred between volcanism and carbonate deposition in Java during the Oligo-Miocene. Magmatic dating from Soeria-Atmadja *et al.* (1998), Paleo-oceanographic setting from Fulthorpe and Schlanger (1989), eustatic sea level from Haq *et al.*

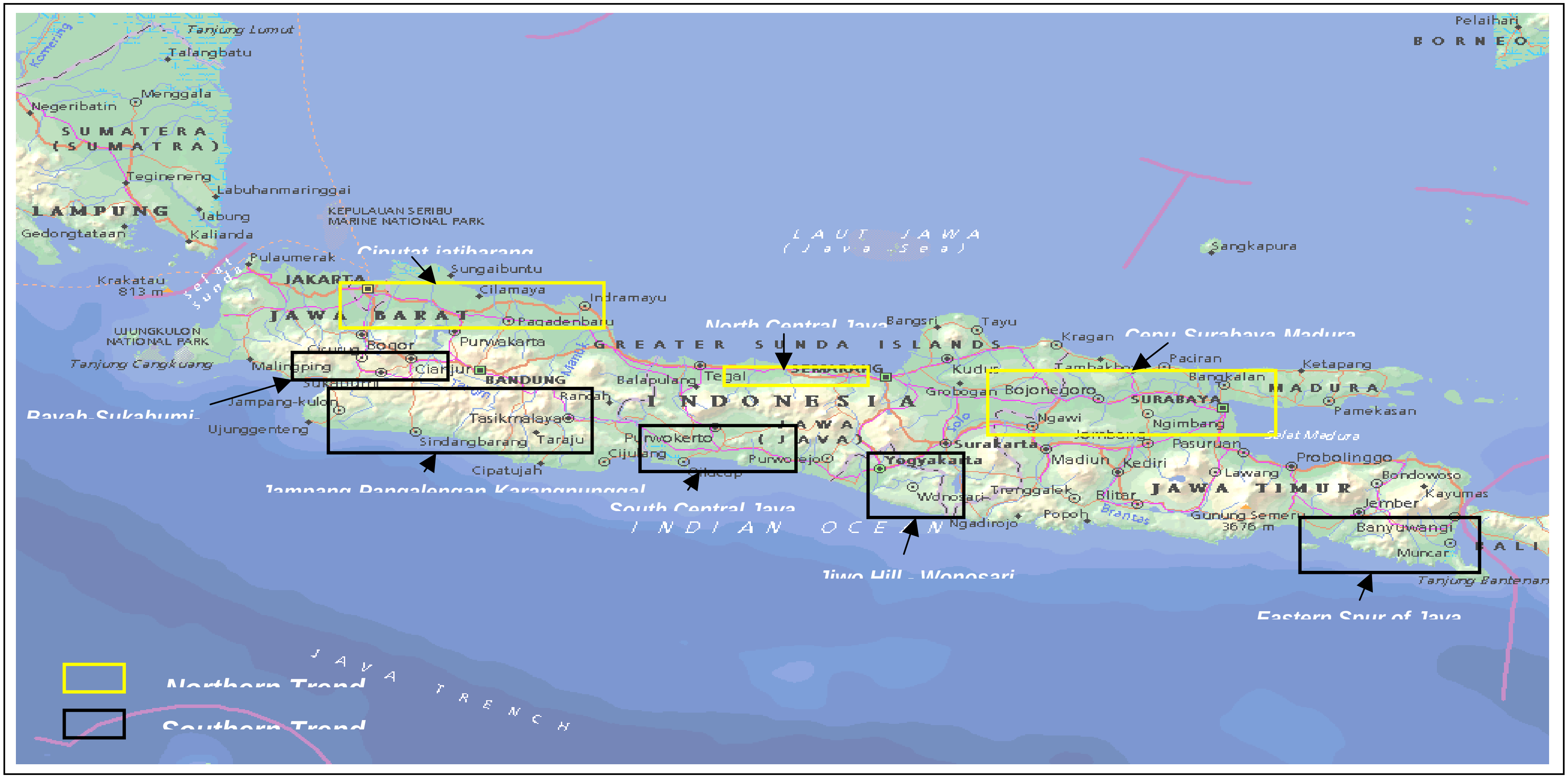


Figure 7 Location map of study areas (in boxes).

