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Geology of the Bayah area: implications for the Cenozoic evolution of West Java, Indonesia

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Abstract: The geological setting of the Bayah area in the Paleogene is indicated by the presence of alternating sedimentary and volcanic rocks. The sedimentary rocks consist of fine to coarse clastic sediments, which suggest regressive deposition in a shallow basin. In the Neogene time, sediments with open marine characteristics and contemporaneous volcanic rocks were deposited in the transition area at the southern border of the basin. The clasts of Neogene sedimentary rocks were derived from a southern source area. The boundary between the Paleogene and the Neogene sequences is characterized by an unconformity, indicated in the field by an erosion surface. Three further tectonic phases can be recognized in this area. They occurred in the Late Paleogene, late Middle Miocene and latest Miocene age.

The Tertiary volcanic rocks can be divided into a lower sequence of Late Eocene to Early Oligocene age (LOA) and upper sequence of Oligocene to Miocene age (UOA). All the rocks, except for one sample from the LOA, are rocks typical of a calc-alkaline island arc. The LOA consists of basalts and basaltic andesites with characteristics that suggest a more primitive magma than those the UOA. The LOA rocks probably correspond to fractional crystallization and contamination with a component of low-Th concentration of the intermediate lower crust. The LOA was generated in the volcanic front and appears to be related to a period of slower subduction. The UOA, which ranges from basalt to rhyolite composition, correspond to an increase of differentiation. They experienced contamination of the parental magma terrigenous sediments and occur in high crustals levels.

INTRODUCTION

The Bayah area is part of West Java (Fig. 1). It is situated in the zone of subduction of the Indian-Australian Plate under the Eurasian Plate. At the surface this junction is expressed by the formation of an island arc, namely the Sunda-Banda arc. At present, active subduction is taking place in the south of Java. The plate movement probably started in the Early Cretaceous and subduction occurred at least since the Late Cretaceous.

This paper represents a reconstruction of the evolution of the Bayah area related to West Java during the Cenozoic. Paleogene and Neogene sedimentary rocks as well as Early Tertiary volcanic rocks are exposed in the Bayah area (Suparka *et al.*, 1982). According to van Bemmelen (1949), these exposures form the most complete Early Tertiary section of Java. A detailed study is focussed to the plutonic and volcanic rocks. From these rocks, a model for the magma generation in the Bayah area has been formed. The reconstruction of this area has been based on these model and on the evidences from the sedimentary rocks and tectonic events.

TERTIARY STRATIGRAPHY AND TECTONICS

The Tertiary stratigraphy of the Bayah area can be divided into Paleogene and Neogene sequences. The Paleogene sequence, includes sedimentary and volcanic rocks of the Bayah Formation, the Cipageur member of Bayah Formation, the Cicarucup Formation, the Cijengkol Formation, the Citarate Formation and the Old Andesite Formation. The Neogene sequence comprises sedimentary and volcanic rocks of the Cimapag Formation, the Sareweh Formation, and the Baduy Formation.

Paleogene sedimentary sequence

Bayah Formation and Cipageur Member

The largest outcrops of the Bayah Formation are in the south of the Bayah area and in the Cimandiri area near the south coast of Banten (Fig. 2). According to Koolhoven (1933) the northward extension of this formation is bounded by a thrust fault. The Bayah Formation has been repeatedly affected by tectonism. From bed dips it

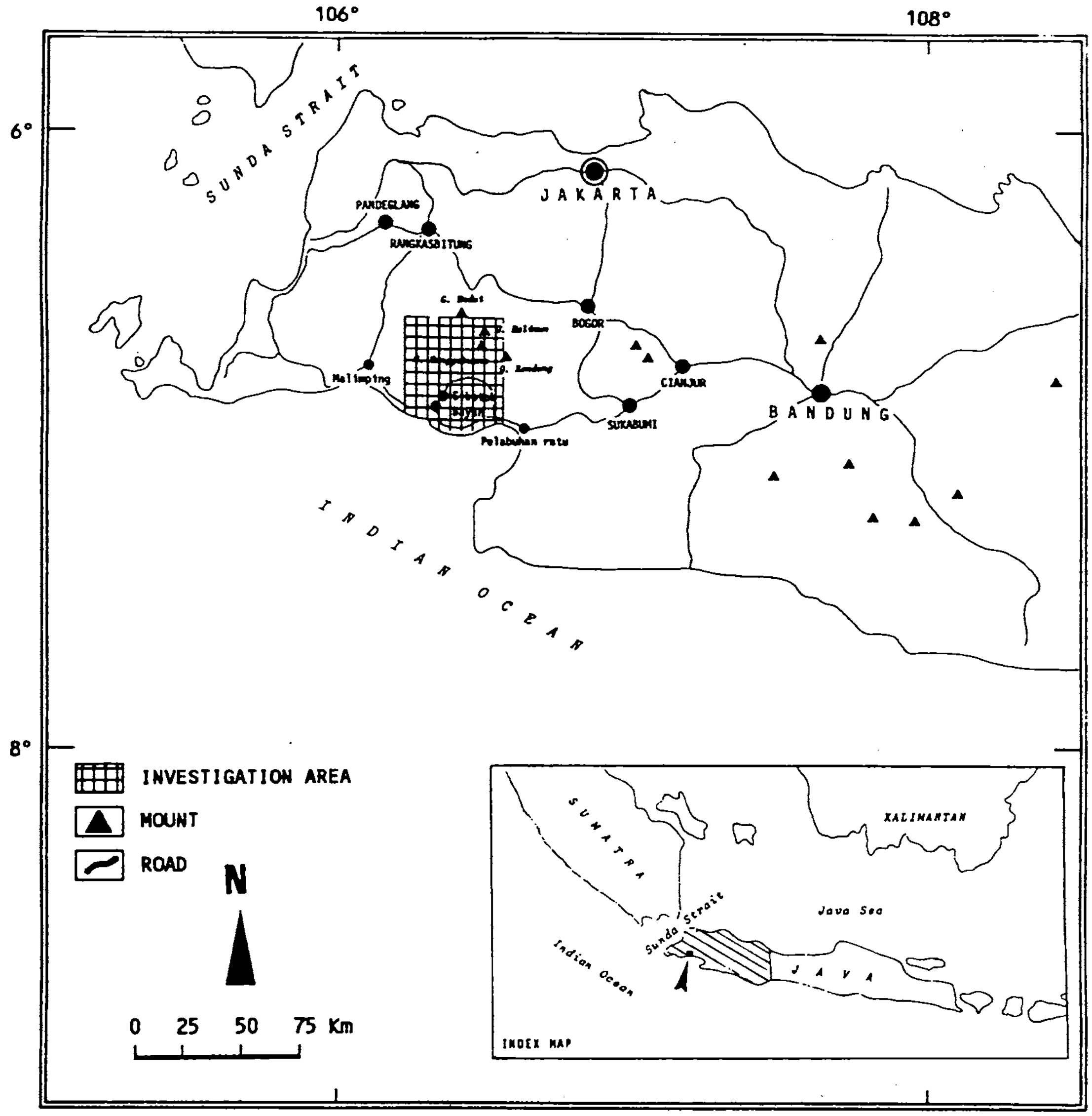

Figure 1. Location of the investigated area.

is known that the Cimandiri block is more intensely folded than the Bayah area (see geological maps of Koolhoven, 1933, and Sudjatmiko and Santosa, 1985).

The stratigraphic relationships of the Bayah Formation indicate an Eocene age. It consists of well bedded quartz sandstone with bed thickness ranging from less than 1 m to up to 10 m, in several places conglomerates and breccias (Fig. 3), upwards intercalated with clay and coal layers. These lithological characteristics are interpreted as changing between braided stream and deltaic deposits. The erosional source of these rocks is the plutonic and metamorphic basement complex (Martodjono *et al.*, 1978; Martodjojo, 1984).

The Cipageur Member appears also in the south of the Bayah area, but north of the Bayah Formation with the largest exposures in the Cihara River. The Cipageur Member is recognized as early to Middle Eocene age. It consists of clay, marly clay, and quartz sandstone with intercalating lenses of limestone (Fig. 3). The presence of black clay with intercalated lenses of limestones, containing macro-foraminifers in the Cipageur Member, probably indicates a closed littoral to neritic environment. The Cipageur Member interfingers with the lower sequence of the Old Andesite Formation.

Cicarucup Formation

Outcrops of the Cicarucup Formation are known only in the anticlinal cores near Cicarucup between the Cimadur and the Cidikit rivers (Fig. 2). The formation has been repeatedly faulted and folded. It consists of conglomerates, quartz sandstones, clays, marly clays, limestones and tuffs which indicate a shallow marine environment (Fig. 3). The source of the rocks are probably from the plutonic and metamorphic basement and from the volcanic arc in the north. The Cicarucup Formation