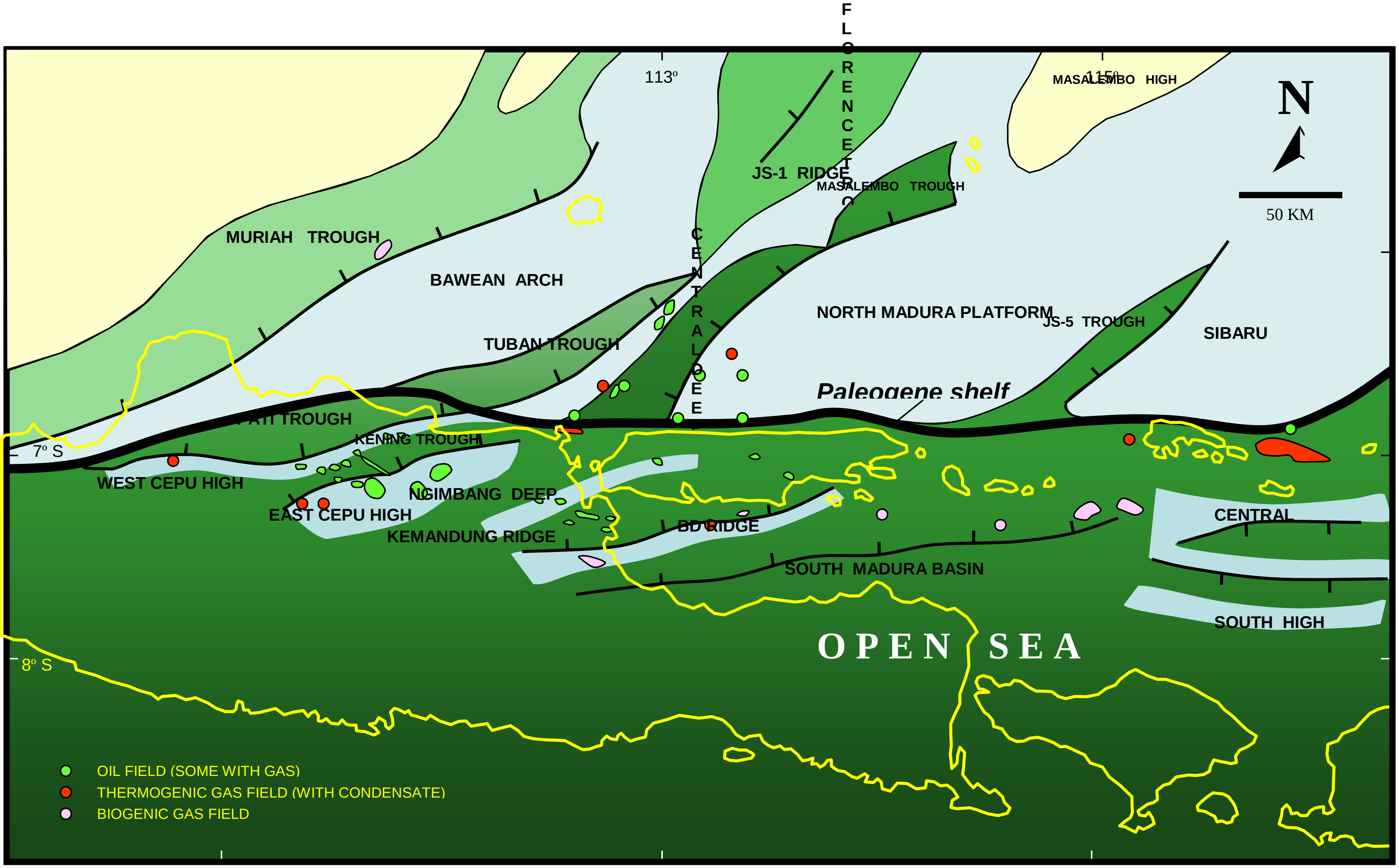


Figure 8 Paleogene geography of East Java Basin. Oligo-Miocene carbonates developed at each high/ platform. At the southern shoreline of Java, Oligo-Miocene volcanism (Old Andesite) contemporaneously developed.

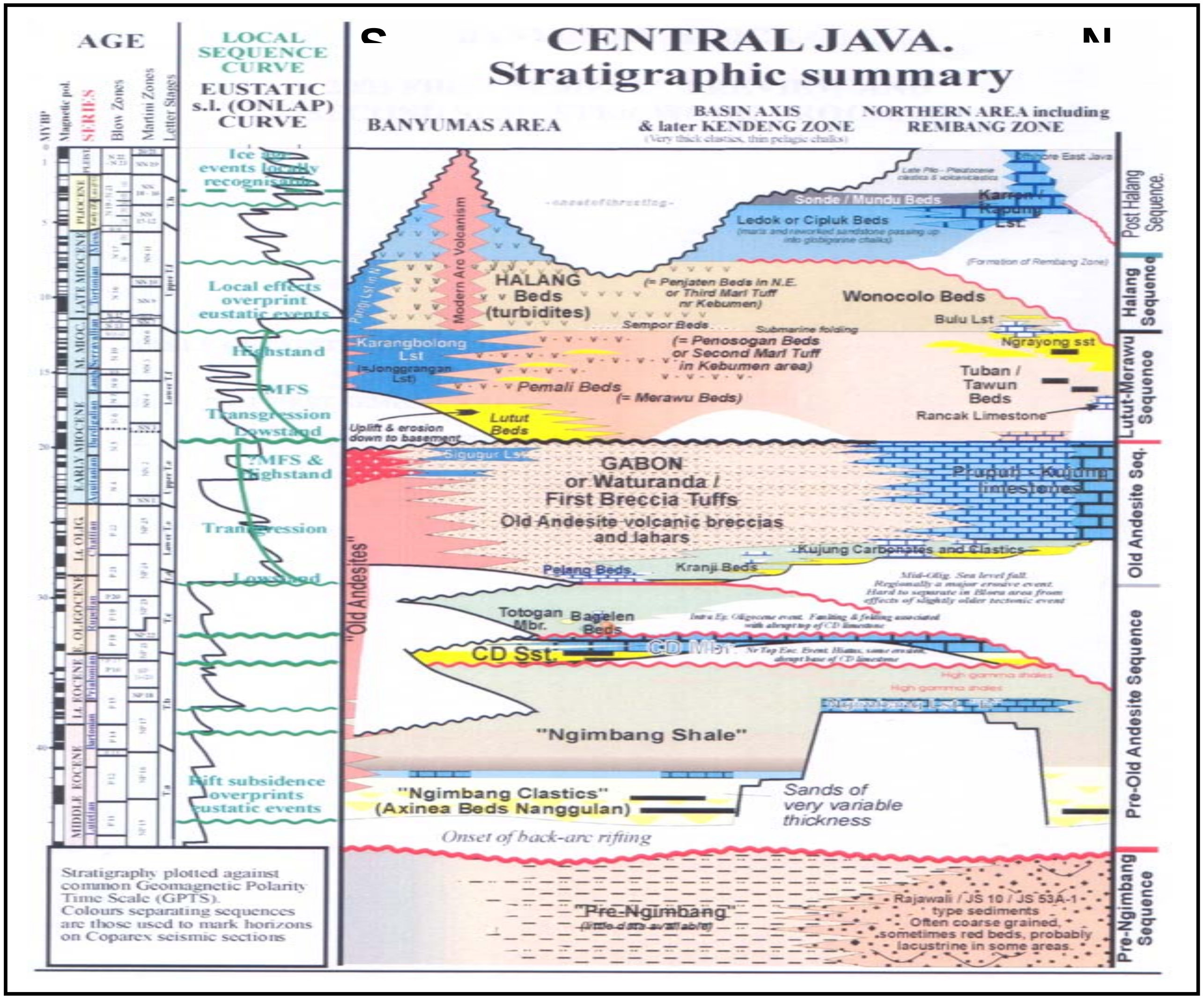
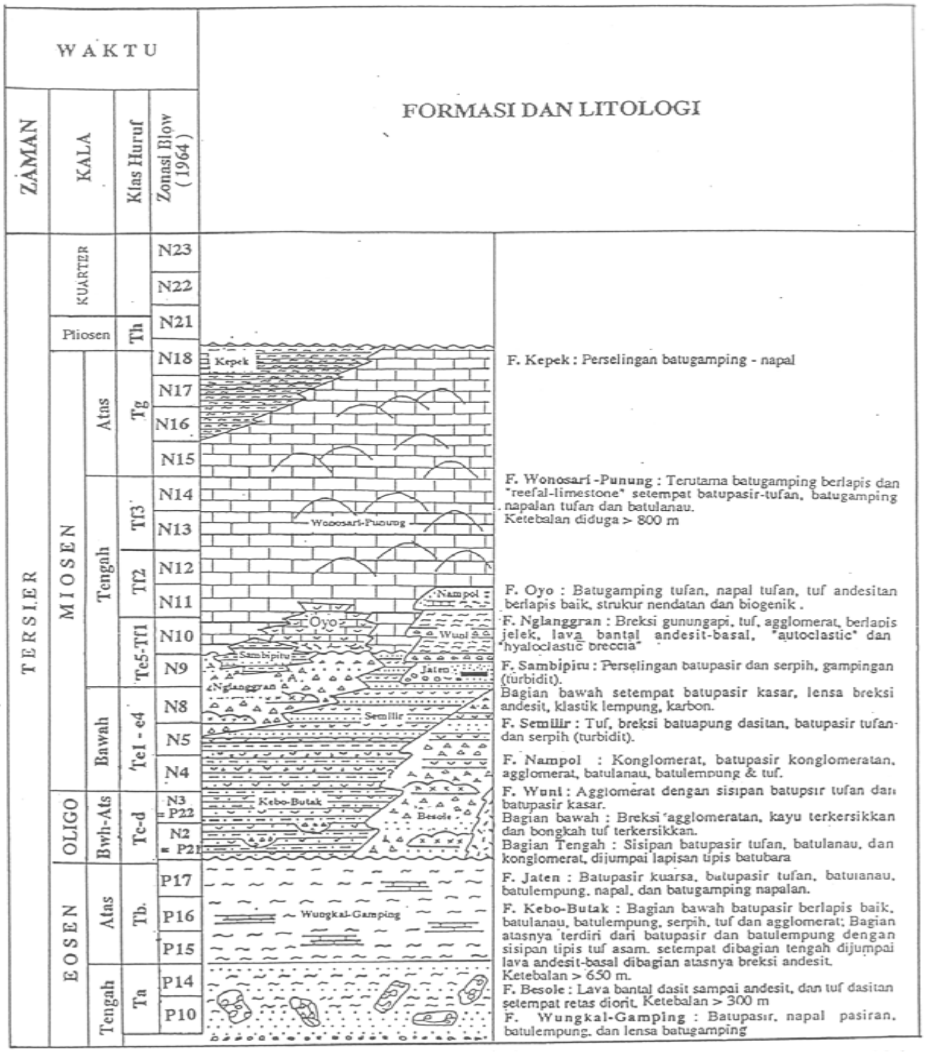