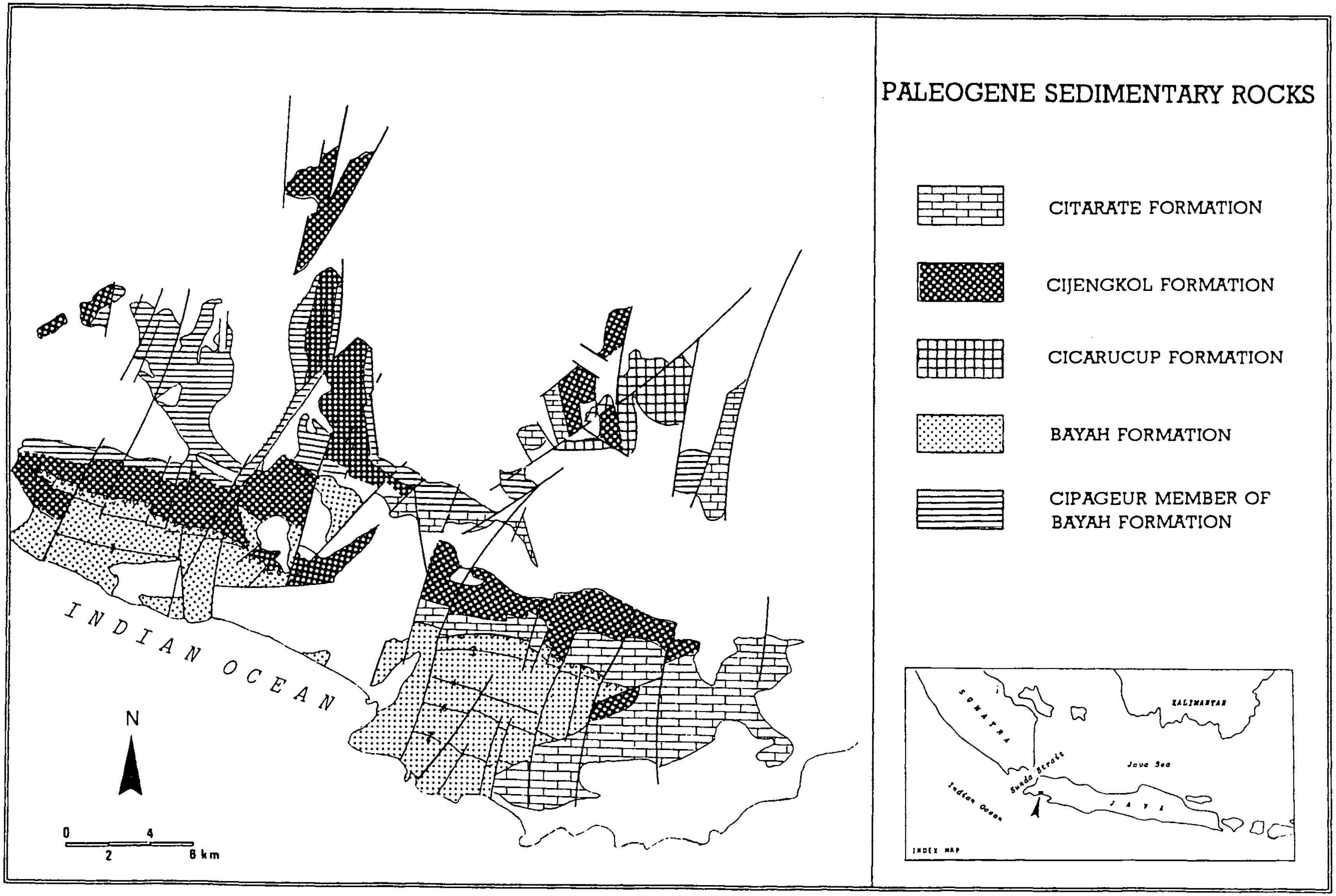

Figure 2. Map showing the distribution of the Paleogene sedimentary formations in the Bayah area.

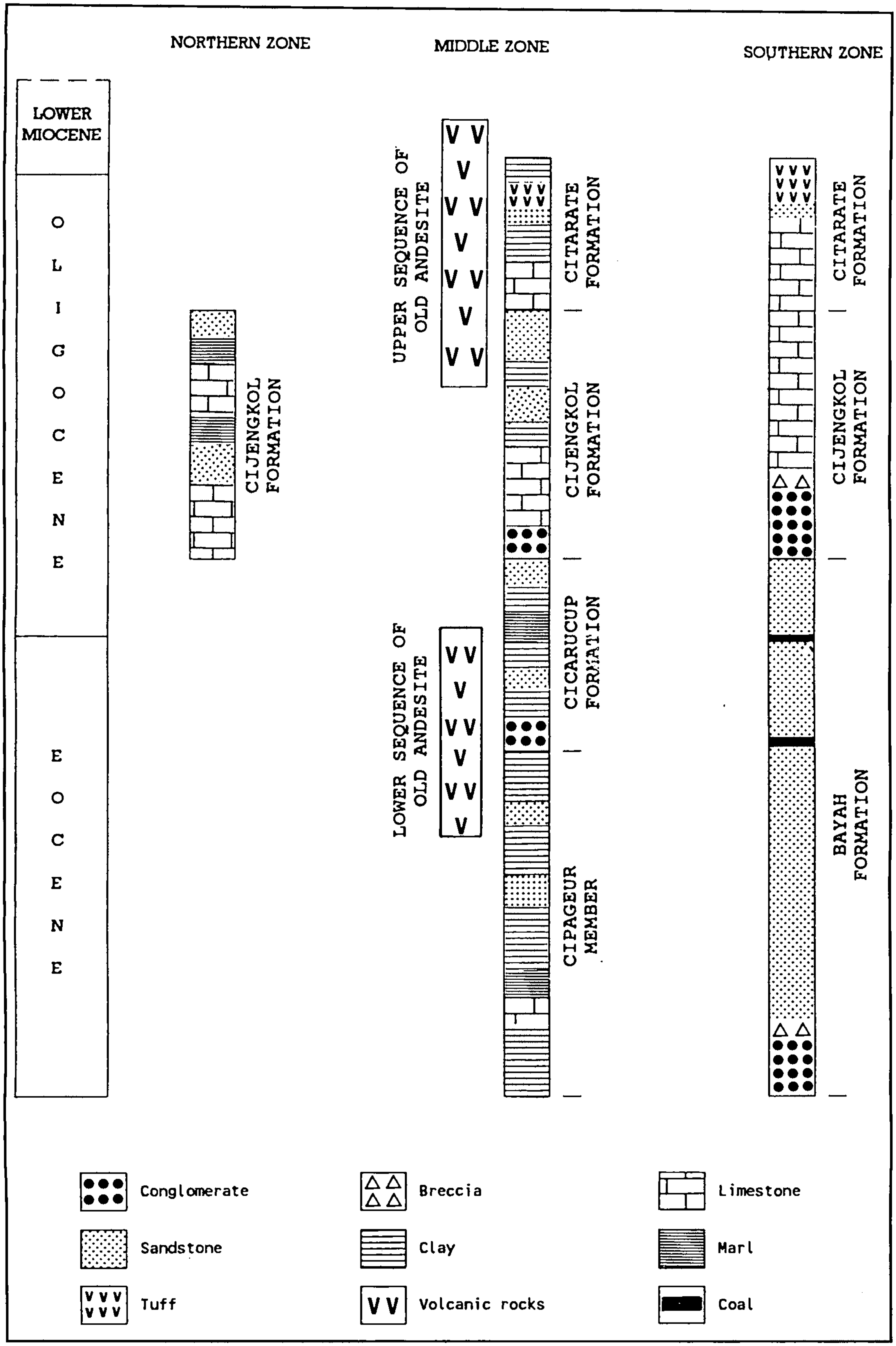

Figure 3. Composite stratigraphy of the Paleogene sequence.

is recognized as Late Eocene to earliest Oligocene according to foraminifers from the marly clay, quartz sandstone and limestone beds (Sudjatmiko and Santosa, 1985).

Cijengkol Formation

The Cijengkol Formation occupies the middle zone of the Cimandiri area and also occurs in the Cihambali village; small exposures are known in the north zone near G. Malang (Fig. 2). The layers have been repeatedly folded and faulted. The sequence consists of bedded conglomerates with breccias and sandy tuffs in the lower part. Calciferous sandstones containing glauconite and limestones, clays and marly clays with intercalated coal lenses and tuffs occur in the upper part (Fig. 3). These sediments which are recognized to range from Early to Late Oligocene, are interpreted to have been deposited in an environment changing gradually from deltaic to marine. The lower part, mostly consisting of conglomerates and breccias, seems to have been deposited in a deltaic environment. The calciferous glauconitic sandstones, marly clays and sandy limestones are described as littoral open marine deposits.

Citarate Formation

The Citarate Formation is exposed in the south and the middle zone (Fig. 2). Deformation including anticlines, synclines, normal and lateral faults occur in this sequence. The rocks in the lower part consist of limestones intercalated with calcareous sandstones, thin quartz sandstones and marly clays. The upper part is made up of tuffaceous calcibreccia and sandstone with intercalated clastic limestones (Fig. 3). According to Koolhoven (1933), the upper part also contains marls, tuffs, glauconitic calcareous sandstones and conglomerates. Based on foraminifers from the limestone and the marly-clay beds, the Citarate Formation has a Late Oligocene to earliest Miocene age (Koolhoven, 1933). These rocks in the lower part indicate a shallow marine deposition, probably littoral, upwards the depositional environment seems to have been probably deeper and an open sea setting is suggested.

Neogene sedimentary sequence

Cimapag Formation

The Cimapag Formation is exposed in the north of the middle zone (Fig. 4). Weak to moderate folds and faults occur. The unit is dominated by conglomerates, polymict breccias, intercalated clays, mudstones, tuffaceous sandstones, altered tuffs and silicified wood with locally reefal limestones in the lower part. Tuffs, agglomerates, lavas and silicified wood are present in the upper part (Fig. 5). These rocks are recognized as latest Lower Miocene age according to foraminifers from clastic limestones (Koolhoven, 1933; Prasetyo, 1979). The Cimapag Formation is interpreted to have been deposited in shallow sea near a continent.

Sareweh Formation

The Sareweh Formation commonly forms karst topography in the northern zone and small exposures are known in the middle zone (Fig. 4). The sequence is dominated by reefal limestones with intercalated clastic sediments, including clays, calcareous sandstones, and mudstones and locally intercalated tuffs and marls (Fig. 5). These sediments are recognized as Middle Miocene (Koolhoven, 1933) and the depositional environment is suggested to be shallow marine. However, the presence of planktonic foraminifers (Koolhoven, 1933) suggests an open sea.

Baduy Formation

The Baduy Formation is exposed northwest of the Bayah area adjacent to the Bogor Basin (Fig. 4). This formation has been folded (anticlines and synclines), and faulted (normal and lateral faults). The sequence consists of sandstones, conglomerates and reefal limestones in the lower part, upward changing to well-bedded clastic limestones, mudstones and marls (Fig. 5). On the basis of the foraminiferal content, the Baduy Formation is late Middle Miocene (Koolhoven, 1933; Sudjatmiko and Santosa, 1985). The succession changes from clastic sediments in the lower part into dominantly carbonate sediments, very probably deposited in a deltaic to shallow open marine environment. Syahbudin *et al.* (1984) suggested an inner sublittoral marine environment with normal salinity.

Cimanceuri Formation

The Cimanceuri Formation consists of calcareous sandstone, conglomerate, breccia, tuff and limestone alternations (Fig. 5). These clastic sediments include Old Andesite materials, silicified rocks, quartz, limestone and quartz-vein fragments (Koolhoven, 1933). Broken molluscs and foraminifers from the limestones (Koolhoven, 1933; Sudjatmiko and Santosa., 1985) indicate Early Pliocene age. These sediments are suggested as deltaic to shallow marine deposits.

TERTIARY PLUTONIC AND VOLCANIC ROCKS

The Tertiary plutonic volcanic rocks in the Bayah area range in age from late Eocene to Pleistocene. They occur in several cycles and are exposed in several places. These rocks consist of plutonic and hypabyssal rocks, lava, volcanic breccias and pyroclastic rocks (Fig. 6) which can be divided into the Old Andesite Formation (OAF) and the Miocene plutonic and volcanic rocks (MPV).

Old Andesite Formation (OAF)

The Old Andesite Formation (OAF) is exposed in the middle zone, forming irregular synclines and anticlines. The dips of the layers, measured in the sedimentary-rock intercalations, ranges from horizontal to 45°, with several abrupt changes over short distances. Some parts are propylitized and contain gold-bearing quartz veins. The OAF can be divided into a lower sequence of Old Andesite (LOA) and an upper sequence of Old Andesite (UOA). The fundamental difference between the two sequences is that the LOA is known only to interfingers with the Cipager member of the Bayah Formation (Eocene). The UOA interfingers with the Upper Cijengkol and the Citarate Formations indicating late Oligocene to earliest Miocene.

Based on the stratigraphic relationships, the LOA is interpreted as late Eocene to early Oligocene. It consists of basalts and basaltic-andesitic rocks (Fig. 7). Whole rock chemistry and microprobe study of the mineralogy indicate that the rocks are calc-alkaline, except one sample which is of tholeiite character (JS63a). However, the LOA rocks have higher values the compatible elements (Ni and Cr) than the average island arc tholeiite and calc-alkaline rocks as defined by Gill (1981). The ratio La/Th is also higher than for common island arc rocks.

An island-arc calc-alkaline classification for the LOA is shown in Figs 8, 9, 10 and 11. The chondritic normalized concentration of the rare earth elements (REE) (Fig. 12) and the incompatible elements (Fig. 13) show that Rb, K, Ba, Sr and LREE are relatively enriched with respect to Th, Ta, Hf, Zr and Ti. This usually occurs in an island-arc magmas (Kay, 1984; Thompson *et al.*, 1984). An island arc pattern is also supported by lower Th_N and Rb_N values as compared with the pattern of the Aleutian arc (Kay,

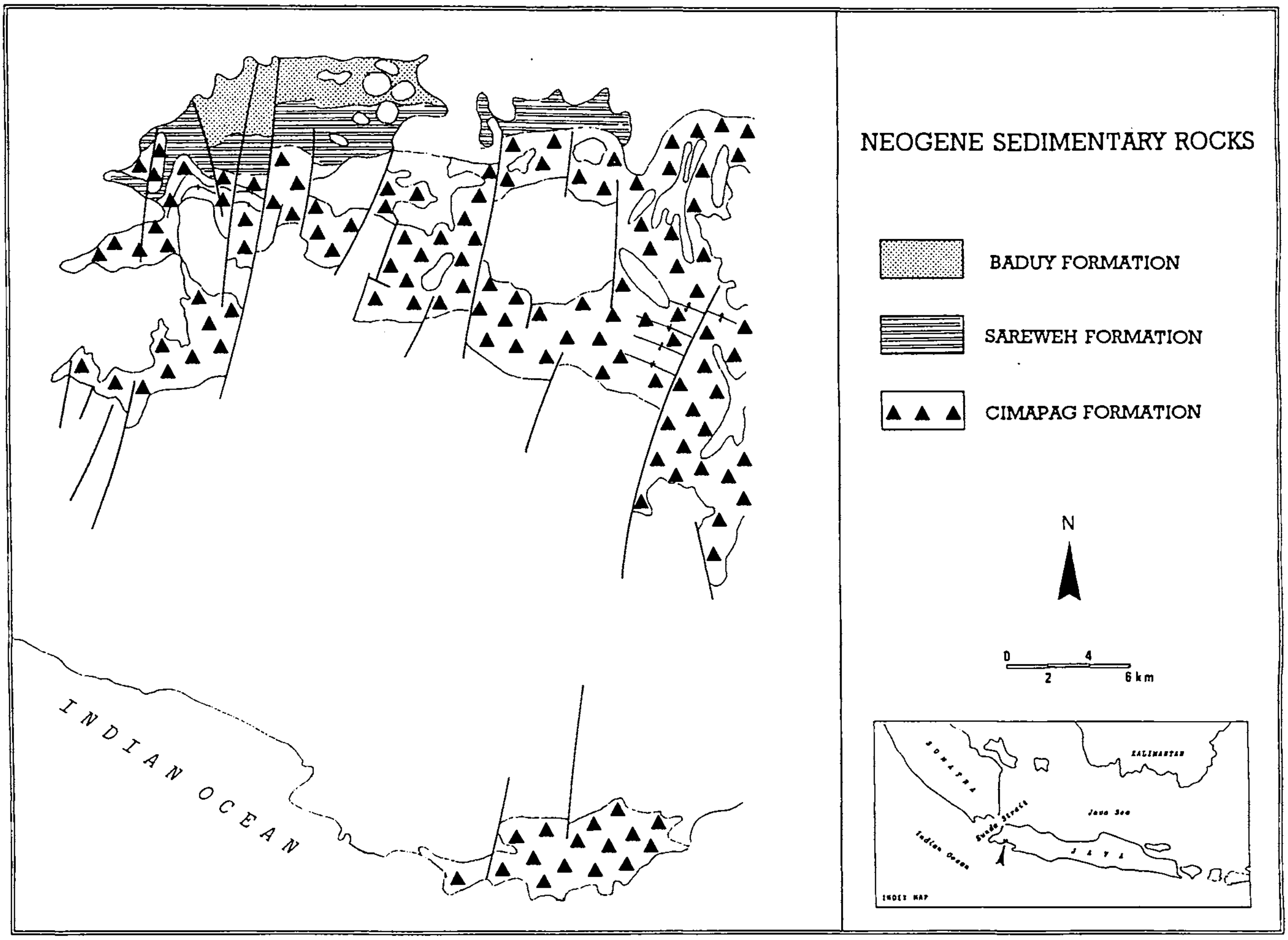

Figure 4. Map showing the distribution of the Neogene sedimentary rocks in the Bayah area.

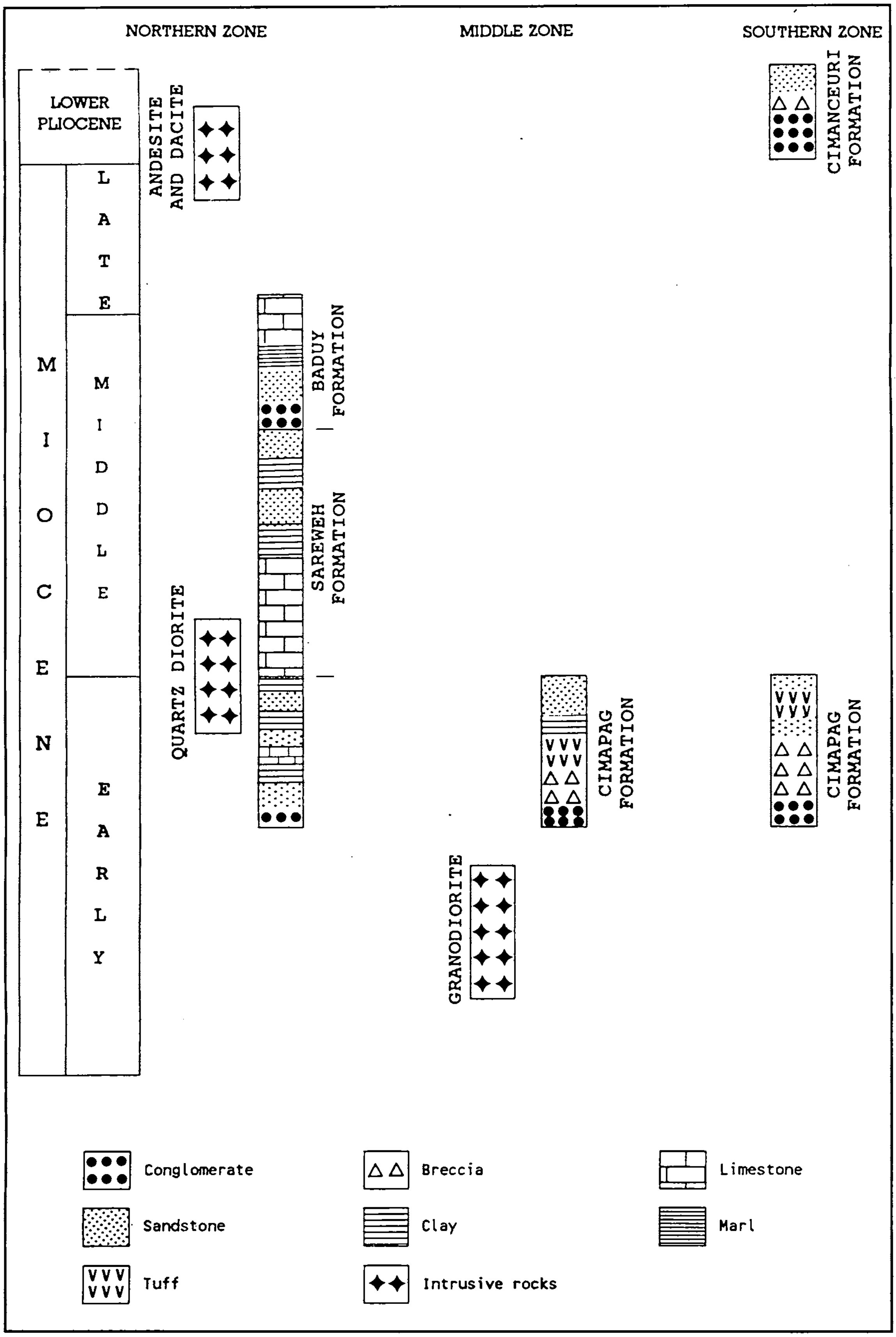

Figure 5. Composite stratigraphy of the Neogene sequence.

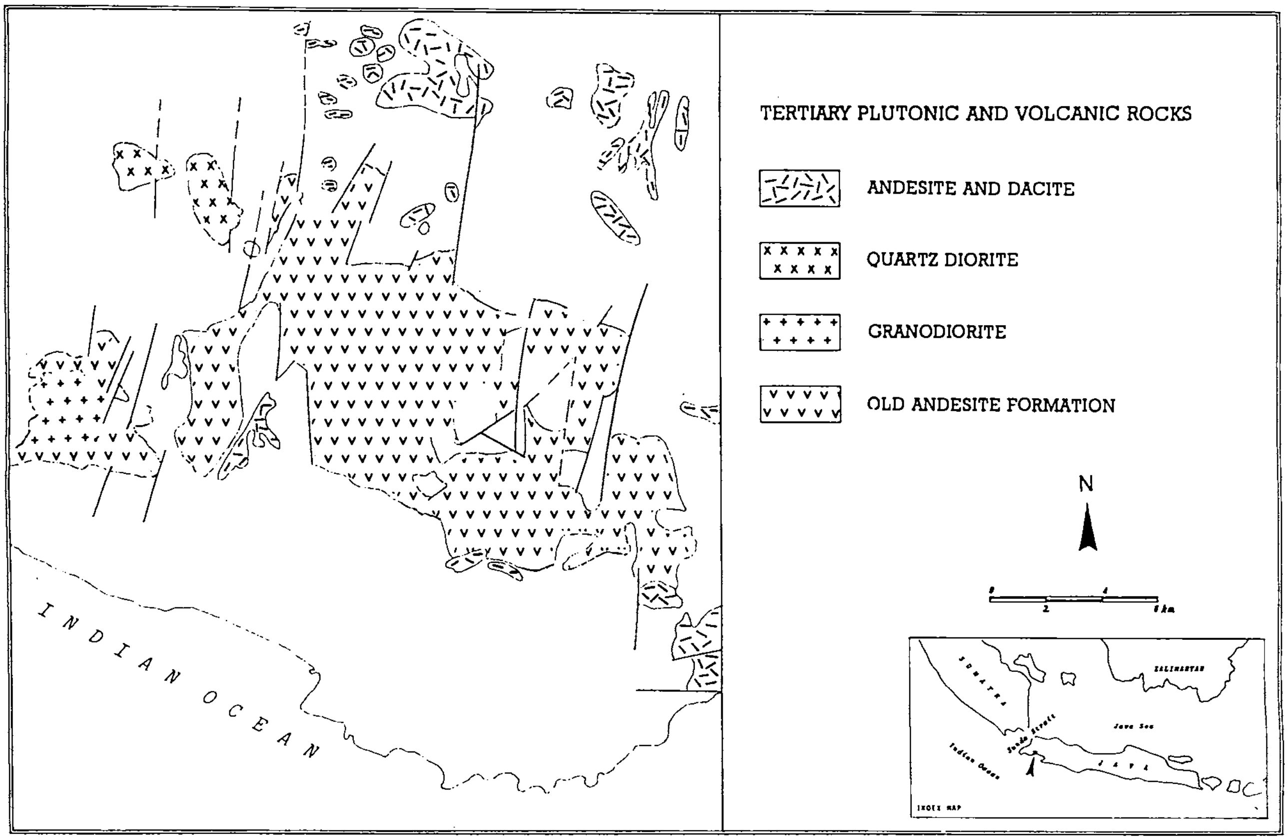

Figure 6. Map showing the distribution of the Tertiary plutonic and volcanic rocks in the Bayah area.