Figure 9 Stratigraphic summary of Central Java from south to north (Banyumas to Rembang areas). Note the relationship between carbonates and volcanics during the Oligo-Miocene. Carbonates developed in areas far from volcanism or when volcanism declined such as during the Middle Miocene. The figure was provided by Lundin Banyumas B.V.



F. Kepek : Perselingan batugamping - napal

F. Wonosari -Punung : Terutama batugamping berlapis dan "reefal-limestone" setempat batupasir-tufan, batugamping napalan tufan dan batulanau.
Ketebalan diduga > 800 m

F. Oyo : Batugamping tufan, napal tufan, tuf andesitan berlapis baik, strukur nendatan dan biogenik .

F. Nglanggran : Breksi gunungapi, tuf, agglomerat, berlapis jelek, lava bantal andesit-basal, "autoclastic" dan "hyaloclastic breccia"

F. Sambipitu : Perselingan batupasir dan serpih, gampingan (turbidit).
Bagian bawah setempat batupasir kasar, lensa breksi andesit, klastik lempung, karbon.

F. Semilir : Tuf, breksi batuapung dasitan, batupasir tufan dan serpih (turbidit).

F. Nampol : Konglomerat, batupasir konglomeratan, agglomerat, batulanau, batulempung & tuf.

F. Wuni : Agglomerat dengan sisipan batupsir tufan dan batupasir kasar.
Bagian bawah : Breksi agglomeratan, kayu terkersikkan dan bongkah tuf terkersikkan.
Bagian Tengah : Sisipan batupasir tufan, batulanau, dan konglomerat, dijumpai lapisan tipis batubara

F. Jaten : Batupasir kuarsa, batupasir tufan, batulanau, batulempung, napal, dan batugamping napalan.

F. Kebo-Butak : Bagian bawah batupasir berlapis baik, batulanau, batulempung, serpih, tuf dan agglomerat; Bagian atasnya terdiri dari batupasir dan batulempung dengan sisipan tipis tuf asam. setempat dibagian tengah dijumpai lava andesit-basal dibagian atasnya breksi andesit.
Ketebalan > 650 m.

F. Besole : Lava bantal dasit sampai andesit, dan tuf dasitan setempat retas diorit. Ketebalan > 300 m

F. Wungkal-Gamping : Batupasir, napal pasiran, batulempung, dan lensa batugamping

Figure 10 Stratigraphy of the Pegunungan Kidul, south of Yogyakarta (after Geology Dept. UGM, 1994) showing the absence of contemporaneous carbonate development within Oligo-Miocene