1984) — the ratios are Ba/Ta (819) and La/Ta (41.6). However, the difference of the LOA rocks from common island arc rocks are indicated by the concentration of some elements. Th contents are relatively low (2), although higher than average mid-oceanic ridge basalt (MORB) (1). Plots of La/Th ratios are between 7 and 15. These value are in the E-MORB field according to graph of Gill (1981) (Fig. 11). The compatible elements (Ni and Cr) values are relatively higher than average orogenic andesite (Ni 40, Cr 100; Gill, 1981). The LOA rocks have Ni values between 41 and 243 ppm, except samples JS131a and JS154a which are less than 40 ppm. Cr contents range from 120 to 786 ppm. These differences in geochemical composition of the LOA from common island-arc rocks are probably related to the magma generation of the LOA. This may be related to the magma generation at the volcanic front.

The UOA is recognized as Oligocene-Miocene based on the interfingering relationship with the Upper Cijengkol Formation and Lower Citarate Formation. They range from basaltic to rhyolitic composition (Fig. 7). The petrography, whole-rock geochemistry and microprobe study of these rocks indicate an orogenic calc-alkaline origin, as shown in Figs 8,9 10 and 11. The island-arc characteristics for the UOA, from the point of view of the chondritic normalized rare-earth elements and the incompatible elements, are shown in Figures 11 and 12. They show steep patterns and a selective enrichment of Rb, K, Ba, Sr, Th and REE related to a low ionic potential (Ta, P, Zr, Hf, Sm, Ti, Y and Yb). This causes relatively high Ba/Ta, Ba/La, La/Ta and low La/Ta ratios (Jakes and Gill, 1970; Jakes and White, 1971; Miyashiro, 1974; Gill, 1981). Thus, it is clear that the UOA rocks are the product of volcanic activity of orogenic origin. These characteristics are closely related to the tectonic setting. The UOA erupted in the central part of the volcanic arc (Sunda-arc) during the Oligocene-Miocene.

Miocene plutonic and volcanic rocks

The Miocene plutonic and volcanic rocks (MPV) occur as lavas and intrusive rocks from Early to Late Miocene. They consist of granodiorite, quartz diorite, basalt, andesite, dacite and rhyolite. The whole-rock geochemistry and microprobe study of these rocks show a similar character with the UOA rocks. The regular chemical trend of those groups can be recognized. The difference is in the degree of magmatic differentiation. The volcanic rocks of the MPV correspond to more fractional crystallization. They have an Mg number lower than the UOA. The chondritic normalized REE

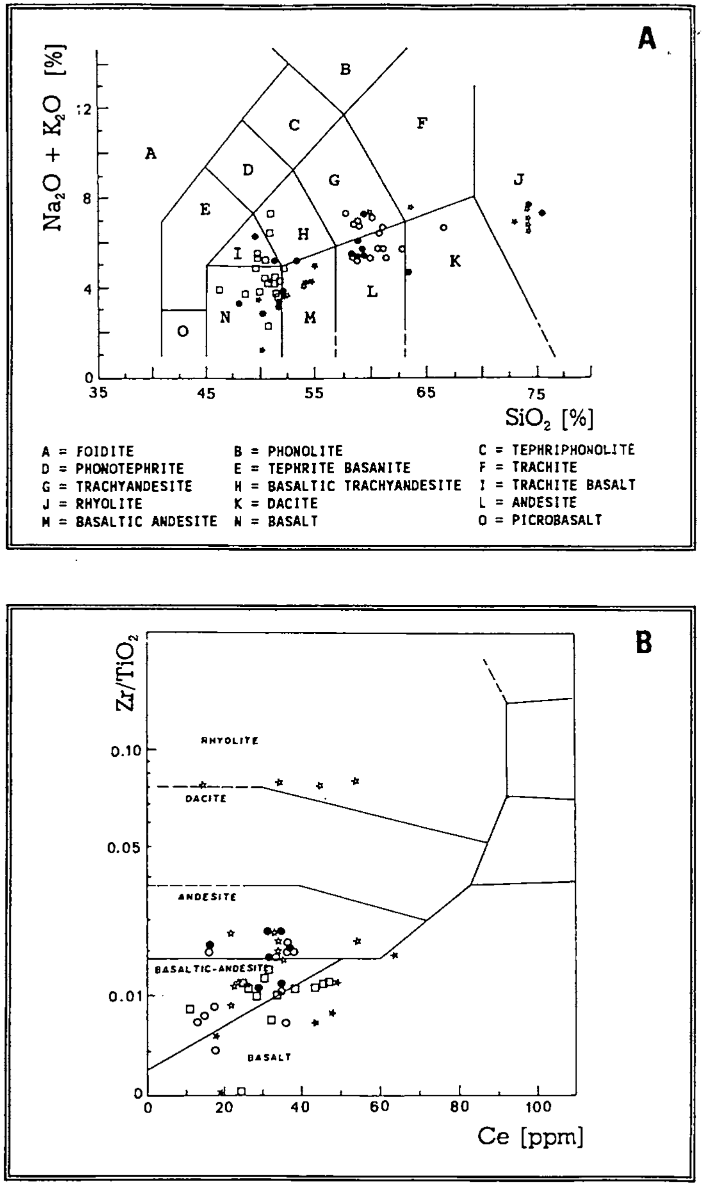

Figure 7. Diagram of rock classification used for the Tertiary plutonic and volcanic rocks in the Bayah area. TAS (total alkali vs silica) after Le Bas (1976). Zr/TiO_2 vs Ce after Andre (1983). The samples are defined as squares for the LOA, stars for the UOA volcanics, full stars for the UOA diabase, full circles for the MVP volcanics and circles for the MVP plutonics.

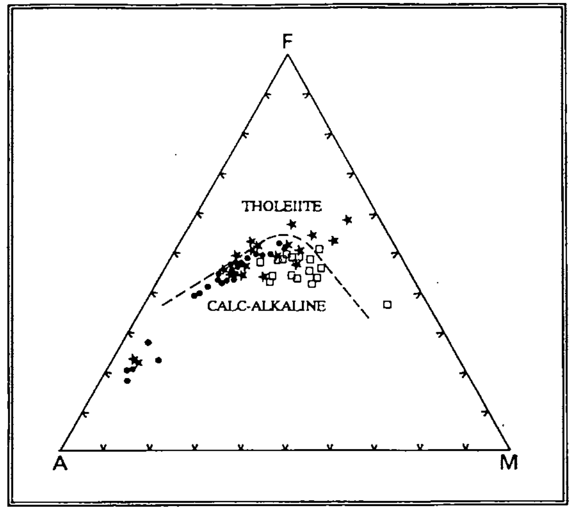

Figure 8. AFM diagram after Irvine and Barargar (1971) for Tertiary plutonic and volcanic rocks of the Bayah area. The samples are defined as squares for LOA, stars for UOA and circles for MPV.

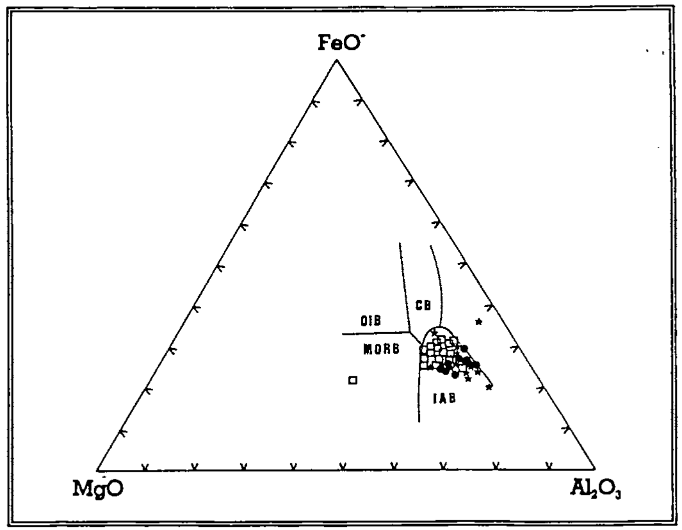

Figure 9. FeO*-MgO-Al_2O_3 diagram after Pearce *et al.* (1977) for the Tertiary plutonic and volcanic rocks in the Bayah area. Fields are CB for continental basalt, IAB for island-arc basalt, MORB for mid-oceanic basalt and OIB for oceanic basalt. The samples are defined as squares for LOA, full circles for the UOA and stars for the MPV.

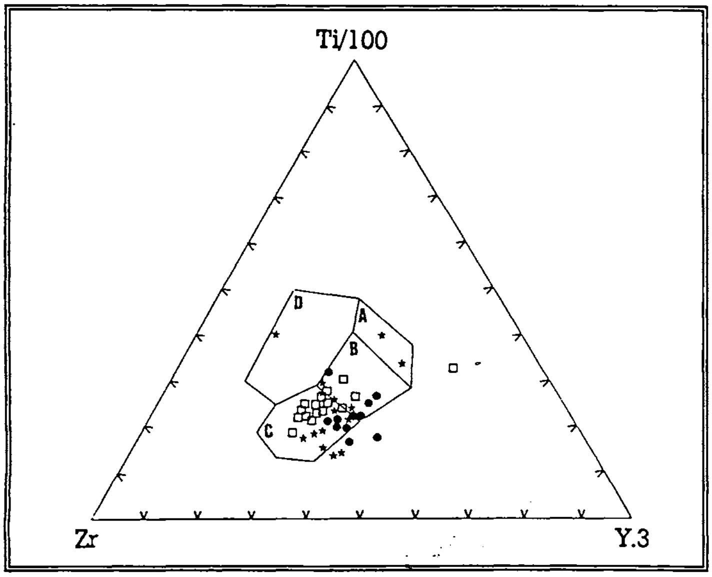

Figure 10. Ti-Zr-Y diagram after Pearce and Cann (1973) for the Tertiary plutonic and volcanic rocks in the Bayah area. Fields are A for low potassium, B for oceanic-floor basalt, C for calc-alkaline and D for plate basalt. The samples are defined as squares for the LOA, full circles for the UOA and stars for the MPV.