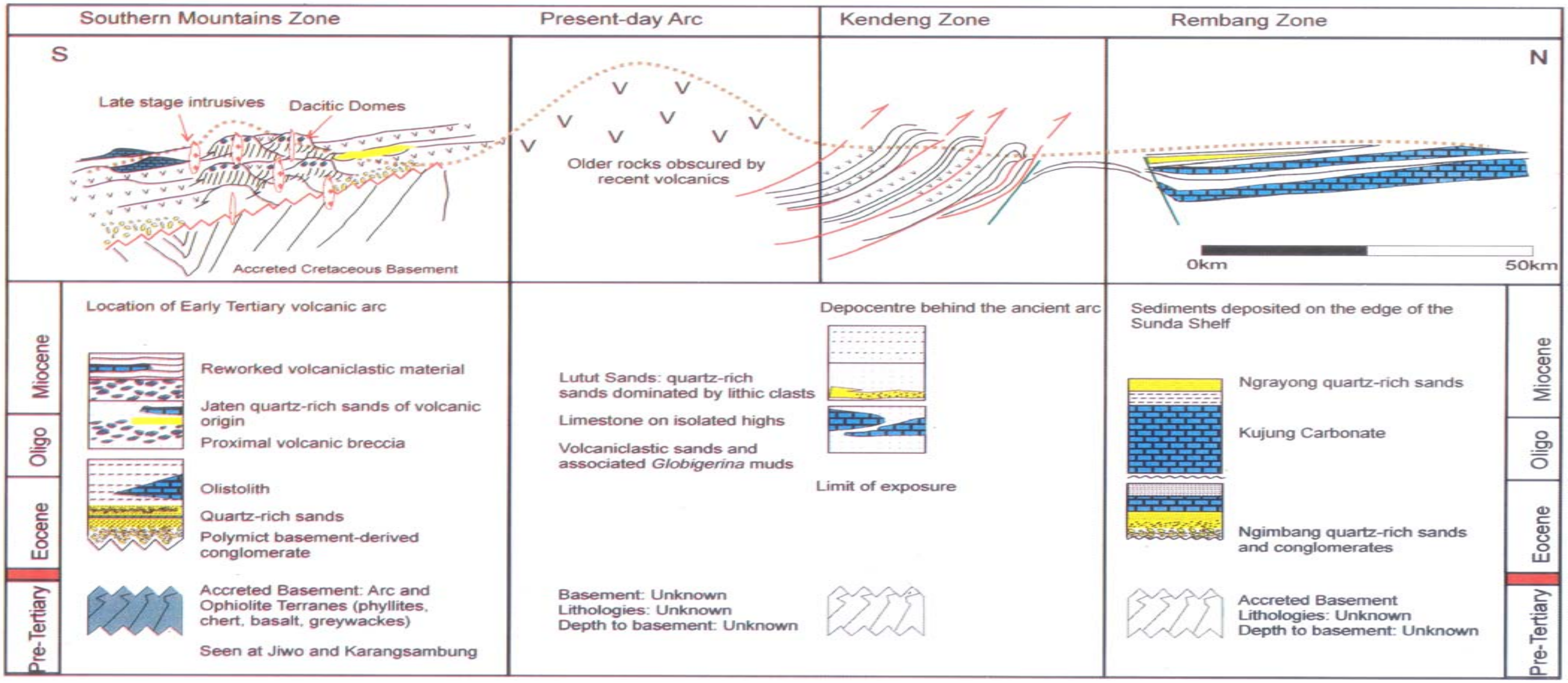


Figure 11 Schematic regional cross section across Central-East Java from south to north showing stratigraphic variabilities in each zone (after Smyth et al., 2003). Note the absences of volcanic intercalations/interbeds/impurities within Oligo-Miocene carbonates in

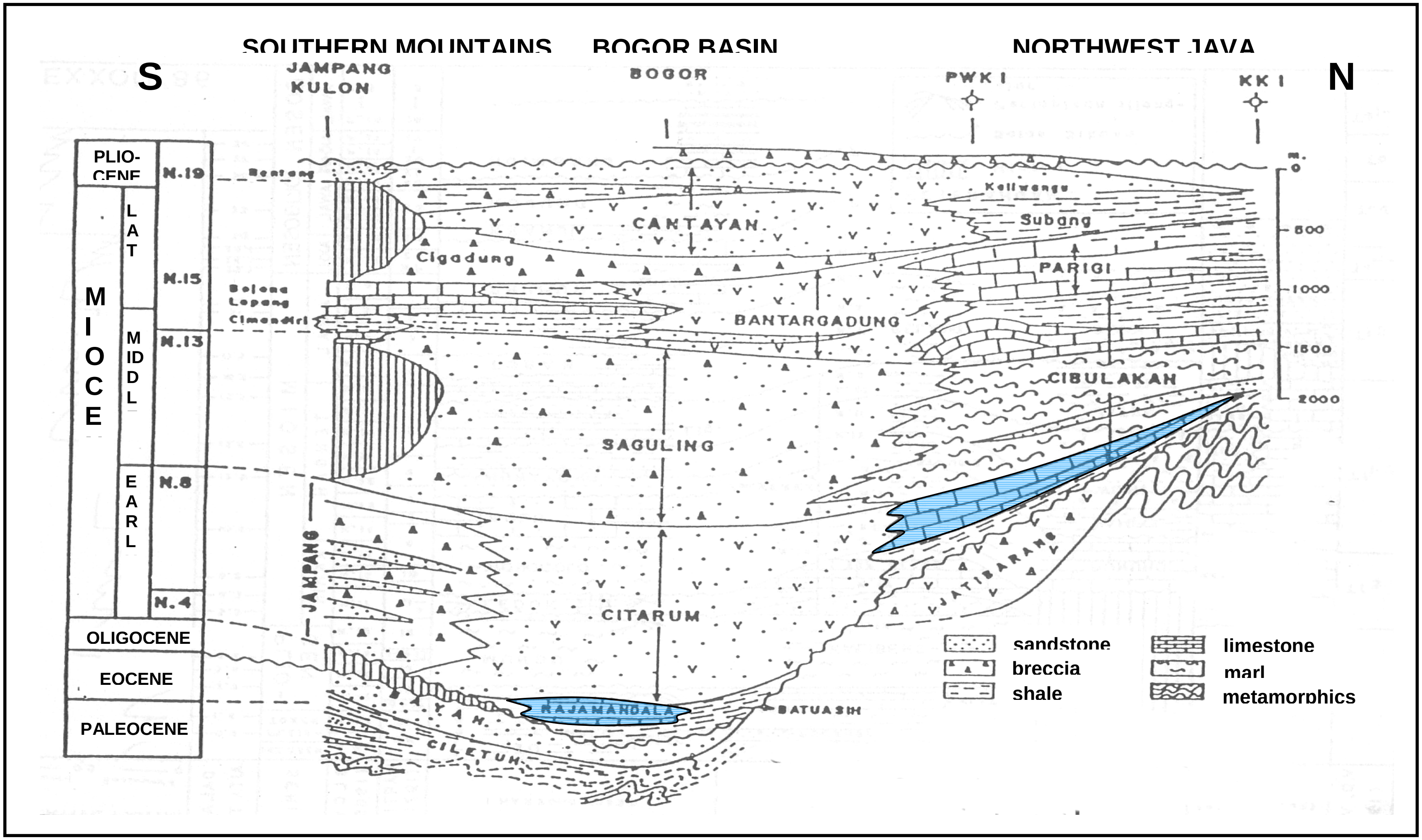


Figure 12 Schematic regional stratigraphic setting across West Java showing relationships between volcanic deposits and carbonates. Oligo-Miocene carbonates (in blue) of Rajamandala developed before onset of volcanism, Lower Cibulakan carbonates were