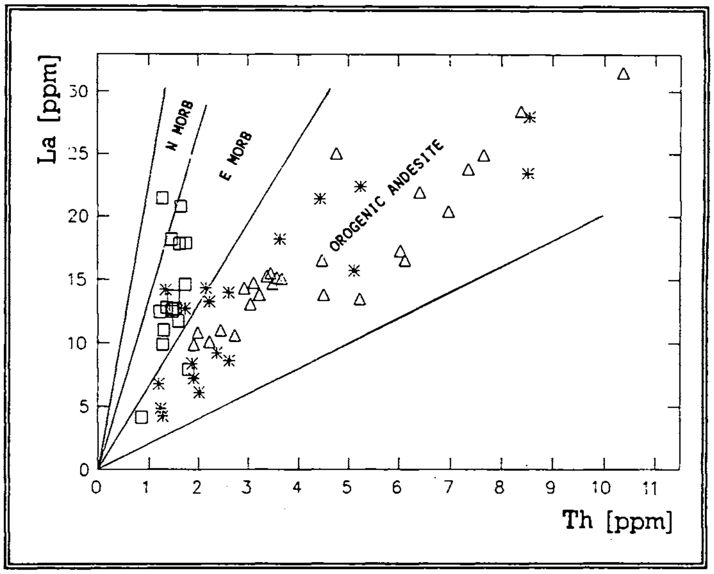

Figure 11. La vs Th (wt. ppm) for the Tertiary plutonic and volcanic rocks in the Bayah area after Gill (1981). The samples are defined as squares for the LOA, stars for the UOA and triangles for the MPV.

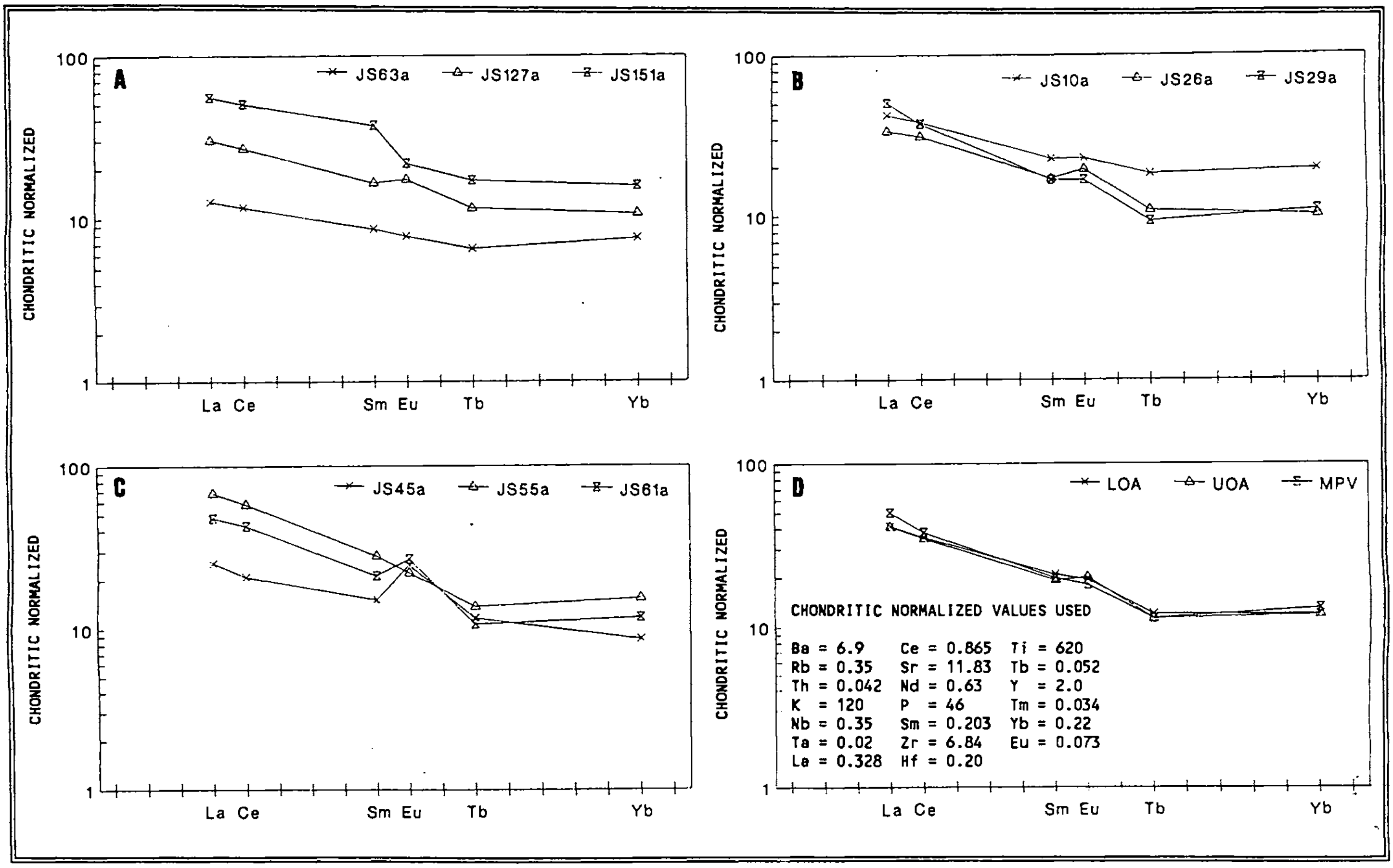

Figure 12. Chondritic normalized concentration of REE for the Tertiary plutonic and volcanic rocks in Bayah area. Individual lava from the LOA (A), the UOA (B), the MVP (C) and average concentration for all samples for each group (D). The shadows are range for each group. The symbols in Figure D are defined as crosses for the LOA, traingles for the UOA and diaboles for the MPV.

and the compatible elements form steeper plats than the UOA. The MPV also has a higher radiogenic content (Sr and Pb isotopes). Thus, there is not doubt that the MPV rocks represent an island-arc calc-alkaline series resulting from an increased crustal thickness.

TERTIARY MAGMATIC GENERATION

The plutonic and volcanic rocks of the Bayah area have been described in the previous discussions. The differences between the LOA and both the UOA and the MPV are clarified by petrology, geochemistry and tectonic setting. However, a difference between groups from the point of view of the incompatible elements is only reflected by the content of the lithophile elements (K, Th, Rb, Ba) and the LREE. The HREE concentration is similar for each group. This suggests that the rocks may have a similar magma source. Sukarna (1991) argued that the source may be the upper mantle. The chemical and isotopic characteristics of the groups corresponding to the evolution of arc during the Cenozoic are: (1) alkalinity increases from the LOA over the UOA to the MPV. It corresponds directly with the Benioff-zone depth, indicating a different crustal thickness. (2) Change in fractional crystallization. From the LOA, over the UOA to the MPV there is an increase of olivine, clinopyroxene and Fe-Ti oxides, fractionation and an increase in total concentration of large lithophile elements (Figs. 14 and 15). (3) The Sr and Pb isotopes (Figs. 16 and 17) also increase from the LOA to the UOA and MPV. They reflect different processes during the arc evolution due to different degree of fractional crystallization and contamination.

The consistency of the available data to indicate fractional crystallization is probably shown by Ni and Cr contents which have a substantial variation. In the LOA rocks, Ni and Cr contents further have a good correlation with the Mg number. The evidence for contamination is provided by Sr and Pb isotopes, the presence of xenocrysts and by the element variations. The microprobe study (Sukarna, 1991) suggests that some samples having bimodal plagioclase and corroded boundaries originally were xenocrysts. Variation of Mg number with the large lithophile elements indicate that additional large lithophile elements occurred during the differentiation process. The positive correlation between the $^{87}Sr/^{86}Sr$ ratio and Ba, Rb, Th and La

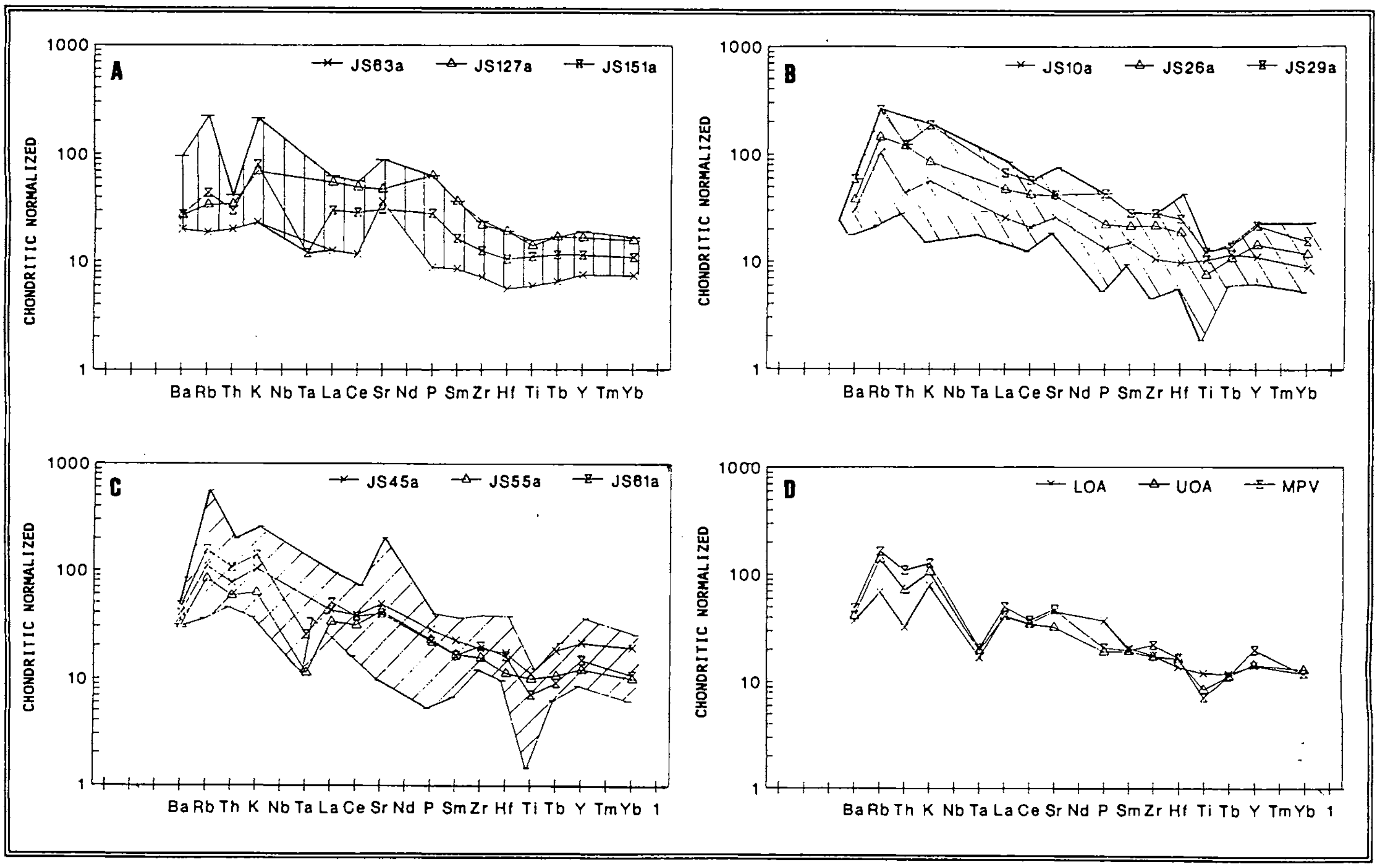

Figure 13. Chondritic normalized concentration of incompatible elements for the Tertiary plutonic and volcanic rocks in Bayah area. Individual lava from the LOA (A), the UOA (B), the MVP (C) and average concentration for all samples for each group (D). The shadows are range for each group. The symbols in Figure D are defined as crosses for the LOA, traingles for the UOA and diaboles for the MPV.