not influenced by volcanism mostly deposited within Bogor Basin. Figure was modified after Martodjojo (1994).

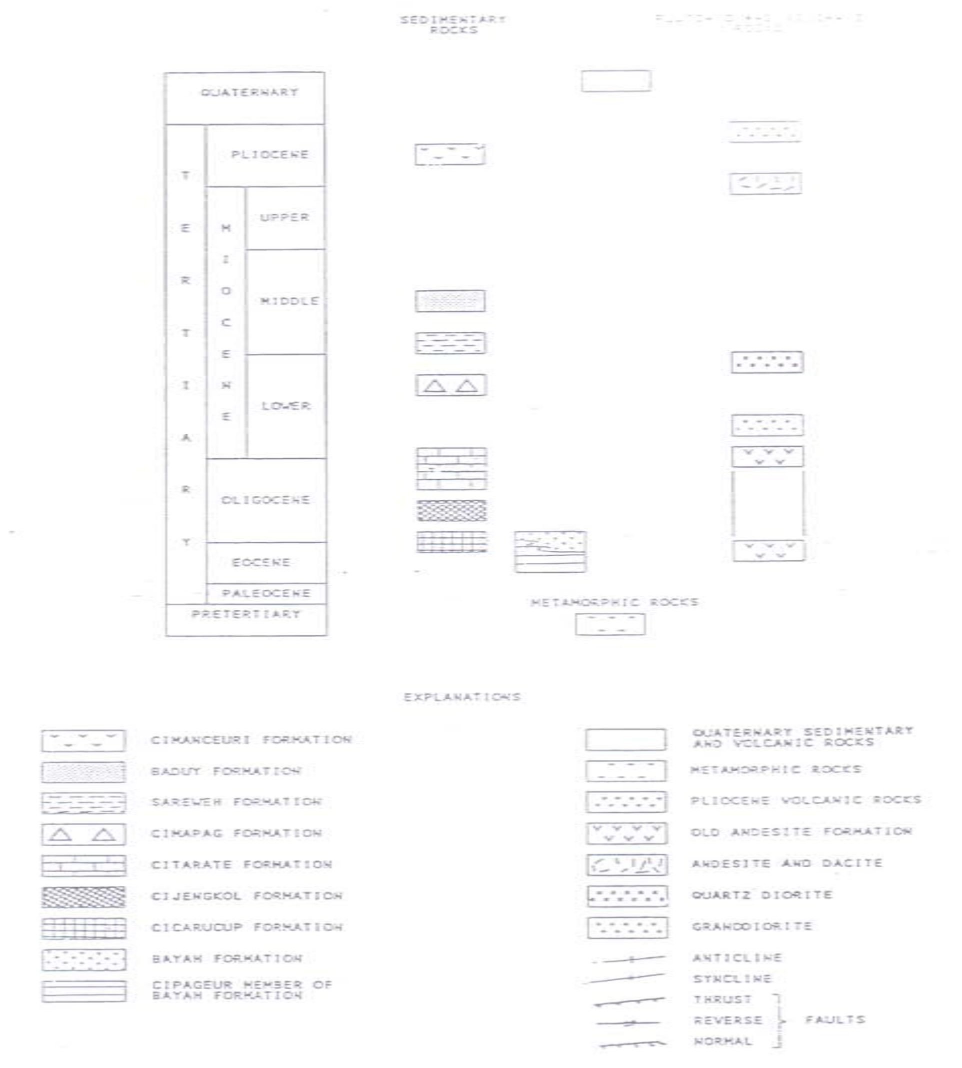


Figure 13 Stratigraphy of the Bayah area (after Sukarna *et al*., 1994). Note that development of carbonates of the Cicarucup, Cijengkol and