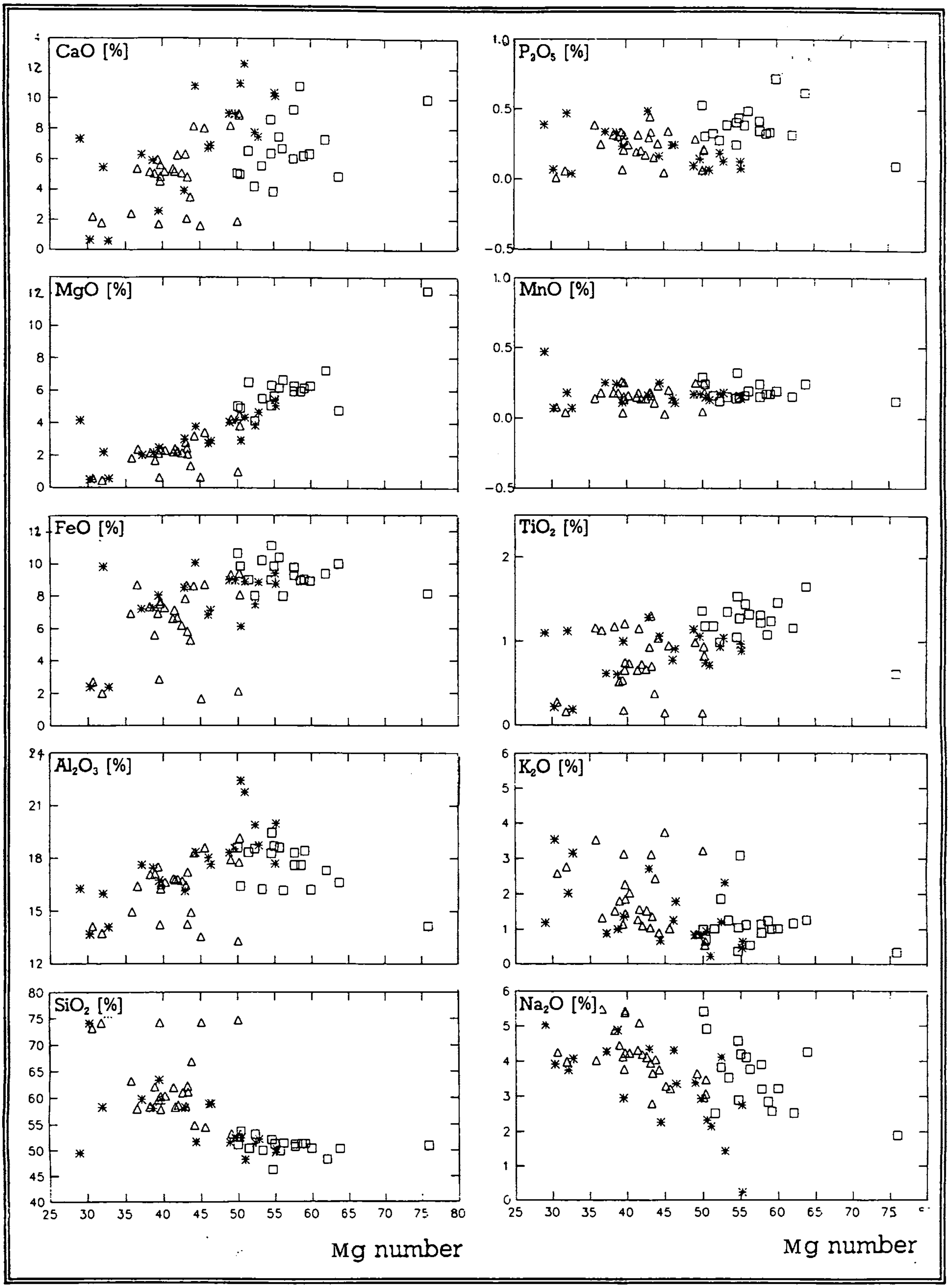

Figure 14. Major elements vs mg-number for the Tertiary plutonic and volcanic rocks in the Bayah area. The mg-number (100 $Mg/Mg+Fe^{2+}$) is calculated based on $Fe_2O_3/FeO = 0.2$ (after Wilkinson, 1986). The samples are defined as squares for the LOA, stars for the UOA and triangles for the MPV.

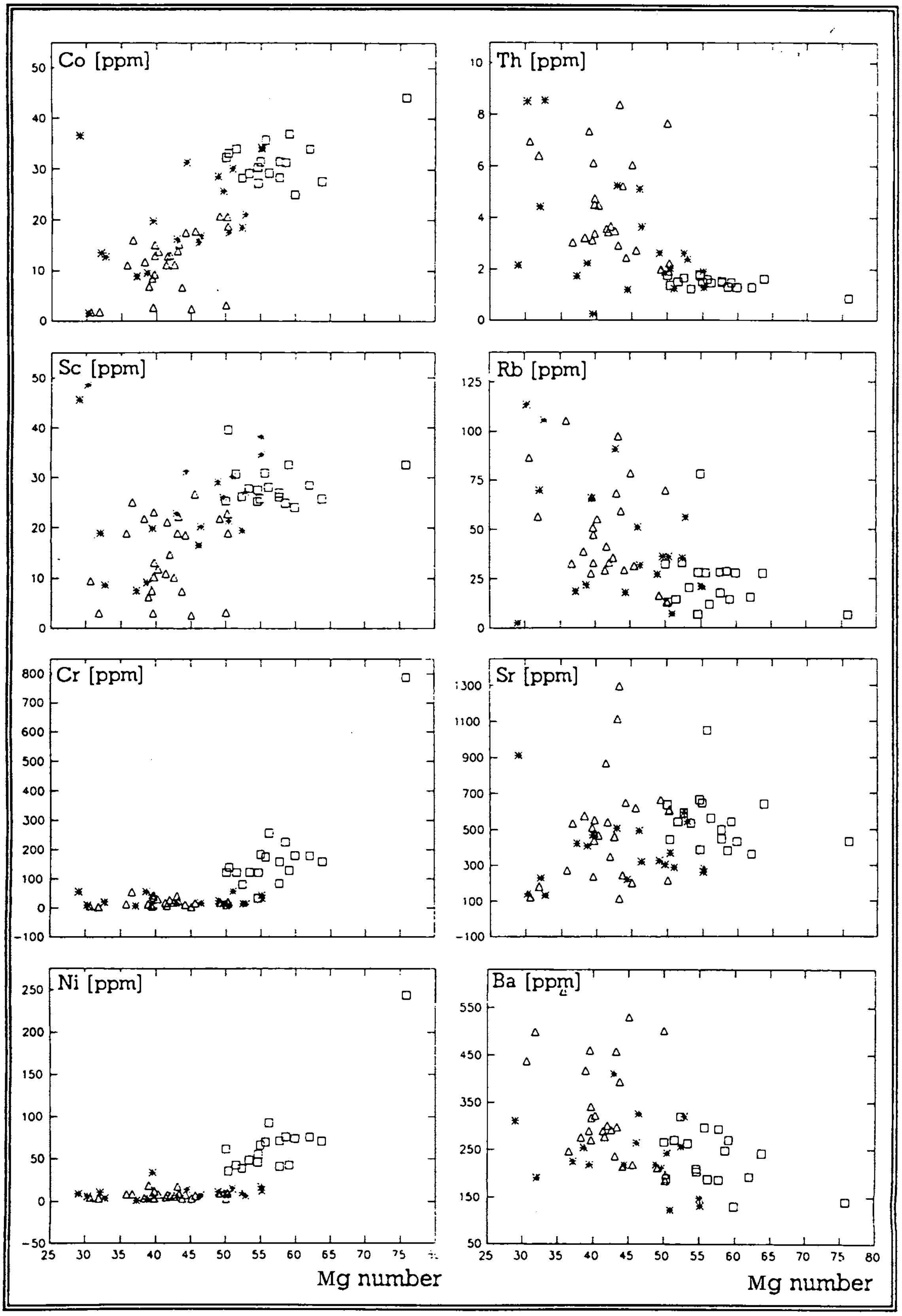

Figure 15. The compatible elements and large lithophile elements vs mg-number for the Tertiary plutonic and volcanic rocks in the Bayah area. The mg-number (100 Mg/Mg+Fe^{2+}) is calculated based on Fe_2O_3/FeO = 0.2 (after Wilkinson, 1986). The samples are defined as squares for the LOA, stars for the UOA and triangles for the MPV.

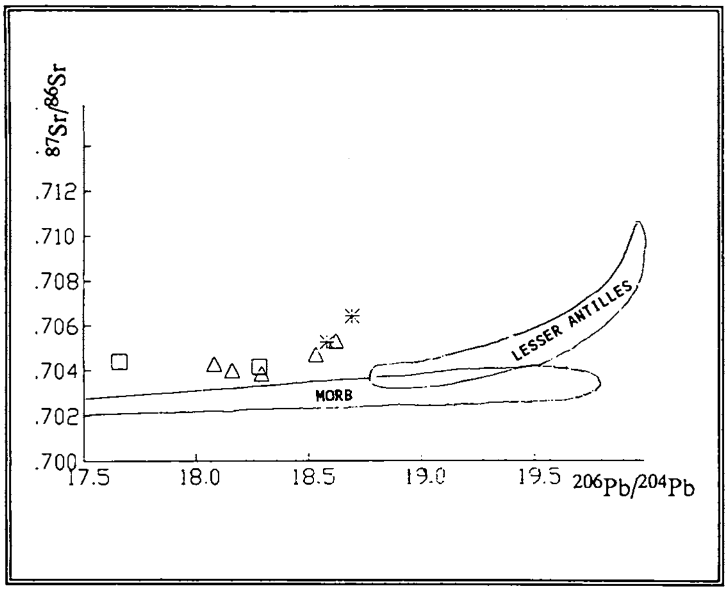

Figure 16. $^{87}Sr/^{86}Sr$ vs $^{206}Pb/^{204}Pb$ for the Tertiary plutonic and volcanic rocks in the Bayah area. MORB from White and Duprë (1986); the Lesser Antilles data after Davidson (1986) and White and Druprë (1986) after Wilson (1989, Fig. 6.44).

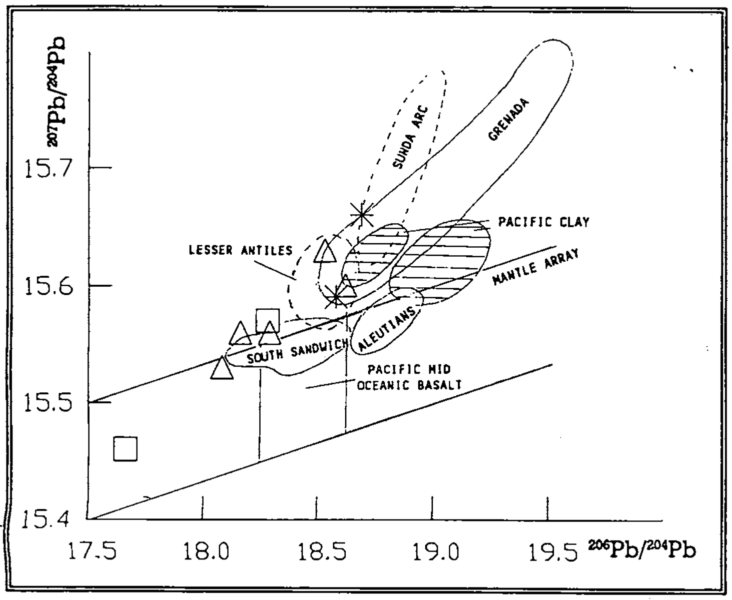

Figure 17. $^{87}Sr/^{86}Sr$ vs $^{206}Pb/^{204}Pb$ for the Tertiary plutonic and volcanic rocks in the Bayah area. Fields after Wilson and Davidson (1984). The samples are defined as squares for the LOA, stars for the UOA and triangles for the MPV.

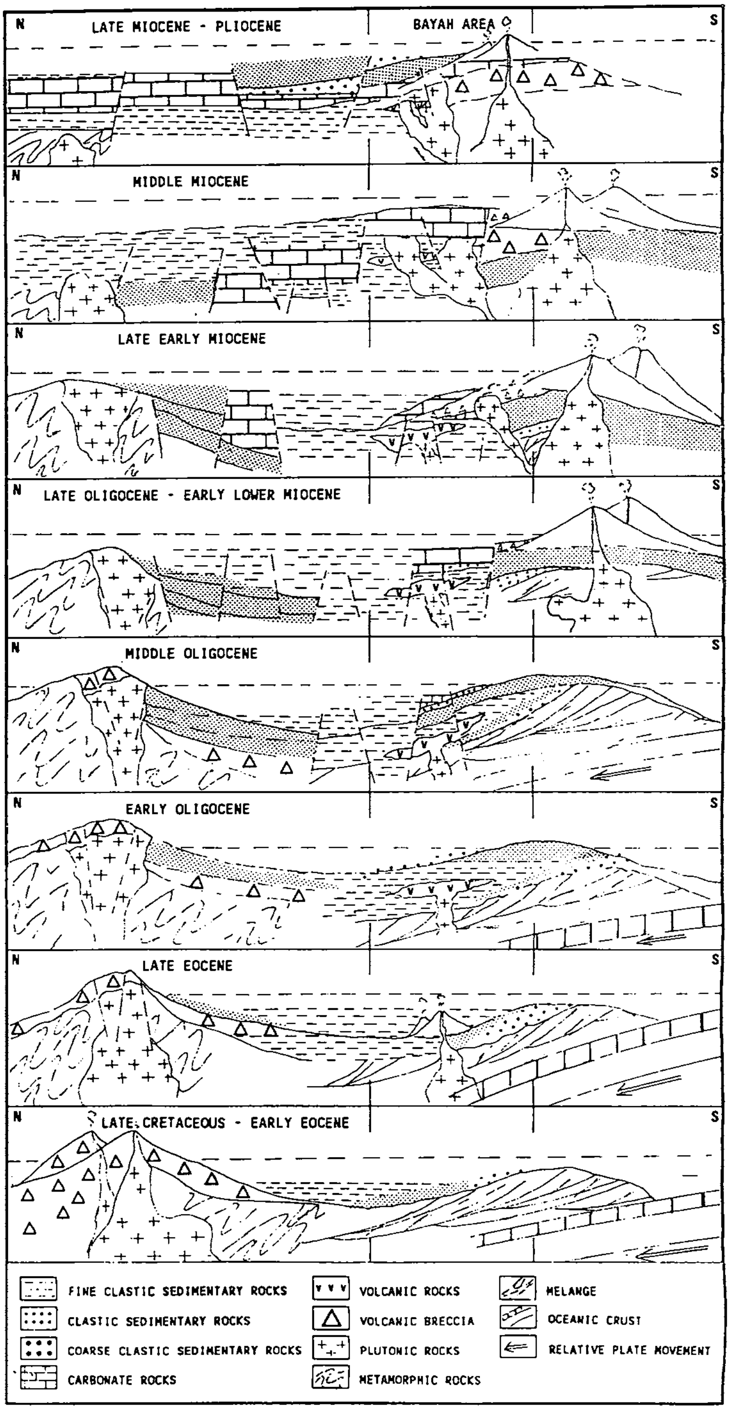

Figure 18. Sketch showing the Tertiary evolution of the Bayah area.

concentration, Th/Zr, Th/Yb and La/Yb confirms an addition of material with a high $^{87}Sr/^{86}Sr$ value (Sukarna, 1991). The characteristics of crustal contamination are also shown by the Pb isotopes values. The contamination of the parental magma with crustal material containing $^{206}Pb/^{204}Pb$ 18.28 might occur in the generation of the LOA.

The evidences suggest that the fractional crystallization is well developed and the contamination of the LOA accompanied by concurrent fractional crystallization. The contamination might have occurred in the magma chamber. For the UOA and the MPV rocks, the addition of $^{206}Pb/^{204}Pb$ 16.69 occurs during the contamination process. This crustal contamination is similar with the Quaternary rocks of the Sunda arc (Whitford, 1975) and suggests an addition of terrigenous sediment. The evidence suggest that the rocks have relatively small amounts of fractional crystallization and that the crustal contamination decrease from the UOA and the MPV, and this might occur at high levels in the crust.

The difference between the LOA and both the UOA and the MPV seems to be related to the difference of segment configuration in the arc, controlled by the phenomena in the Lower crust, such as fracturing of subduction zone or motion of the subducted plate. The magma generation in the Bayah area can not be explained as the result from one magmatic activity. The UOA and the MPV magma generation probably belong to the Oligocene-Miocene magmatic activity. The emplacement time as well as the tectonic setting are clearly supported. This activity occurs in the volcanic-arc due to active subduction by northward motion of the Indian-Australian plate beneath the Eurasian Plate. Their emplacement may be related to the magma traversing the thick lithosphere slowly, a compressed and cooler environment with a relatively high pressure. The LOA generation which is recognized as Late Eocene to earliest Oligocene, however, is older than those magmatic activities and was generated at the volcanic front. During late Eocene to Middle Oligocene a period of a decrease of magmatic activities of the Sunda arc is noted. Daly *et al.* (1991) noted that the Sunda subduction system was not active during this period.

The geochemistry of the LOA rocks indicates that they came into being by higher fractionation, shallower crystallization and at higher magma temperature near the surface. The cause of this is that the lithosphere overlying the magma was thin or fractured, allowing the magma to traverse the lithosphere faster. So the tectonic environment of the LOA is either thin lithosphere, a fracture zone or a combination of both in a fore-arc near the convergent plate boundary.

The magmatic activities in the Sunda arc decreased during late Eocene to late Oligocene. Daly *et al.* (1991) noted that the Sunda subduction system was not active during this period. The LOA rocks which are part of the eruption activities of the Sunda arc were generated in this period. However, the LOA volcanism was not centred around one single spot but was probably scattered throughout a trend. In South and Central Sumatra, intrusives, extrusives and tuffs of similar age are known (deCoster, 1975). Sukarna (1991) proposed two models for magma generation of the LOA rocks which can explain the geochemical data and tectonic environment as found in the Bayah area.

The first model is volcanism related to a change of plate motion. This model is relevant to the change in motion rate of the Indian Plate at 53 Ma. This change caused faulting at the plate boundary and a decrease in volcanism. Two possible locations for the LOA magma generation in the weakness zone of the transform faults are taken in to consideration: (1) an oblique fault area or (2) along the fracture zone of the transform fault, which might correspond to extensional tectonics. This explanation seems to be the best one. The second model is volcanism related to triple junction. In the Bayah area this occurs by intersection of a third plate with an active convergent plate and by migration of that triple junction, the depth of the underthrusted lithosphere becomes more oblique or a transform fault occurs at the remains of the triple junction. The volcanism further moved near to a trench area. The two models above provide better explanation for the LOA magma generation. A change of plate motion is proposed because it gives an explanation for the evolution of the Sunda arc and for the motion of the Indian Plate.

GEOGRAPHIC EVOLUTION

Figure 18 is a sketch of the Tertiary tectonic evolution of the Bayah area. The Bayah area is integrated into the evolution of West Java, although tectonic events in the Bayah area are known earlier than in the rest of Java. This area corresponds to a subducted segment of the Indian Oceanic Plate (Wharton Basin; 80 to 45 Ma) under the Eurasian Plate. Therefore, the evolution of the Bayah area as well as West Java is very much related to evolution of the Indian Ocean Plate.

Late Cretaceous-Early Eocene

India migrated away from Australia and Antarctica plates along a new spreading ridge from 80 to 56 Ma (Royer and Sandwell, 1989). The spreading velocity was between 15 and 20 cm/year (Patriat and Achache, 1984; in Daly *et al.*, 1987) with a motion from east to west. This spreading caused the northward moving part of Indian Ocean Plate to be subducted beneath the Eurasia Plate. In Java, the subduction created the Late Cretaceous to Early Tertiary mélange in the Lok-Ulo, Central Java and Ciletuh West Java and the Paleogene magmatic arc in the north of Java.

The West Java including the Bayah area at this time was situated in the fore arc region. It is shown by the sedimentary deposits during the Eocene time, characterized by regressive period and showing fining clastic northward. They were formed in different subbasins in the early stage and later were integrated in one single shallow basin. They are believed to underlain the mélange complex of Late Cretaceous to Early Tertiary. The magmatic arc of this period is located in north Java with subduction zone in south Java.

Late Eocene-Early Oligocene

The evidence for subduction activity during Middle Eocene to Early Oligocene (53 to 36 Ma) is unclear. Uplifts occurred over most parts of Sundaland. In the Sunda-Banda arc the volcanic activities decreased. The intrusives, extrusives and tuffs occur only in the Barisan range and decrease towards the north. In Java, volcanic activity moved southward into the fore arc area. This period represent the spreading between Australia and Antarctica. The Indian, Australian and Antarctica plates became separated. McKenzie and Sclater (1976) inferred that the northward motion of the Indian Ocean floor was between 3 and 7 cm/yr. It caused the subduction of the Indian Ocean under the Eurasian Plate to slow down.

In the Bayah area, the regressive sedimentary sedimentation continued. The lower sequence of Old Andesite (LOA) was erupted in the fore arc and has an interfingering relationship with the Cipageur Member in the Bayah area.

Oligocene-Miocene

The Indian and Australian plates separation ceased and they behaved as a single plate after seafloor spreading ceased in the Wharton Basin (36 Ma). The Indian and Australian plates moved northward with the velocity 5 to 6.5 cm/yr and collided with the Eurasian continent (Sclater and Fisher, 1974). In the sunda-Banda arc, a new subduction zone was formed in the south of Java, called Sumatra-Java trench. The magmatic are moved to the south Java.

The Bayah area became a transition area between the magmatic arc and the back arc. The Upper sequence of Old Andesite was erupted and has an interfingering relationship with the late Paleogene sedimentary rocks. Isostatic equilibrium further ensured causing block faulting. Following the emplacement of the plutonic rocks, the Bayah area was domed up.

Miocene

The southward shift of the subduction zone has been continuous. In the Bayah area, the Neogene sedimentary rocks were deposited unconformably over the Paleogene sequences. They were deposited in a transition area at the southern border of a basin. They were further folded and block-faulted. The volcanism results in intermediate to acid volcanic rocks commonly occurred as lava and shallow intrusive rocks.

CONCLUSIONS

The geology of the Bayah area is an integral part of the geology of West Java. At the beginning of the Tertiary, sedimentation of rocks with regressive characteristics alternated with volcanic activity. The fine to coarse-grained sediments, volcanic rocks and carbonates were deposited in a shallow basin with a northern rock source. During the Neogene, the area expanded and became a transition area at the southern border of a basin. Sedimentary and volcanic rocks in the south acted as the sediment source, while the northern zone was related with a basin.

The Tertiary plutonic and volcanic rocks in the Bayah area can be divided stratigraphically into the lower sequence of Old Andesite (LOA) of Late Eocene to Early Oligocene, the upper sequence of Old Andesite (UOA) of Oligocene-Miocene and the Miocene plutonic and volcanic rocks (MPV) of late Early Miocene to Late Miocene.

Except for one sample, a tholeiite, all the rocks have calc-alkaline characteristics. However, the rocks of the LOA and both the UOA and the MPV can be distinguished petrographically and geochemically. The LOA rocks are calc-alkaline basalts and basaltic andesites which were generated in the fore-arc region. They are related to a thin crust or a fracture zone, shallower magma crystallization, higher magma temperature at the surface and low pressure. The UOA and MPV calc-alkaline basalts, andesites, dacites and rhyolites were erupted in the magmatic arc zone. They may have come into being in the following way: the magma traversed the thick lithosphere slowly, a compressed and cooler environment with relatively high pressure. Moving of the magma to the higher levels in the crust caused the formation of plutonic rocks with granodioritic and quartz-dioritic composition, followed by the eruption of acid andesites and dacites.

The parental magma of all the groups originates from the upper mantle. The parental magma experienced fractional crystallization and contamination. Magma processes in the LOA may correspond to fractional crystallization and contamination. The component addition to the parental magma is characterized by low Th contents and an intermediate composition, which might be assigned to the lower crust. The contamination might occurred in the magma chamber. The UOA and the MPV correspond to an increasing differentiation process. The UOA and the MPV remain related to contamination of the parental magma with terrigenous sediments. They occur in the high crustal levels. Evidence from Sr and Pb isotopes suggests that the MPV rocks are less contaminated than the UOA rocks.

The Tertiary plutonic and volcanic rocks in the Bayah area may be related to two magma generations. The LOA magma probably corresponds to the Late Cretaceous to Early Eocene subduction activity. The Oligocene-Miocene subduction activities result in the UOA and the MPV magma generation. The volcanic activities of the LOA appear as eruptions along the weakness zones of the transform fault (lateral slip fault), possibly within the tensional zone of the fractures and appear to be related to the period of subduction ceased or slowed down. The UOA and the MPV were generated from active subduction with increasing thickness of the crust.

The evolution of West Java is very much influenced by subduction of the Indian-Australian Plate under the Asian continent. The collision of these plates since the Late Cretaceous caused changes of West Java tectonic setting. In the Early Tertiary the Bayah area was located in a fore-arc region. From the Neogene to the present, the area is situated near or on the magmatic arc.

REFERENCES

BAUMANN, P., OESTERLE, H., SUMINTA AND WIBISONO, 1972. The Cenozoic of Java and Sumatra. *Proc. 1st Annu. Convention Indonesian Petroleum Ass.*, 31-42.

DALY, M.C., COOPER, M.E., WILSON, I., SMITH, D.G., AND HOOPER B.G.D., 1991. Cenozoic plate tectonics and basin evolution in Indonesia. *Marine and Petrol. Geol.*, 8, 2-21.

DAVIDSON, J.P., 1986. Isotopic and trace element constraints on petrogenesis of subduction related lava from Martinique, Lesser Artilles. *J. Geophys. Res.* 91, 5943-5962.

DECOSTER, G.L., 1975. The geology of the Central and South Sumatra basins. *Proc. 3rd Annu. Conv. Indonesian Petroleum Ass*, 77-110.

GILL, J.B., 1981. *Orogenic Andesite and Plate Tectonics*, Springer, Berlin, 390p.

IRVINE, T.N. AND BARARGAR, W.R., 1971. A guide to the chemical classification of the common igneous rocks. *Can. J. Earth Sci.* 8, 523-548.

JAKES, P. AND WHITE, A.J.R., 1971. Composition of island arcs and continental growth. *Earth Planet. Sci. Lett.* 12, 224-230.

JAKES, P. AND GILL, J., 1970. Rare-earth elements and the island arc tholeiite series. *Earth Planet. Sci. Lett.* 9, 17-28.

KAY, R.W., 1984. Elemental abundances relevant to identification of magma sources. *In*: Moorbath, S., Thompson, R.N. and Oxburgh, E.R. (Eds.), *The relative contribution of mantle, oceanic crust and continental crust to magma genesis.* Proceeding of a Royal Society discussion meeting, Cambridge University Press, 97-110.

KOOLHOVEN, W.C.B., 1933. Geological map of Java, scale 1:100.000. Explanatory notes to sheet 14 (Bajah), 42p. Bandung: Geological Research and Development Centre (unpubl).

MARTODJOJO, S., 1984. Evolusi cekungan Bogor, Jawa Barat, 412p – Bandung: Fakultas Paska Sarjana, Institute Teknologi Bandung (Unpubl. Ph.D. thesis).

MARTODJOJO, S., SUPARKA, S. AND HADIWISASTRA, S., 1978. Status Formasi Ciletuh dalam evolusi Jawa Barat. *Proc. Ass. Indonesian Geologists* 5, 29-38.

MCKENZIE, D.P. AND SCLATER, J.G., 1976. The evolution of the Indian Ocean since the Late Cretaceous. *In*: Johnson, D., Powel, McA. and Veevers, J., 1976 (Eds.), Spreading history of the eastern Indian Ocean and greater India's northward flight from Antarctica and Australia. *Geol. Soc. Am. Bull.* 87, 1560-1566.

MIYASHIRO, A., 1974. Volcanic rock series in island arcs and active continental margins. *Am. J. Sci.* 274-A, 321-355.

PEARCE, T.H. AND CANN, J.R., 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth Planet. Sci. Lett.* 19, 290-300.

PEARCE. T.H., GORMAN, B.E. AND BIRKETT, T.C., 1977. The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks. *Earth Planet. Sci. Lett.* 36, 121-132.

PRASETYO, H., 1979. Geologi daerah Cikadongdong dan sekitarnya, Kabupaten Lebak, Jawa Barat. Bandung: Jurusan Geologi UNPAD (thesis sarjana unpubl).

SCLATER J.G. AND FISHER R.L., 1974. Evolution of the east Central Indian Ocean. With emphasis on the tectonic setting of the Nine-Yealt Ridge. *Geol. Soc. Amer. Bull.* 85, 683-732.

SUDJATMIKO AND SANTOSA, S., 1985. Laporan geologi Lembar Lewidamar, Jawa Barat, skala 1:100.000, 54p. Bandung: *Geological Research and Development Centre.*

SUPARKA, S., DHARMA, A. AND SOPAHELUWAKAN, Y., 1982. Batuan volkanik di daerah Bayah dan Cidikit, Banten Selatan, 10p. Bandung: LGPN, LIPI, no. 17/LGPN/1982.

SYAHBUDIN, A., SUMANTRI, Y.R., KARTANEGARA, L., AND ASIKIN, S., 1984. Pola perkembangan tektonik cekungan Rangkasbitung, Jawa Barat selama Tersier sebagai akibat dari letaknya yang berada diantara cekungan Bogor, cekungan Jawa Barat Daya dan cekungan Sumatra Selatan. *Proc. Ass. Indonesian Geologists* 15, 132-154.

THOMPSON, R.N., MORRISON, M.A. HENDRY, G.L. AND PARRY, S.J., 1984. An assessment of the relative of crust and mantle in magma genesis: an elemental approach. *In*: Moorbath, S., Thompson, R.N. and Oxburgh, E.R. (Eds.), *The relative contribution of mantle, oceanic crust and continental crust to magma genesis.* Proceeding of Royal Society discussion meeting, University Press, Cambridge, 111-146.

VAN BEMMELEN, R.W., 1949. *Geology of Indonesia*, vol. Ia, The Hague, Martinus Nijhoff, 732p.

WHITFORD, D.J., 1975. Geochemistry and petrology of volcanic rocks from Sunda arc, Indonesia, 449p. Camberra: Australian National University (Unpubl. Ph.D thesis).

WILKINSON, J.F.G., 1986. Classification and average chemical compositions of common basalts and andesites. *J. Petrol.* 27, 31-62.

WILSON, M., 1989. *Igneous petrogenesis*, London, Harper/Collins, 153-190.

WILSON, M. AND DAVIDSON, J.P., 1984. The relative roles of crust and upper mantle in the generation of oceanic island arc magmas. *In*: Moorbath, S., Thompson, R.N. and Oxburgh, E.R. (Eds.), *The relative contribution of mantle, oceanic crust and continental crust to magma genesis*. Proceeding of a Royal Society discussion meeting, University Press, Cambridge, 223-235.

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